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Peacekeeper Rail Garrison Test of Launch Control Car EMS-2

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16. Abstract

Tests were performed on the Peacekeeper Rail Garrison Launch Control Car(LCC), EMS-2 according to specifications in Chapter XI of the AAR's, *Manual of Standards and Recommended Practices*. The tests included vehicle characterization, service worthiness, and track worthiness. These tests address vehicle safety performance for freight equipment. The primary measurement of safety as described in Chapter XI is the ratio of lateral to vertical wheel force (L/V ratio). No examination of ride comfort is addressed.

The LCC encountered high L/V's in the bunched spiral and standard spiral. The LCC performed within the Chapter XI 95th percentile; however, several high short duration L/V's did occur and the car was not tested at speeds above balance in sharp curves at the direction of the Air Force. The LCC also encountered high L/V's on the Dynamic Curving Test. The LCC became unstable above 55 mph, but hunting was not sustained as defined by Chapter XI. Vehicle motions at 55 mph are likely to be a source of passenger discomfort.

The LCC performed satisfactorily in the Pitch and Bounce Test and the Twist and Roll Test. The LCC also performed well in the Yaw and Sway Test. Post-test modeling should be performed to examine car performance with possible design changes.

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EXECUTIVE SUMMARY

The Association of American Railroads (AAR), Transportation Test Center (TTC), Pueblo, Colorado, was contracted by the Federal Railroad Administration (FRA) to perform vehicle performance tests on the Peacekeeper Rail Garrison (PKRG) rail cars according to specifications in Chapter XI, of the AAR's, M-1001, *Manual of Standards and Recommended Practices* (Appendix A). Chapter XI represents a realistic but severe environment for freight cars.

These tests include rail car service worthiness, rail car track worthiness, static and quasi-static truck characterization, and vehicle dynamic characterization.

The second of the PKRG cars to be tested at TTC was the Launch Control Car (LCC). The LCC will carry launch control equipment and personnel. It is an eight axle rail car with a design weight not to exceed 400,000 pounds. The car uses two standard Buckeye 100-ton design span bolsters. The actual car tested was an EMS-2 (Engineering Mass Simulator). This car utilized steel containers that held sand bags to simulate the weight and center of gravity of the LCC.

Objective

The objective of this test program was to provide a data base of vehicle performance for the LCC as operated over a severe but realistic freight railroad environment. The data base will assist the Air Force in determining the suitability of the LCC design for PKRG. To achieve this objective the following tests were performed to examine the vehicle dynamic performance (track worthiness) of the LCC, EMS-2.

High Speed Stability (Hunting)
Constant Curving
Curve Entry and Curve Exit
Pitch and Bounce
Twist and Roll
Dynamic Curving
Turnouts and Crossovers
Yaw and Sway

A set of tests was also performed to evaluate the service worthiness or structural adequacy of the LCC, EMS-2. These tests included:

Single Car Impact
Compressive End Load
Jacking Stability Test
Curve Stability Test

Tests to measure the static and quasi-static suspension characteristics of four 100-ton conventional three piece trucks that will be used under the LCC, EMS-2 were performed. These parameters are required as input for the AAR developed mathematical model New and Untried Car Analytical Regime Simulator (NUCARS) used to predict rail car performance.

Another series of tests were performed to measure the modal parameters of the LCC, EMS-2. These parameters are also used as a comparison with the mathematical model (NUCARS) used to predict rail car performance. The modal parameters included:

Pitch	Vertical Bending
Bounce	Lateral Bending
Roll	Longitudinal Torsion (Twist)
Yaw	Sway

Test Procedure

Detailed test procedures were written for each test. Procedural outlines are presented in this report.

Vehicle characterization was performed on the LCC as stated in Appendix A of Chapter XI. These tests are designed to document suspension and car body characteristics.

The LCC service worthiness testing consisted of four separate tests including The Single Car Impact Test, The Compressive End Load Test, The Jacking Test and The Curve Stability Test.

The LCC track worthiness testing consisted of the eight separate tests stated above in the objective. All of the tests were conducted on TTC track with the car in the loaded configuration under which it will operate in actual service. Tests were conducted at various speeds on track shimmed to excite vehicle instability modes observed during typical but severe railroad operation. Other track tests were conducted on unperturbed track to observe the vehicle operation on nominal track configurations.

Results

The results of the LCC testing are presented in this report in four sections. Vehicle characterization, track worthiness and the static brake test are summarized here.

The following table summarizes all of the vehicle characterization results provided for NUCARS vehicle dynamics modeling support.

PARAMETER	VALUE
Vertical Spring Stiffness with snubbers	26.08 kips/in
Vertical Spring Damping with snubbers	11.61 kips
Vertical Spring Stiffness without snubbers	26.32 kips/in
Vertical Spring Damping without snubbers	8.83 kips
Truck Roll Spring Rate	56,519 in-kips/radian
Lateral Truck Stiffness	24.48 kips/in
Lateral Truck Damping	34.40 kips
Span Bolster Yaw Moment	350,000 in-lbs
Single Truck Yaw Moment	112,500 in-lbs
Axle Alignment	Truck No. 1 - 2.496 mrad Truck No. 2 - 0.636 mrad
Longitudinal Stiffness	98.5 kips/inch
Axle Yaw and Inter Axle Bending Stiffness	1,200,000 in-kips/mrad
Inter Axle Shear Stiffness	Not Used for NUCARS
Bounce Frequency	4.0 Hz
Pitch Frequency	7.0 Hz
Roll Frequency	0.5 Hz
Upper Center Roll Frequency	7.0 Hz
Yaw Frequency	6.0 Hz
First Vertical Bending Frequency	13.25 Hz
First Torsional Frequency	20.0 Hz
First Lateral Bending Frequency	17.0 Hz

Track Worthiness Testing

Track worthiness testing shows acceptable freight car performance on tangent track at speeds below 55 mph. High single wheel L/V's were encountered in the Constant Curving Tests and Spiral Negotiation Tests. Dynamic curving, 12-degree curving and spiral negotiation were identified as potential problem areas. The following table summarizes the track worthiness results.

--- The LCC becomes unstable at 55 mph. The ride quality at this speed becomes very poor.

--- The LCC does not curve well with its present design. High wheel L/V's were encountered on the 12-degree curve. The LCC was not tested at above balance speeds for any curve during the Constant Curving Tests at the direction of the Air Force.

--- The LCC was not tested at speeds above 8 mph for the Dynamic Curving Tests at the direction of the Air Force. Normal test speeds range from 12 mph to 32 mph.

--- The LCC encountered high single wheel L/V's while entering and exiting the 12-degree curve through a bunched spiral. The LCC also encountered high single wheel L/V's while entering the 12-degree curve through a standard spiral. The bunched spiral was only tested at a speed of 16 mph at the direction of the Air Force.

--- The LCC performed satisfactorily in the Pitch and Bounce Test.

--- The LCC performed satisfactorily in the Twist and Roll Test.

--- The LCC negotiated a No. 8 turnout and a No. 10 crossover at their maximum speeds without difficulty.

--- The LCC performed satisfactorily in the Yaw and Sway Test.

Static Brake Test

The LCC, EMS-2, only obtained an equalization pressure of 46 psi with a 20 pound reduction from a 70 psi brake pipe pressure. The equalization pressure should be between 48 and 52 psi.

The net braking ratio for the LCC was calculated to be 12% with a full service brake application from a 90 psi brake pipe pressure. Using a 70 psi brake pipe pressure, a full service brake application resulted in a 9.2% net braking ratio. This net braking ratio is within the AAR 6.5% minimum and 10% maximum allowable range.

The handbrake net braking ratio that could be obtained with a 125 pound application to the handbrake wheel was 10.79%. This value is lower than the AAR 11% minimum.

Recommendations

Curving:

1. Curving tests should be completed. Curving tests were not performed at balance and above balance speeds at Air Force direction. Poor performance in the 12-degree curve may indicate potential problems in other curving situations and should not just be addressed as an upper limit for normal operations.
2. Post test modeling should be performed to examine car performance in dynamic curving. Possible design changes may be considered and modeled for improvements in performance.

Ride Quality:

1. High speed stability performance needs closer examination for personal comfort and ride quality reasons.

Braking:

1. The handbrake should be redesigned to give a higher net braking ratio.
2. The air brake system needs closer examination. Equalization pressure of 48 to 52 psi in the brake cylinder was not obtained.

1.0 INTRODUCTION

The Association of American Railroads (AAR), Transportation Test Center (TTC), Pueblo, Colorado, has been contracted by the Federal Railroad Administration (FRA) to perform vehicle performance tests on the Peacekeeper Rail Garrison (PKRG) rail cars according to specifications in Chapter XI, of the AAR's, M-1001, *Manual of Standards and Recommended Practices* (Appendix A). Chapter XI represents a realistic but severe environment for freight cars. These tests include rail car service worthiness, rail car track worthiness, static and quasi-static truck characterization, and vehicle dynamic characterization.

The track worthiness tests determine the track safety performance over normal track and over track specially configured to excite various vehicle dynamic modes.

The service worthiness tests determine the structural adequacy of the vehicle body.

The characterization tests provide engineering values necessary for computer modelling of the vehicle dynamic performance.

The second of the PKRG cars to be tested at TTC was the Launch Control Car (LCC). The LCC will carry launch control equipment and personnel. It is an eight axle rail car with a design weight not to exceed 400,000 pounds. The car uses two standard Buckeye 100-ton design span bolsters. The actual car tested was an EMS-2 (Engineering Mass Simulator). This car utilized steel containers that held sand bags to simulate the weight and center of gravity of the LCC.

2.0 OBJECTIVE

The objective of this test program was to provide a data base of vehicle performance for the LCC as operated over a severe but realistic freight railroad environment. The data base will assist the Air Force in determining the suitability of the LCC design for PKRG. To achieve this objective many tests were performed.

The following tests were performed to examine the vehicle dynamic performance (track worthiness) of the LCC, EMS-2.

High Speed Stability (Hunting)
Constant Curving
Curve Entry and Curve Exit
Pitch and Bounce
Twist and Roll
Dynamic Curving
Turnouts and Crossovers
Yaw and Sway

A set of tests were also performed to evaluate the service worthiness or structural adequacy of the LCC, EMS-2. These tests included:

Single Car Impact
Compressive End Load
Jacking Stability Test
Curve Stability Test

Tests to measure the static and quasi-static suspension characteristics of four 100-ton conventional three piece trucks that will be used under the LCC, EMS-2 were performed. These parameters are required as input for the AAR developed mathematical model New and Untried Car Analytical Regime Simulator (NUCARS) used to predict rail car performance.

Another series of tests were performed to measure the modal parameters of the LCC, EMS-2. These parameters are also used as a comparison with the mathematical model (NUCARS) used to predict rail car performance. The modal parameters included:

Pitch
Bounce
Roll
Yaw
Vertical Bending
Lateral Bending
Longitudinal Torsion (Twist)
Sway

3.0 TEST DESCRIPTION

Chapter XI of the AAR's, M-101, *Manual of Standards and Recommended Practices* presents guidelines for testing and analysis to ascertain the interchange service worthiness of freight cars. The regimes of vehicle performance examined are divided into two sections in Chapter XI. Service worthiness covers structural, static, and impact requirements. Track worthiness covers vehicle dynamic performance.

Vehicle characterization, as described in Appendix A of Chapter XI, is used to define the car body and suspension parameters for the test vehicle. After the characteristics of the suspension and the car body system are found, the results can be used to build a model to predict Chapter XI performance.

3.1 VEHICLE CHARACTERIZATION

3.1.1 Truck Characterization

Truck characterization tests are conducted to determine the dynamic suspension characteristics of the 100-ton trucks used to support the LCC. Tests are conducted on the Mini-Shaker Unit (MSU) to measure the vertical and lateral displacement values for given force inputs at various truck component interfaces. Tests are also conducted on low friction tables to determine rotational stiffnesses in the truck. These results will allow comparison between measured and design values and are used as part of the NUCARS model input parameters.

3.1.2 Modal Characterization

Modal characterization tests are conducted to determine the dynamic characteristics of the suspension and the car body as a system. The results of these tests can be compared to the NUCARS model predictions to validate its vehicle representation. There results will also be required as input data for the Train Dynamics Model (TDM) which will make integrated train performance predictions.

3.2 SERVICE WORTHINESS

Service Worthiness Tests address the structural integrity of the vehicle.

3.2.1 Single Car Impact Test

The Single Car Impact Test is conducted to determine if any permanent damage occurs to the LCC upon impact into three loaded 70-ton hopper cars with the handbrake on the non-struck hopper tightly set. Impacts for the LCC are conducted up to 1.25 million pounds coupler force or 6 mph, which ever comes first. This test is done to simulate possible impacts that a rail car is subject to while in service.

3.2.2 Compressive End Load Test

The Compressive End Load Test is conducted to document ability to withstand an axially applied load of 1-million pounds for 1 minute without permanent deformation. The loading simulates an axially loaded beam with rotation-free translation fixed ends.

3.2.3 Jacking Test

The Jacking Test is conducted to test the jacking pads and car structure. As the car is lifted at the jacking pads, it is monitored for permanent deformation around the pads. Since the LCC is designed with two trucks and a span bolster at each end, it is not necessary to conduct the coupler vertical load test that is done for standard car design.

The jacking pads are used for any repairs that are needed on the trucks or span bolster which would require the weight of the car to be removed from the suspension. The Jacking Test is conducted while configuring the LCC for other tests.

3.2.4 Curve Stability Test

The Curve Stability Test is done to document any car body suspension separation and wheel lift while the car is subjected to a buff and draft (compression and tension) force. The test is conducted on a section of curved track with a limited amount of superelevation. Extremely short and long cars are connected adjacent to the car being tested to simulate the worst case situation.

3.3 TRACK WORTHINESS

Track Worthiness Tests are conducted to assess the dynamic performance of the car in typical railroad operation. These tests utilize instrumented wheel sets to measure lateral and vertical forces (L/V) between the wheel and rail. These wheel sets have modified Heumann profiles which simulate worn wheel profiles.

Results are compared to criteria as stated in Chapter XI. The primary criteria are the tendency to wheel climb derailment, as defined by the ratio of L/V, and the tendency to cause rail rollover, as defined by the ratio of truck side lateral to vertical forces.

The test regimes described in the Track Worthiness section of Chapter XI address the dynamic vehicle modes historically associated with poor performing vehicles. The track is intentionally adjusted (perturbed) to excite these modes for most tests.

The wavelength for these repetitive perturbations is based upon historical rail length of 39 feet. No attempt has been made to adjust this wavelength to a particular vehicle's dimensions. The amplitude of the perturbations is less than the theoretical amplitude possible under FRA track class specifications.

3.3.1 High Speed Stability Test

High speed stability tests are conducted to confirm that hunting (lateral oscillating instability in the trucks) does not occur within normal operating speeds of the car. Chapter XI states that the maximum lateral car body acceleration (g) is 1.0 g peak-to-peak sustained for 20 seconds or a maximum axle sum L/V of 1.3. The maximum individual peak-to-peak acceleration (g) is 1.3 g. Hunting is inherent in some truck designs and is also seen in normally stable truck designs when components are allowed to wear beyond normal limits. A truck may be unstable but still be below the Chapter XI allowable limits; however, the ride quality while a truck is hunting, even below the Chapter XI limits, is very poor. If hunting occurs, the resonant speed is identified for operational considerations.

3.3.2 Constant Curving Test

The Constant Curving Test is designed to determine the car's ability to negotiate normal track curves. The test car is operated through many standard curves at typical operating speeds. The maximum wheel L/V is 0.8 or the maximum axle sum L/V is 1.3 (Chapter XI, Table 11.1). This test verifies that the car will not have wheel climb or impart large lateral forces to the rails during curving.

3.3.3 Curve Entry and Curve Exit Test

The Curve Entry and Curve Exit Test is performed in conjunction with the Constant Curving Test. A spiral is the transition from a curve to a tangent track. This transition includes changes in crosslevel and curvature. The purpose of the exaggerated bunched spiral described in Chapter XI is to twist the trucks and the car body. Chapter XI states that the minimum acceptable vertical load of a wheel is 10 percent of the static wheel load and that the maximum acceptable wheel L/V is 0.8.

3.3.4 Pitch and Bounce Test

The Pitch and Bounce Test is designed to determine the dynamic pitch and bounce response of the car as it is excited by vertical inputs from the track. Track with this type of input to the vehicle may be found at bridges, road crossings, and where there is a change in the underlying vertical support structure to the track. The Chapter XI criterion is a minimum vertical wheel load of 10 percent of the static vertical wheel load.

3.3.5 Twist and Roll Test

The Twist and Roll Test is conducted to determine the car's ability to negotiate through cross-level perturbations. These perturbations will excite the natural twist and roll motions of the car. This type of track condition may be found in locations where rail joints are staggered or low spots on the track occur. Three criteria are given for this test: the maximum roll angle is 6 degrees peak-to-peak, the maximum axle sum L/V is 1.3, and the minimum vertical wheel load is 10 percent of the static vertical wheel load (Chapter XI).

3.3.6 Dynamic Curving Test

The Dynamic Curving Test is designed to determine the ability of the car to negotiate track with simultaneous cross-level (vertical) and gage (lateral) misalignments. Four different criteria are given in Chapter XI: the maximum wheel L/V is 0.8, the maximum axle sum L/V is 1.3, the maximum roll angle is 6 degrees peak-to-peak, and the minimum vertical wheel load is 10 percent of the static vertical wheel load.

3.3.7 Turnout and Crossover Test

The Turnout and Crossover Test is conducted to determine performance in negotiating typical turnouts and crossovers. A turnout is an arrangement of a switch and a frog with closure rails, by which cars may be diverted from one track to another. A crossover is an arrangement of two turnouts with the track between the frogs arranged to allow passage between two nearby and generally parallel tracks. The wheel/rail forces determine if there is a tendency for wheel climb or to induce lateral forces into the track. This test is not described in Chapter XI.

3.3.8 Yaw and Sway Test

The Yaw and Sway Test is conducted to determine the ability of the car to negotiate laterally misaligned track, which will excite the car in a yaw and sway motion. Track with perturbations of this type may be found where the underlying ground is unstable and allows the track to shift in the lateral direction. The maximum truck side L/V is 0.6 and the maximum axle sum L/V is 1.3 (Chapter XI).

3.4 STATIC BRAKE TEST

The Static Brake Test is conducted to determine the static forces on the brake shoes when various brake cylinder pressures are applied. This information is compared to accepted standards and is used to correlate stop distance information to the designed braking ability of the car. This test is also used to ensure the compatibility between all car brake systems in the PKRG train (e.g. MLC, MC, etc.).

This test is normally performed at the car builders facility using a sample car of a production run. It is an AAR Mechanical Division requirement but is not a Chapter XI requirement.

4.0 TEST PROCEDURES

Detailed test procedures were written for each test. Procedural outlines are presented in this section.

4.1 VEHICLE CHARACTERIZATION

Vehicle characterization was performed on the LCC as stated in Appendix A of Chapter XI. These tests are designed to document suspension and car body characteristics. There is no criteria for acceptable performance.

4.1.1 Truck Characterization Procedures

Quasi-static truck characterization was performed on four 100-ton ride control trucks. Each truck was equipped with eight D-7 outer springs, seven D-7 inner springs, and a Stucki HS-7 hydraulic snubber in each spring nest. Truck characterization tests were performed on the Mini-Shaker Unit (MSU) in the Rail Dynamic Laboratory (RDL). A Union Pacific (UP) gondola (UP31923) loaded to approximate the LCC axle loads (48,000 lbs) was used to weigh down the LCC trucks for the following MSU tests:

Vertical Stiffness and Damping
Roll Stiffness and Damping
Lateral Stiffness and Damping

These tests are described in more detail in Sections 4.1.1.1 to 4.1.1.3. Each of the four 100-ton trucks was individually tested under the B-end of the UP gondola.

The MSU utilized two 140 kip hydraulic actuators for vertical input excitation to the vehicle and one 140 kip hydraulic actuator for lateral excitation. The actuators were attached to a reaction mass that is bolted to the floor of the RDL and were connected between the car body and the reaction mass with special brackets welded to the UP gondola. Sinusoidal input signals were provided to the actuator control valves with a Hewlett-Packard (HP) 360 desktop computer teamed with a programmable function generator. The actuators were controlled with 0.1 Hz to 0.25 Hz signals, with either a constant displacement or a constant force, during the quasi-static tests. Vertical and lateral rail forces were also measured by instrumented rail at each wheel/rail interface. Figures 4.1 and 4.2 show the MSU in the vertical and lateral configuration, respectively.

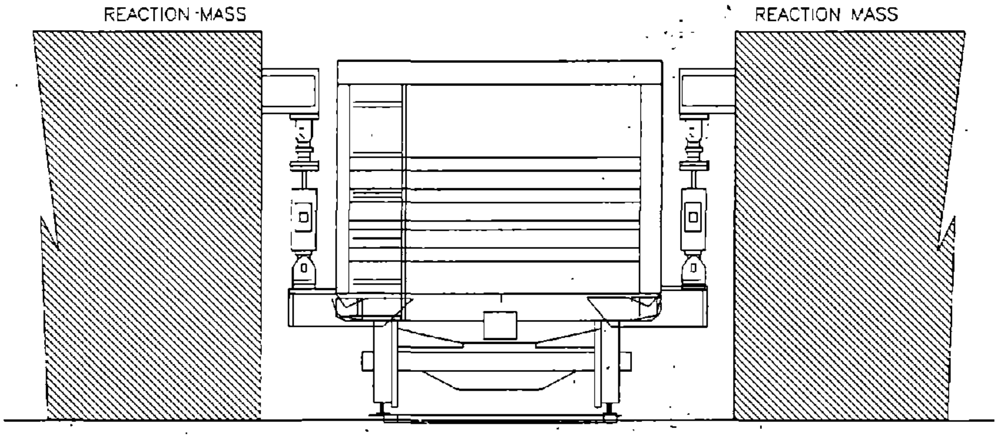


Figure 4.1 MSU in the Vertical Configuration

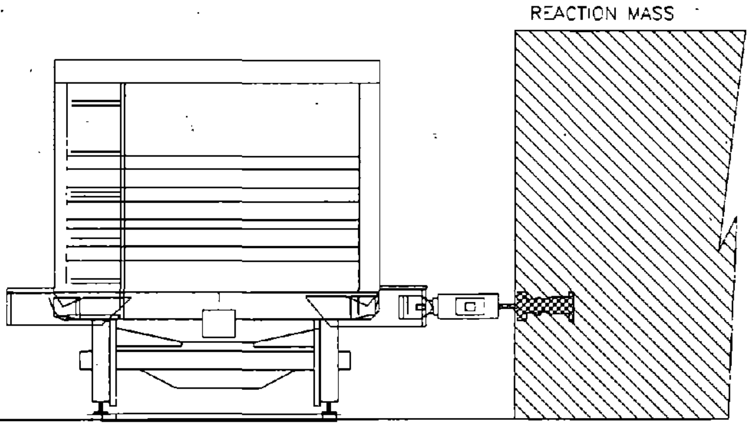


Figure 4.2 MSU in the Lateral Configuration

Next, static truck characterization was performed on the two 100-ton trucks using air bearing tables. The tables utilize six air bearings to float an object off the ground on a cushion of air. This eliminates the friction between the wheels and the rail during rotation testing. Figure 4.3 shows an air bearing table.

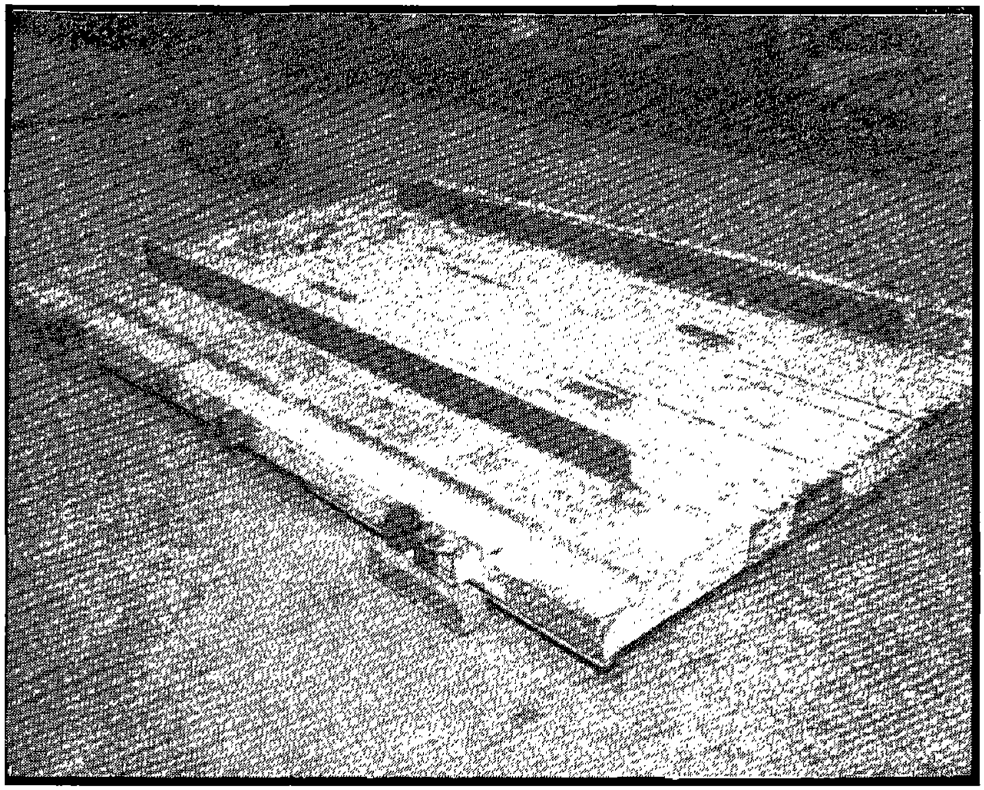


Figure 4.3 Air Bearing Table

The following tests were performed using the air bearing table:

Span Bolster Yaw Moment Test
Truck Yaw Moment Test
Axle Alignment Test
Truck Longitudinal Stiffness Test
Truck Inter-axle Yaw and Bending Test
Inter-axle Shear Test

These tests are described in more detail in Sections 4.1.1.4 to 4.1.1.9.

4.1.1.1 Vertical Stiffness and Damping Procedures

The Vertical Stiffness and Damping Test was conducted by cycling both vertical actuators in-phase with constant amplitude at frequencies of 0.1 and 0.25 Hz. The actuators were extended and retracted to the full extent of the LCC spring travel and to various levels less than the maximum spring travel. It was determined, during the tests, that approximately 2 inches of stroke was sufficient to fully compress the springs.

4.1.1.2 Roll Stiffness and Damping Procedures

The Roll Stiffness and Damping Test was similar to the vertical characterization tests, except the vertical actuators were operated 180 degrees out-of-phase. Actuator displacements up to ± 2 inches were tested.

4.1.1.3 Lateral Stiffness and Damping Procedures

The Lateral Stiffness and Damping Test required reconfiguration of the MSU to a single lateral actuator arrangement. The input force was cycled at 0.1 and 0.25 Hz in the range from ± 10 kips to ± 20% of the vertical static load of the car (± 20 kips), which is the AAR Chapter XI criterion.

4.1.1.4 Span Bolster Yaw Moment Procedures

The Span Bolster Yaw Moment Test was done to determine the torque necessary to rotate the span bolster about the car body center plate. This break away torque is related to the static friction between the car body center plate and truck center bowl. When the LCC enters a curve, the lateral wheel forces cause the span bolster to break away and rotate. The breakaway torque will affect curving and high speed stability performance. Figure 4.4 illustrates the basic test setup.

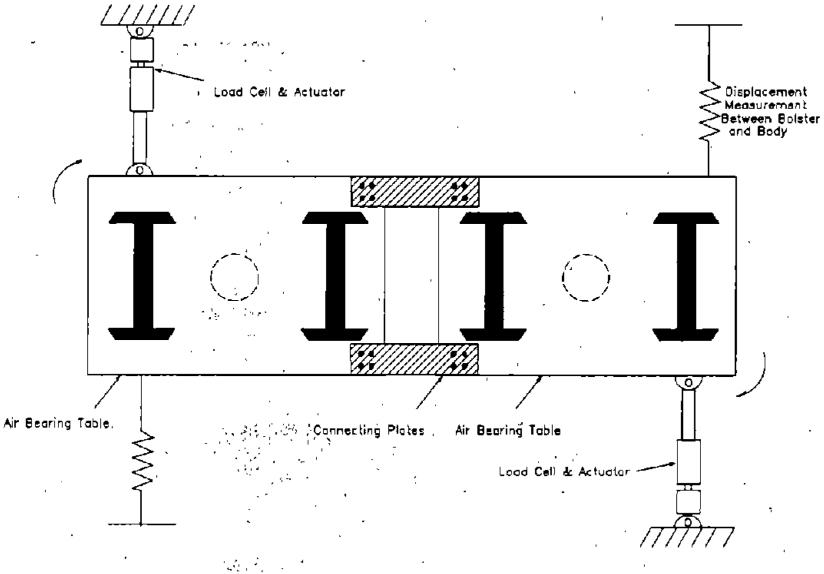


Figure 4.4 Span Bolster Yaw Moment Test Setup

One air bearing table was placed under each truck in the A-end span bolster of the LCC and the two tables were bolted together. Actuators were attached at opposite corners of the table assembly. String pots were then placed at the two free corners to measure the displacement at the two tables. Figure 4.5 shows the LCC positioned on the air tables.

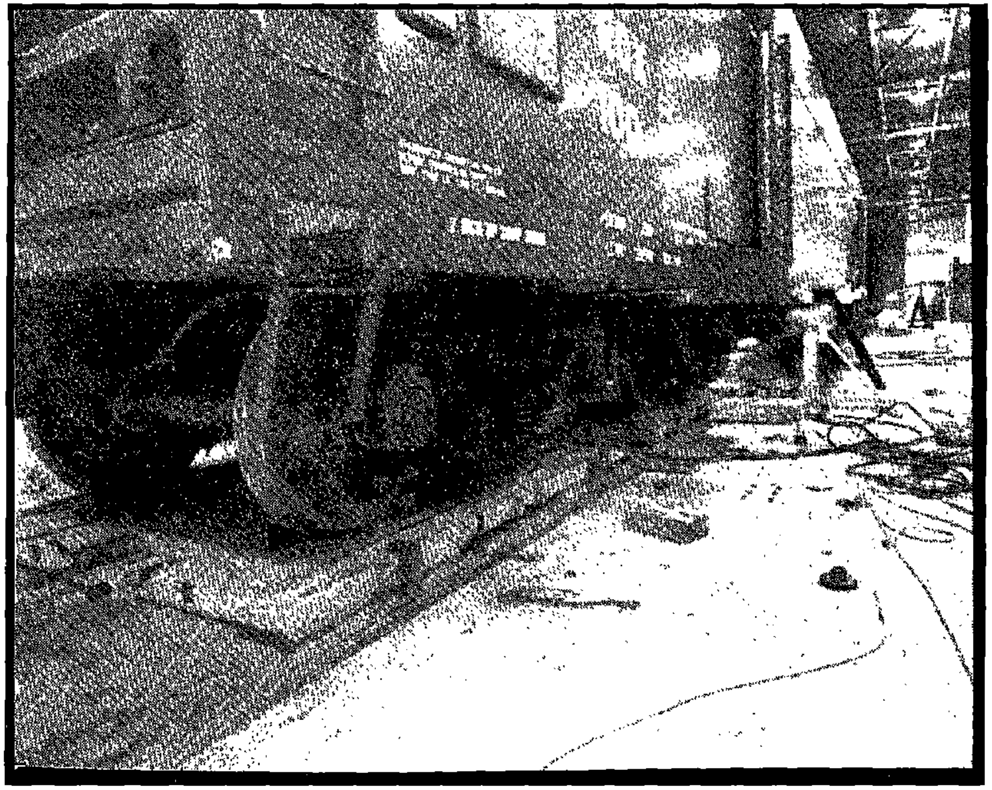


Figure 4.5 LCC on Air Tables

Force was applied equally and gradually with both actuators until the span bolster began to rotate. The test was stopped when the span bolster had rotated approximately 2 inches, which equated to 18.5 milliradians (mrad). The span bolster was rotated in clockwise and counterclockwise directions by reversing the location of the actuators and string pots.

4.1.1.5 Truck Yaw Moment Procedures

The setup for the individual Truck Yaw Moment Test was similar to the span bolster test. The two A-end tables were unbolted and the actuators and string pots were assembled on one table only (Figure 4.6).

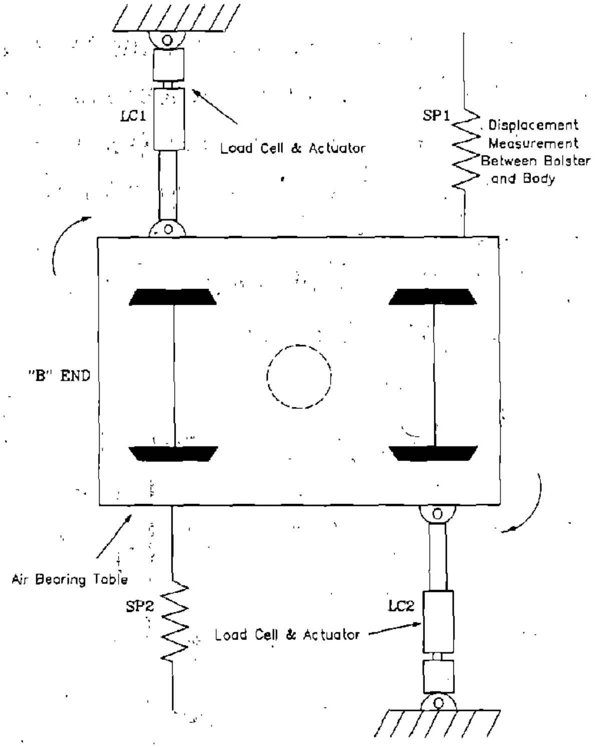


Figure 4.6 Truck Yaw Moment Test Setup

The truck tests were performed in the same manner as the span bolster test; with one exception, the trucks were only rotated 1 inch, which equated to 27.8 mrad. Each of the two trucks was tested in clockwise and counterclockwise directions by reversing the locations of the actuators and the string pots to the other corners.

4.1.1.6 Axle Alignment Procedure

The Axle Alignment Test was performed to determine the lateral and radial misalignment between the two axles in a truck. The two test trucks were placed under the UP gondola (UP31923), loaded to simulated the LCC axle load (48,000 pounds).

To allow each axle in the truck to align itself independently, both air tables were placed under one truck; one table under each axle.

In order to measure radial and lateral misalignments, an optical transit and precision scales were used in the arrangement shown in Figure 4.7.

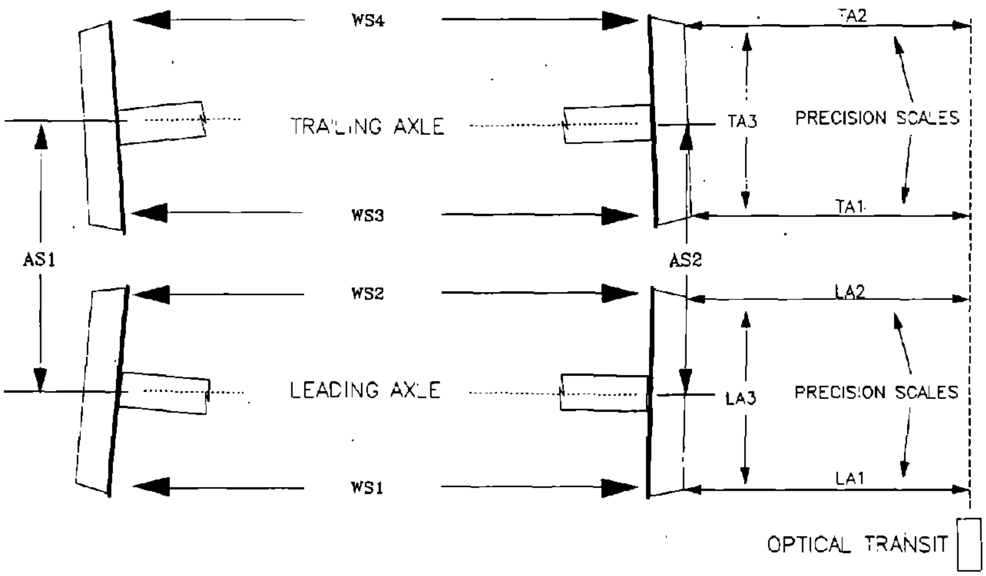


Figure 4.7 Axle Alignment Test Setup

Each time the tables were floated and set back down, the axle spacing on each side of the truck was measured. The scales were then put in place and the misalignments calculated (Figure 4.8). The test was performed three times on each of the two trucks.

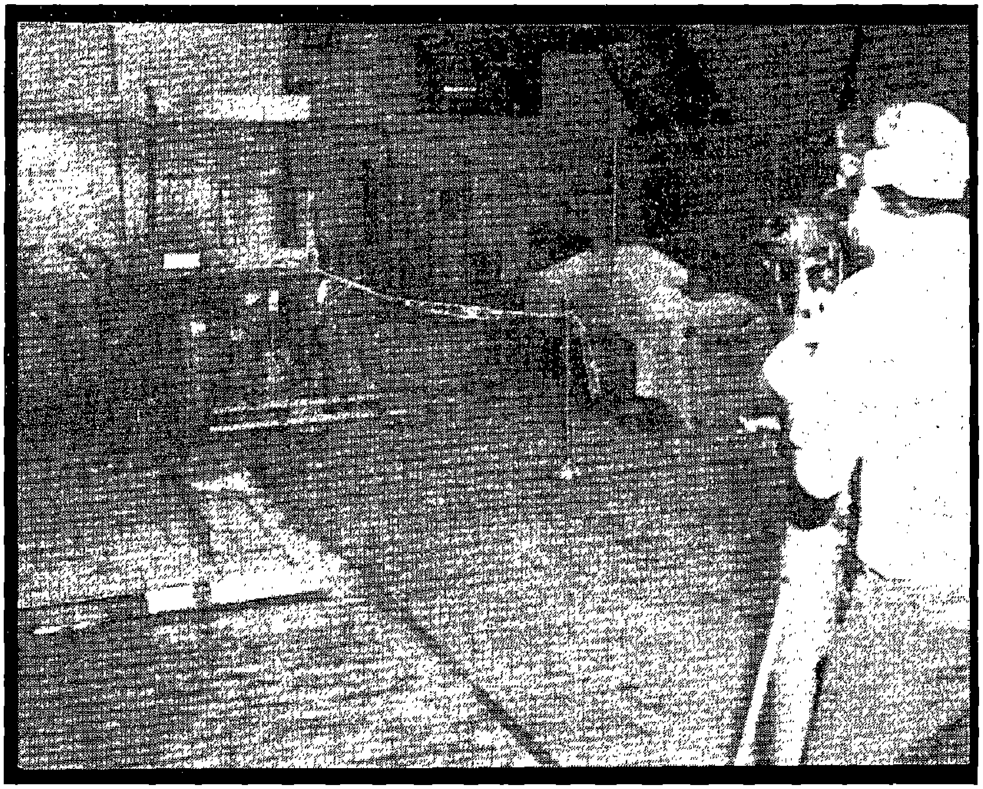


Figure 4.8 Axle Alignment Test

4.1.1.7 Truck Longitudinal Stiffness Procedure

The air tables were left in the same configuration for the Longitudinal Stiffness Test as they were for the Axle Alignment Test. Actuators were connected between the ends of the axles on both sides of each truck via axle spuds bolted on the bearing end caps (Figure 4.9).

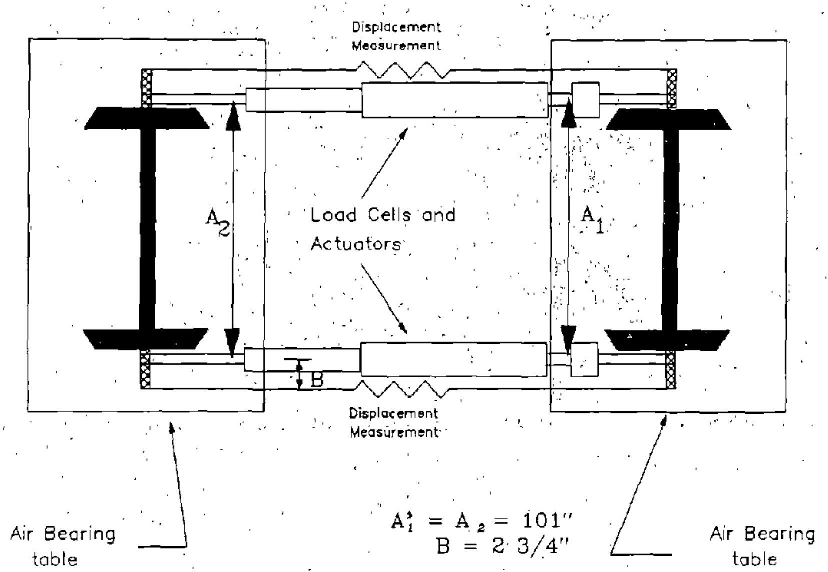


Figure 4.9 Truck Longitudinal Stiffness Test Setup

String pots were used to measure displacement between the two axles on each side of the truck. The axles were pushed apart and pulled together to determine the longitudinal stiffness. This test was repeated on the second truck.

4.1.1.8 Truck Inter-Axle Yaw and Bending Procedure

The Inter-Axle Yaw and Bending Test was performed in conjunction with the Longitudinal Stiffness Test. The axles were yawed by pushing them apart on one side of the truck while pulling them together on the opposite side of the truck. The same test setup was used for this test as for the Longitudinal Stiffness Test (Figure 4.9).

4.1.1.9 Inter-Axle Shear Procedure

The tables were left in the same configuration for the Inter-Axle Shear Test as they were in the Longitudinal Stiffness Test. The axle spuds were removed and a lateral actuator was installed between the two tables via connector plates (Figure 4.10).

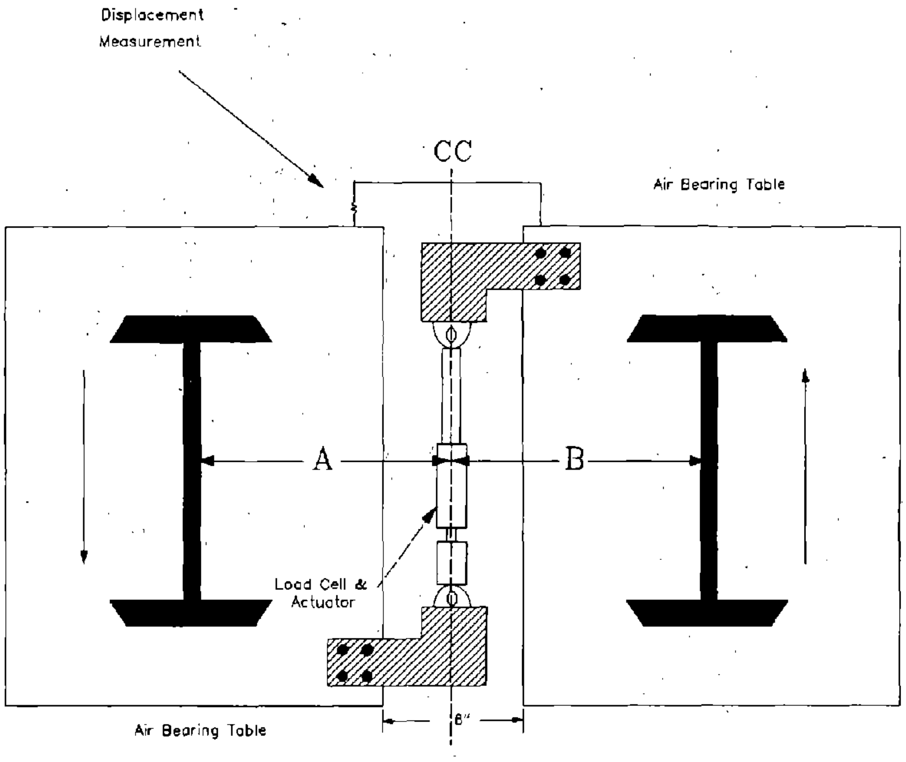


Figure 4.10 Inter-Axle Shear Test

By applying a force at the connector plates, the axles were sheared apart. The displacement was measured with two string pots; one for shear displacement and one for longitudinal displacement. The axles were sheared in both directions on each truck. Figure 4.11 shows the Inter-Axle Shear Test Setup.

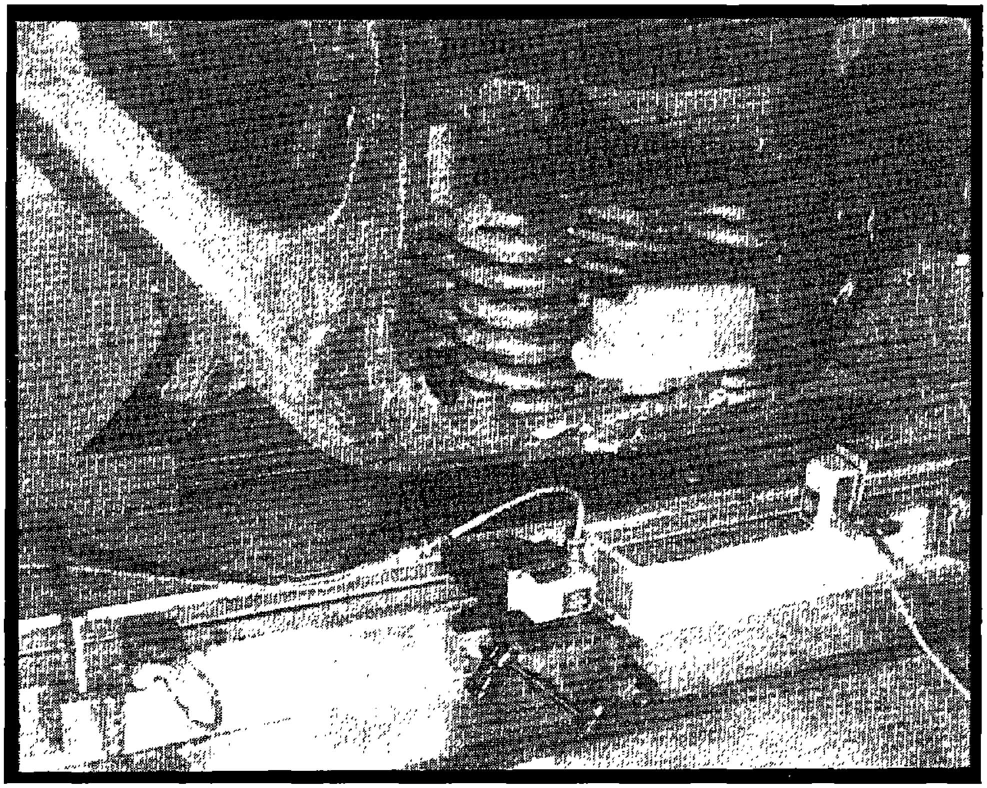


Figure 4.11 Inter-Axle Shear Test Setup

4.1.2 Modal Response Procedures

The Modal Response Test was performed using the MSU to determine the resonant frequencies for the following modes:

Pitch
Bounce
Roll
Yaw
Vertical Bending
Lateral Bending
Torsion (Twist)
Sway

The MSU utilized two 55 kip hydraulic actuators for vertical car body excitation and one 55 kip hydraulic actuator for lateral car body excitation. One of the vertical actuators was disconnected for a few tests for a computer model that requires data obtained with only one excitation point.

The actuators were attached to the car via fixtures welded to the car body (Figure 4.12).

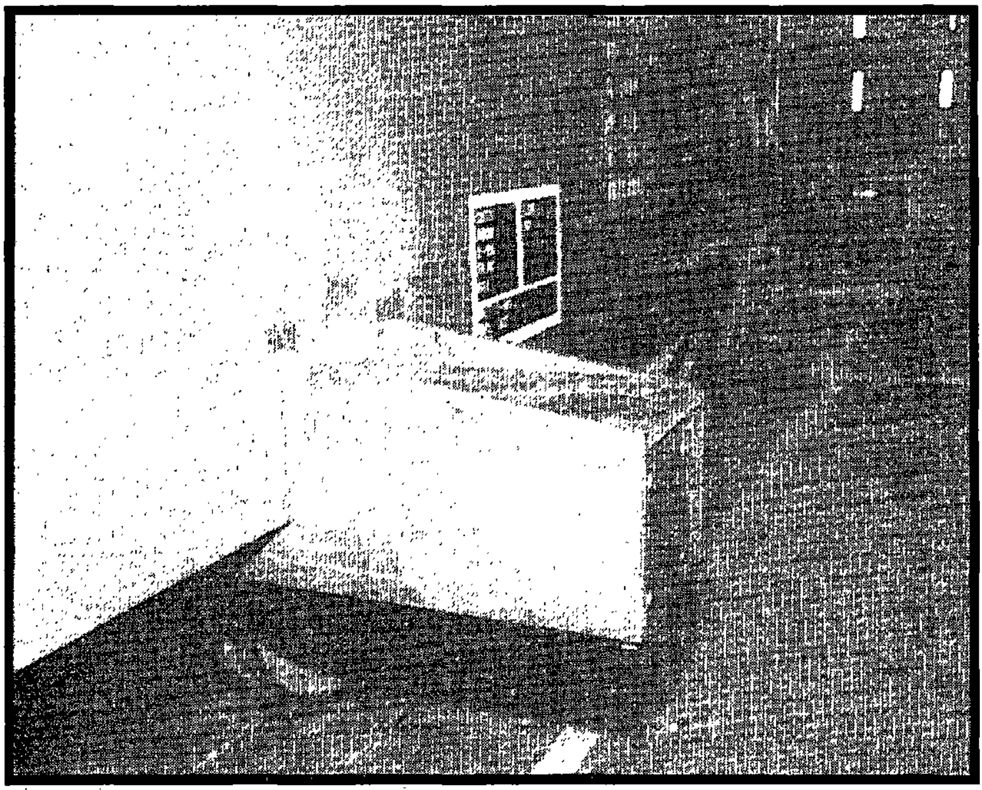


Figure 4.12 LCC Modal Attachment Fixture

The actuators were attached to a reaction mass bolted to the floor of the RDL. Sinusoidal input signals were provided to the actuator control valves with a HP 360 desktop computer teamed with a programmable function generator. Figure 4.13 shows the LCC being placed on the MSU.

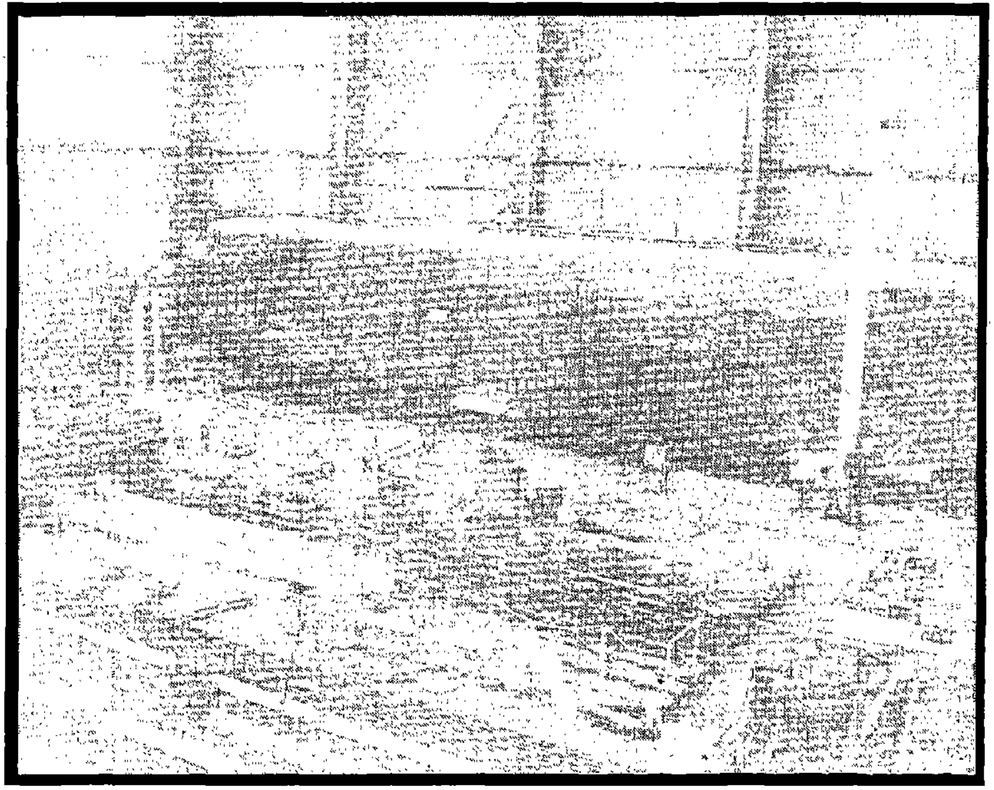


Figure 4.13 LCC Being Placed on the MSU

4.1.2.1 Rigid Body Vertical Procedure

The MSU was set up in the vertical test configuration for the Rigid Body Vertical Test. The actuators were cycled in-phase with 5, 10, and 15 kip sinusoidal inputs. The frequency increased from 0.2 Hz to 10 Hz in 0.1 Hz steps at 10 cycles per step. Pitch and bounce modes were determined by the phase relationship between the A- and B-end displacements and accelerations of the car body.

4.1.2.2 Rigid Body Roll Procedure

The MSU setup remained in the vertical configuration for the Rigid Body Roll Test. The same procedure was used for this test as was used for the Rigid Body Vertical Test except the actuators were cycled 180 degrees out-of-phase. A roll frequency was determined by the phase relationship between displacements and accelerations at different locations along the car body.

4.1.2.3 Flexible Body Vertical Procedure

The MSU remained in the vertical test configuration for the Flexible Body Vertical Test. The actuators were cycled in-phase but they were in displacement control rather than force control. Displacement control was used to get a constant acceleration (g) input. The actuators were controlled with frequency sweeps from 3 Hz to 30 Hz in 0.1 Hz steps at constant g of 0.1, 0.2, and 0.3. Additional sweeps of 0.4 g at 10 Hz to 30 Hz and 0.5 g at 15 Hz to 30 Hz were also performed.

4.1.2.4 Flexible Body Twist Procedure

The Flexible Body Twist Test was performed in the vertical configuration. The inputs were identical to the Flexible Body Vertical Test except the actuators were cycled 180 degrees out-of-phase.

4.1.2.5 Rigid Body Lateral Procedure

The MSU was reconfigured to the lateral test position for the Rigid Body Lateral Test. Sinusoidal inputs of 5, 10, and 15 kips from 0.2 Hz to 10 Hz in 0.1 Hz steps at 10 cycles per step were provided to the actuator control values for input into the LCC. Yaw and sway frequencies were determined by the relationships between displacements and accelerations of the car body at various locations.

4.1.2.6 Flexible Body Lateral Procedure

The Flexible Body Lateral Test was performed with constant g inputs of 0.1, 0.2, and 0.3, from 3 Hz to 30 Hz in 0.1 Hz steps. An additional sweep of 0.4 g from 10 Hz to 30 Hz was also used.

4.2 SERVICE WORTHINESS

The LCC service worthiness testing consisted of four separate tests described in Sections 4.2.1 to 4.2.4:

Single Car Impact Test
Compressive End Load Test
Jacking Test
Curve Stability Test

4.2.1 Single Car Impact Procedure

The Single Car Impact Test was conducted with the loaded LCC on the Precision Test Track (PTT). The PTT has a known slope; therefore, the LCC was positioned on track at points that result in proper speeds at impact when released from a locomotive. The LCC impacted three loaded 70-ton design hopper cars (225,000 pounds each) with the handbrake on the non-struck car set tightly. The LCC was impacted in 1 mph increments until either 6 mph was reached or a coupler force of 1.25 million pounds was reached. The 6 mph speed limit was set by the Air Force. The LCC was then inspected for any damage that would cause the car to be brought in for repairs. Figure 4.14 shows the Single Car Impact Test Setup.

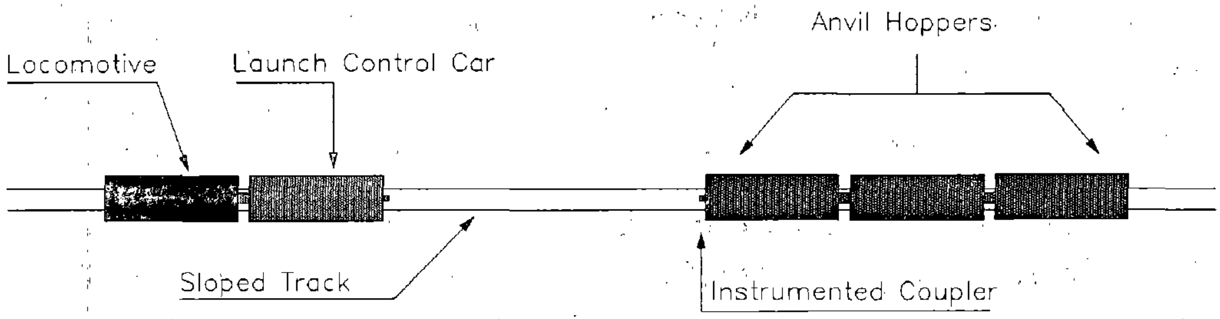


Figure 4.14 Single Car Impact Test Setup

4.2.2 Compressive End Load Procedure

The Compressive End Load Test was performed on the LCC. The couplers are removed from the LCC and replaced with shanks. The LCC is then placed in the squeeze fixture and an axial load applied incrementally to a maximum of 1 million pounds. The load must be held at 1 million pounds for a period of 1 minute. The LCC was then inspected for damage. Figure 4.15 shows the test setup.

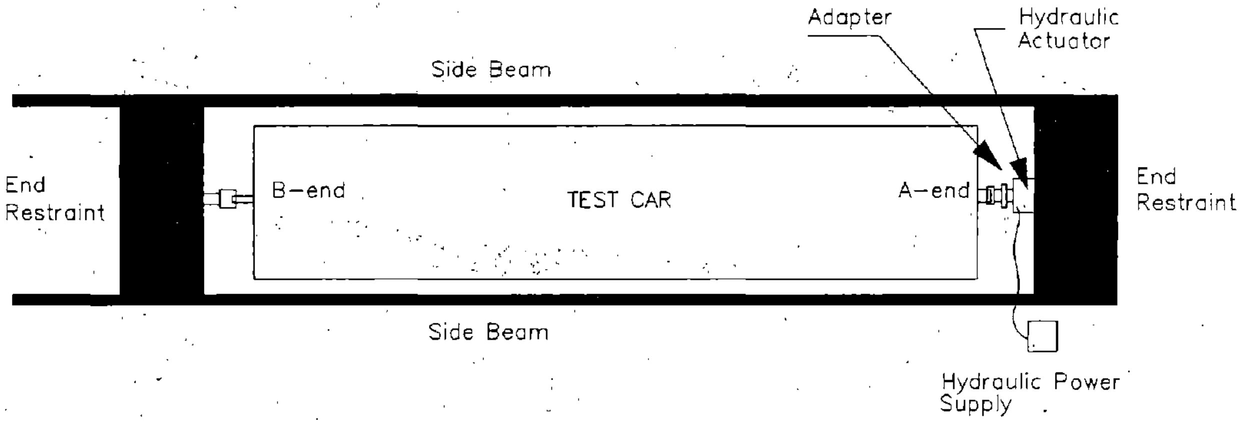


Figure 4.15 Compressive End Load Test Setup

4.2.3 Jacking Procedure

The Jacking Test was performed with the LCC in the loaded condition while the car was being configured for other tests. Hydraulic jacks applied a load to the jacking pads, large enough to raise the car body and allow the trucks and span bolster to be rolled out from under the body. The LCC was monitored for permanent deformation.

4.2.4 Curve Stability Procedure

The Curve Stability Test was conducted with the LCC in the loaded condition. The LCC has no true unloaded condition. The south wye of the Urban Rail Building (URB) at TTC was used for the test. The wye is a 10-degree curve with less than 0.5 inches of superelevation. The LCC was subjected to static buff and draft loads of 200,000 pounds for 20 seconds. The LCC was monitored for wheel lift or any separation of the trucks, span bolster, and car body. Figure 4.16 shows the Curve Stability Test setup.

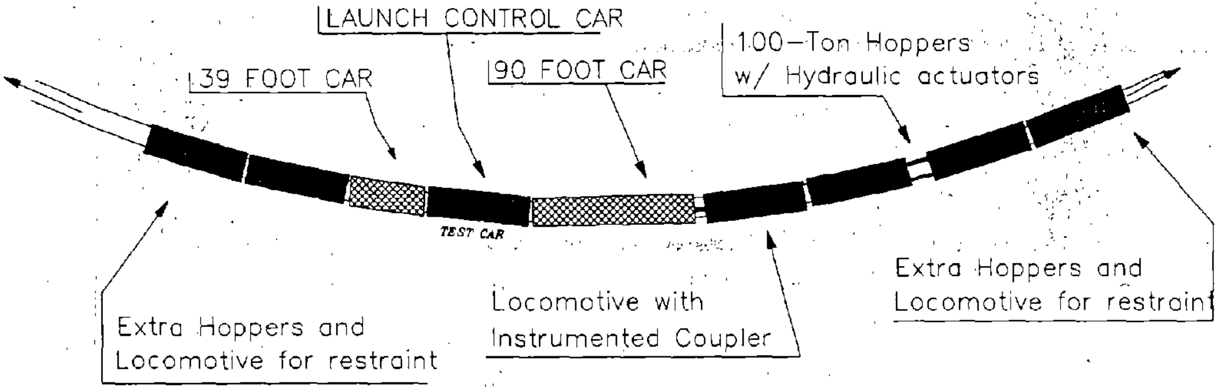


Figure 4.16 Curve Stability Test Setup

4.3 TRACK WORTHINESS

The LCC track worthiness testing consisted of eight separate tests. All of the tests were conducted on TTC track with the car in the loaded configuration under which it will operate in actual service. Figure 4.17 is a track location diagram for all track tests, the specific maps are found in each of the test description Sections.

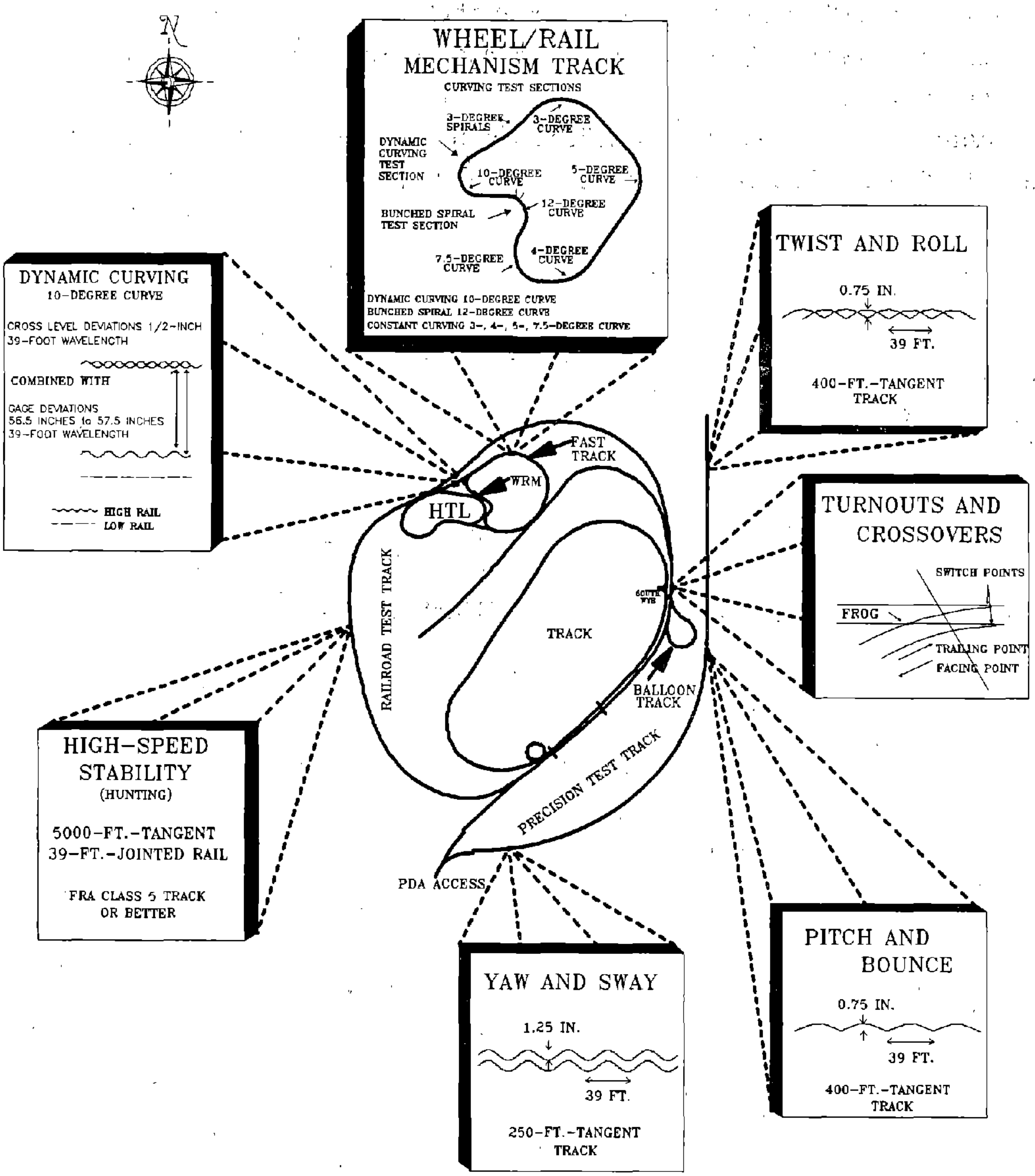


Figure 4.17 Track Location Diagram

The track worthiness testing required specific buffer cars adjacent to the LCC. The front buffer car was the T-5 Instrumentation Car and the rear buffer car changed, depending on the particular test.

Instrumented wheel sets were installed under the LCC lead axle of each truck (Figure 4.18). The A-end of the LCC was always leading for the track worthiness testing.

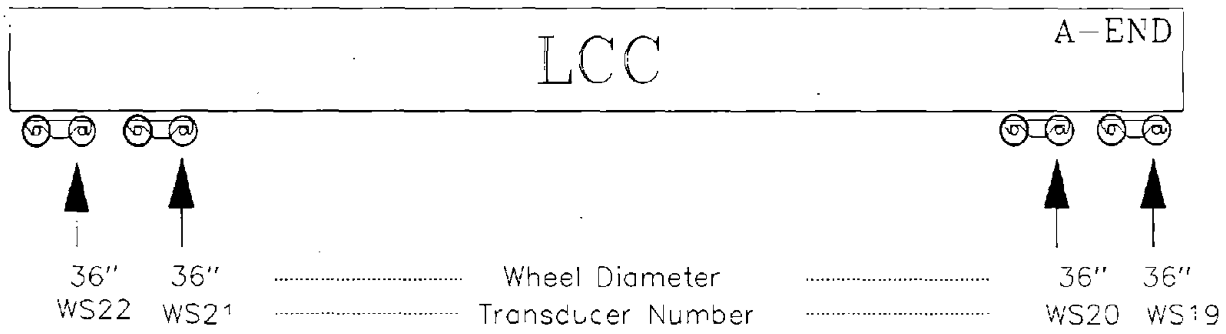


Figure 4.18 Instrumented Wheel Set Locations

4.3.1 High Speed Stability Procedure

The LCC was behind the T-5 Instrumentation Car. No buffer car is required in the Hunting Test. The consist was operated at speeds up to 60 mph on 5,000 feet of tangent track with 39-foot jointed rail, class 5 or better. Axle sum L/V's and car body lateral accelerations were monitored. Chapter XI testing requires speeds up to 70 mph. The 60 mph speed limit was set by the Air Force.

HIGH-SPEED
STABILITY
(HUNTING)

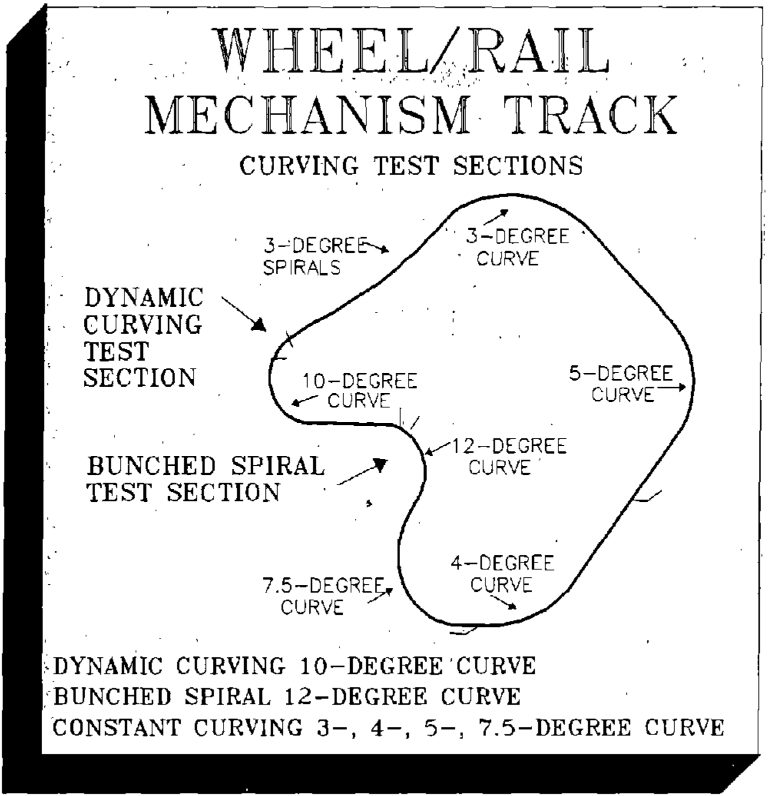
5000-FT.-TANGENT
39-FT.-JOINTED RAIL

FRA CLASS 5 TRACK
OR BETTER

Figure 4.19 Hunting Test Track Description

4.3.2 Constant Curving Procedure

The Constant Curving Test was conducted on the Wheel/Rail Mechanism (WRM) track (Figure 4.20). The LCC was operated on several degrees of curvature and superelevation. The test was run at below balance, above balance, and at balance speeds in both clockwise and counterclockwise directions. Wheel L/V's and car body accelerations were monitored in real time to ensure safe operation.



DEGREE	SUPER ELEVATION	BALANCE SPEED
3	2	31.4
4	3	33.3
5	4	34.4
7.5	3	24.3
10	4	24.3
12	5	24.8

Figure 4.20 Constant Curving Test Facility

4.3.3 Curve Exit and Curve Entry Procedure

The Curve Exit and Curve Entry Testing was conducted on the WRM track in conjunction with the Constant Curving Test on the bunched spiral section found at one end of the 12-degree curve and on the standard spirals found at the ends of the remaining curves.

A standard spiral is the section of track which makes the transition from tangent to curve with constant changes in curvature and superelevation with distance. The bunched spiral makes a change in curvature throughout the spiral but the change in superelevation is bunched in the middle 100 feet of the spiral. Tests were done at the same speeds as the Constant Curving Test and in both the clockwise and counter clockwise directions. Single wheel L/V's and axle L/V's were monitored for any unsafe condition.

4.3.4 Pitch and Bounce Procedure

The Pitch and Bounce Test was conducted on the PTT. The LCC was tested at speeds up to 60 mph on track shimmed to represent parallel low spots with 0.75 inch amplitude at 39-foot intervals (Figure 4.21). Minimum vertical wheel load were monitored in the Pitch and Bounce Test. Chapter XI testing requires speeds up to 70 mph. The 60 mph speed limit was set by the Air Force.

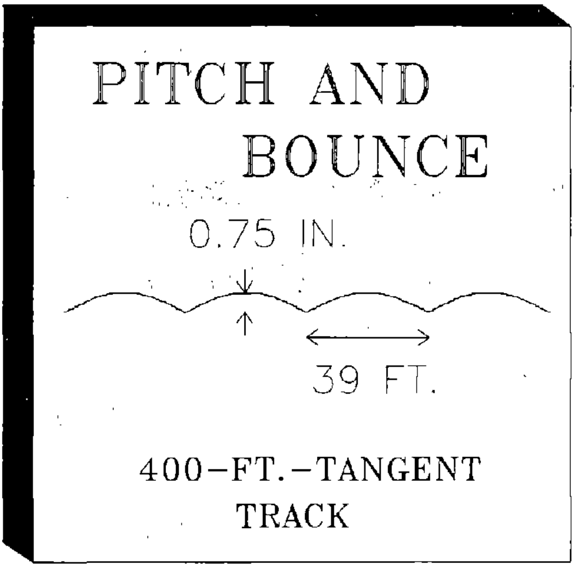


Figure 4.21 Pitch and Bounce Facility

4.3.5 Twist and Roll Procedure

The Twist and Roll Test was also conducted on the PTT. The LCC was tested again up to 60 mph on tracks shimmed to represent rail with cross level deviations of 0.75 inch at 39-foot intervals (Figure 4.22). Three criteria were monitored during this test: maximum axle sum L/V's, minimum vertical wheel load, and maximum roll angle. Chapter XI testing requires speeds up to 70 mph. The 60 mph speed limit was set by the Air Force.

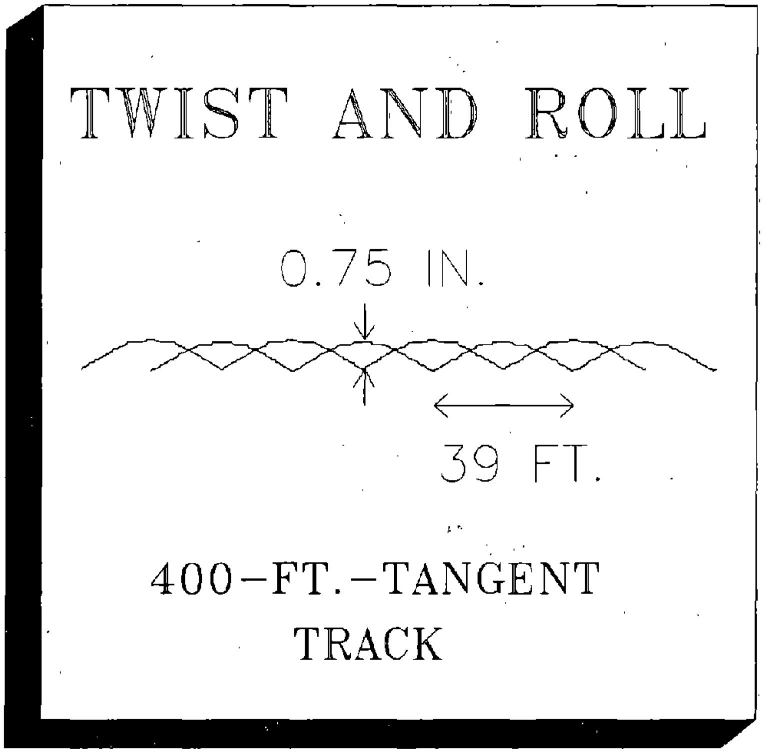


Figure 4.22 Twist and Roll Test Facility

4.3.6 Dynamic Curving Procedure

The Dynamic Curve Test was conducted on the 10-degree curve of the WRM track. The 10-degree curve is shimmed to provide a cross level of 0.5 inch combined with lateral perturbations giving a maximum gage of 57.5 inches and a minimum gage of 56.5 inches (Figure 4.23). Four areas of concern were monitored to ensure safe conduct of the test: maximum wheel L/V, maximum axle sum L/V, maximum roll angle , and minimum vertical wheel load.

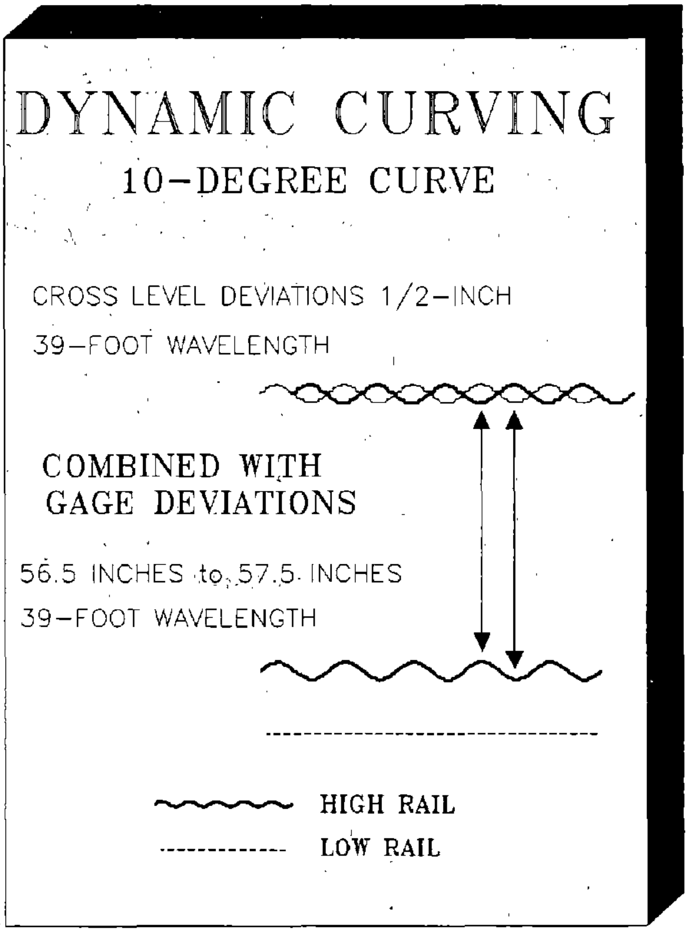


Figure 4.23 Dynamic Curving Test Facility

4.3.7 Turnout and Crossover Procedure

The Turnout and Crossover Tests were conducted on a No. 8 turnout and a No. 10 crossover. The LCC was tested at the maximum speeds allowed on these switches (15 mph and 20 mph respectively). This test is not addressed in Chapter XI. Figure 4.24 shows a typical turnout or crossover.

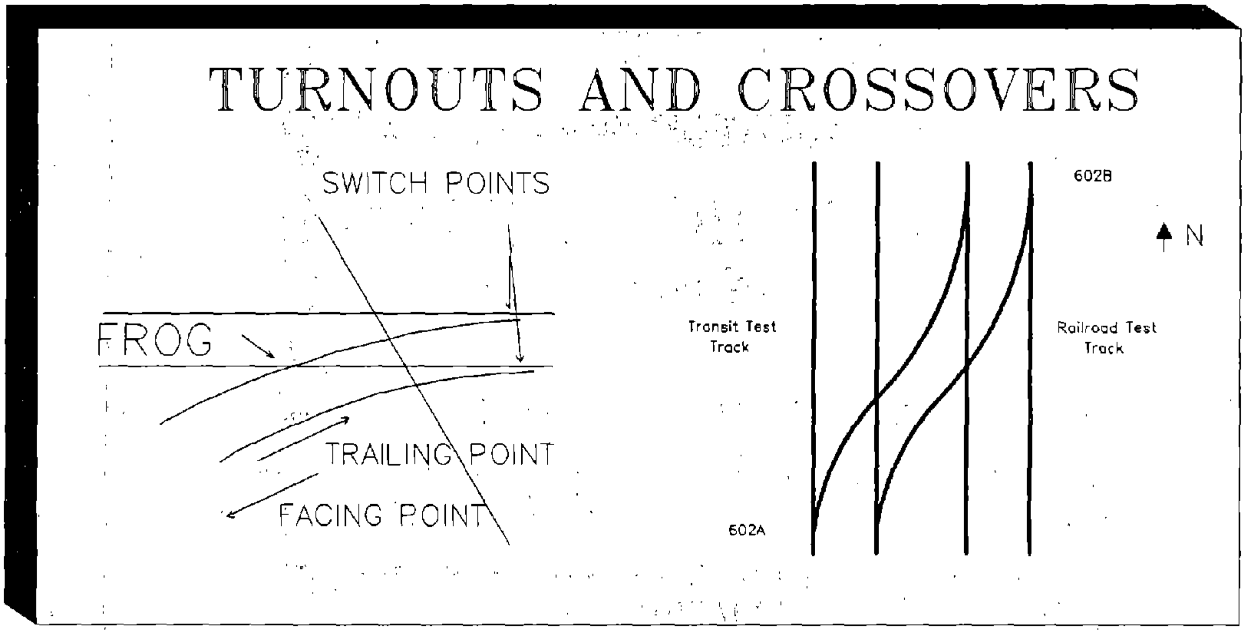


Figure 4.24 Turnout and Crossover Test Facilities

4.3.8 Yaw and Sway Procedure

The last track worthiness test performed on the LCC was the Yaw and Sway Test. The instrumented wheel sets were relocated to the lead truck of both span bolsters (Figure 4.25). The car was tested with the A-end leading. This is done to allow calculations for the Chapter XI criteria of truck side L/V. Chapter XI testing requires speeds up to 70 mph. The 60 mph speed limit was set by the Air Force.

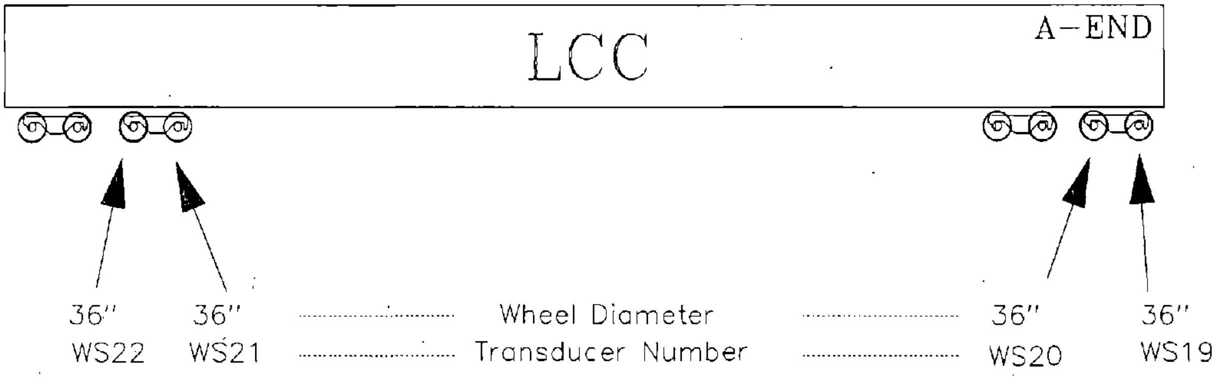


Figure 4.25 Instrumented Wheel Set Locations

The LCC was tested at speeds up to 60 mph in the yaw and sway section of the PTT. This section has sinusoidal track alignment deviations of 39-foot wavelength and an amplitude of 1.25 inches peak-to-peak on both rails at a constant wide gage of 57.5 inches, as shown in Figure 4.26. Truck side L/V sums and axle sum L/V's were monitored.

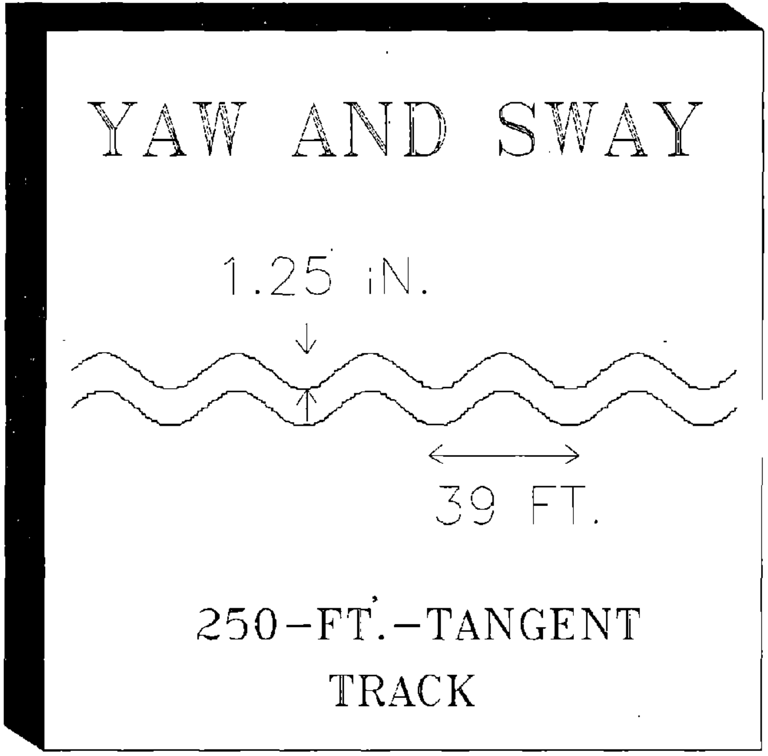


Figure 4.26 Yaw and Sway Test Facility

4.4 STATIC BRAKE TEST PROCEDURE

The Static Brake Test was performed by Blaine Consulting Services with some assistance by the AAR. The brake test was performed to ensure compliance with existing AAR and FRA rules and regulations. Appendix B contains the test plan used for this test. This testing procedure included a single car brake test following the *AAR Single Car Test Code Booklet*, IP No. 5039-4 Sup. 1, which is the AAR Standard S-486. This test was performed on both ends of the LCC because there is an Automatic Brake Diaphragm -- Westinghouse (ABDW) valve located on each end. Next, a net shoe force test was performed. Instrumented brake shoe load cells were installed at each wheel/brake interface on the A-end of the LCC. Brake shoe forces were read from a digital readout for a series of different brake pipe pressure reductions. The test was then repeated on the B-end of the LCC. Finally, a handbrake net shoe force test was performed while the instrumented brake shoes were in the B-end trucks. The handbrake was applied in increments and brake shoe forces were measured and recorded. Figure 4.28 shows a partial Static Brake Test setup.

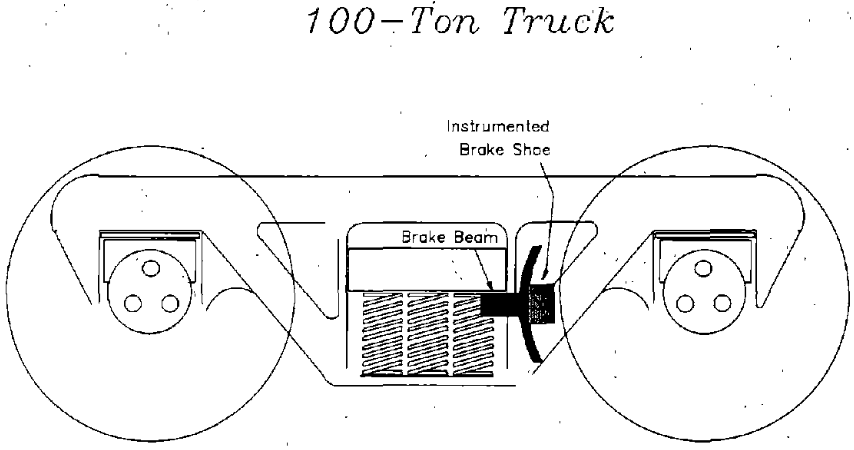


Figure 4.28 Static Brake Test with Instrumented Brake Shoe Assembly

5.0 MATERIALS AND INSTRUMENTATION

5.1 TEST VEHICLES

5.1.1 Launch Control Car Description

The Launch Control Car, EMS-2 was supplied by Rockwell. The car was designed by Rockwell and Chamberlin Gard and built by the St. Louis Refrigerator Company. Figure 5.1 shows the LCC, which is 90 feet long over the strikers.

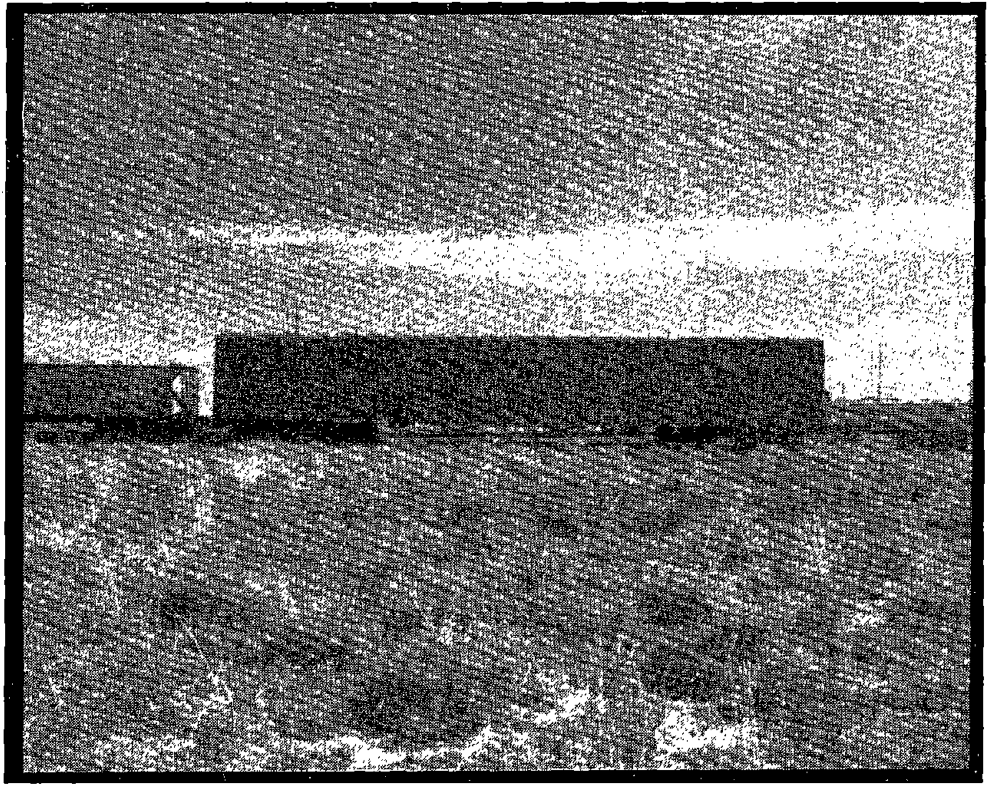


Figure 5.1 Launch Control Car

The loaded weight of the LCC was 392,400 pounds. The interior was loaded with steel and sand bags to simulate the operational LCC weight and center of gravity. The car rides on two Buckeye span bolsters. Each span bolster rides on two conventional three piece trucks with standard non-contacting side bearings. Figure 5.2 shows one of the span bolsters with two trucks.

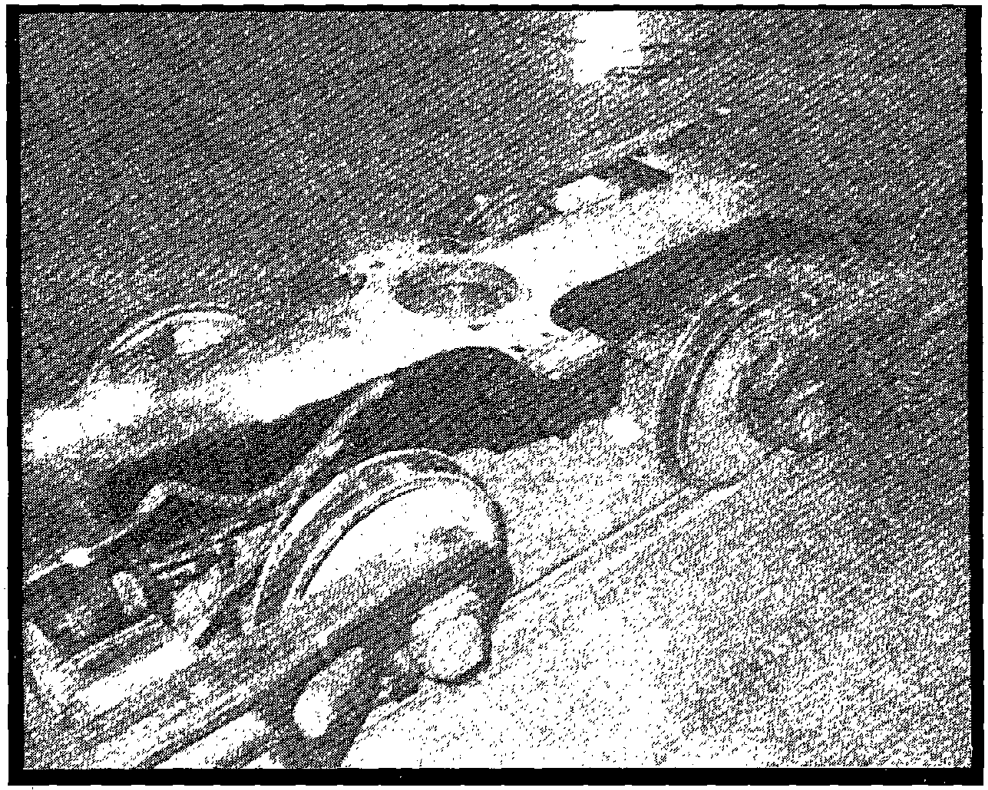


Figure 5.2 LCC Span Bolster and Truck

Each of the three piece trucks was an American Steel Foundries (ASF) ride control 100-ton design, equipped with eight D-7 outer springs, seven D-7 inner springs, a Stucki HS-7 hydraulic snubber in each spring group, and two 36-inch wheel sets with AAR-1B wheel profiles. Figure 5.3 shows one of the LCC three piece trucks.

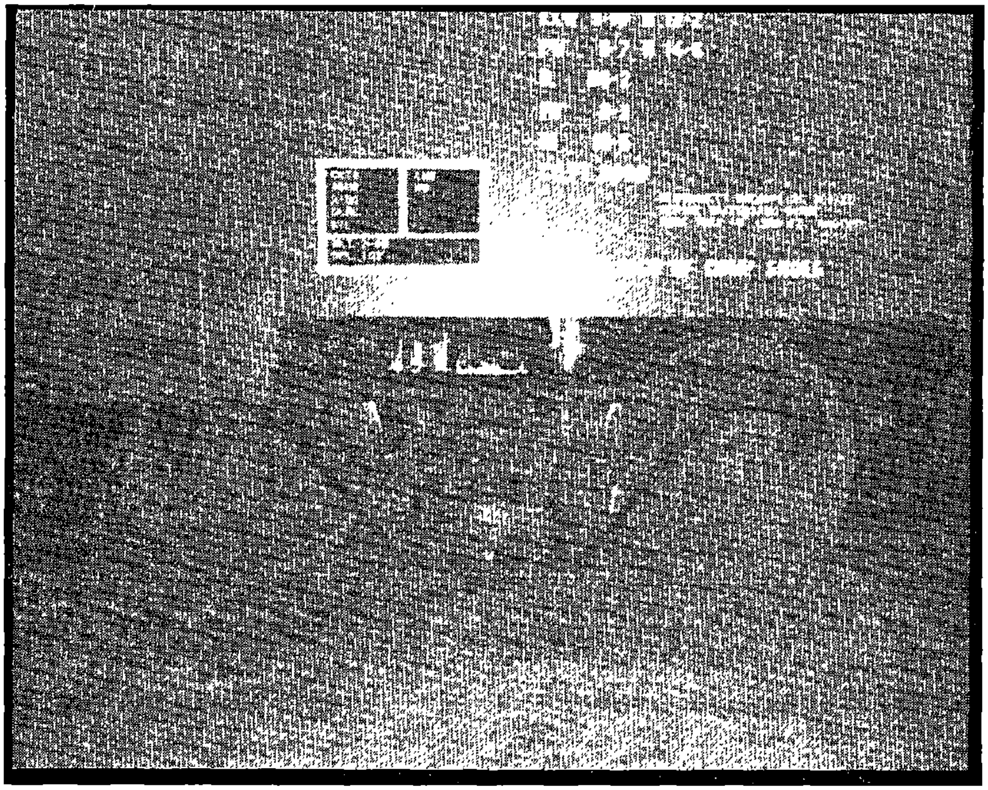


Figure 5.3 Standard LCC Truck

5.1.2 Instrumentation Car Description

The instrumentation car used for the track worthiness testing of the LCC was the DOTX205 (T-5) Instrumentation Car. The car was equipped with instrumentation and computer equipment required for testing the LCC and other PKRG cars.

5.1.3 Locomotive Description

Dedicated locomotives were used for conducting all LCC track worthiness testing. The locomotives were GP40-2, four axle models, similar to the locomotive being purchased for the PKRG trains. Other TTC locomotives were used for logistic moves, as required.

5.1.4 Buffer Cars

As required for Chapter XI, a loaded 100-ton buffer car was used for all track worthiness testing except for the Pitch and Bounce Test and the High Speed Stability Test. An empty flatcar was used for the Pitch and Bounce Test, and no buffer car was used for the High Speed Stability Test.

5.1.5 Test Train Configuration

Figure 5.4 shows the standard test train configuration for the LCC track worthiness testing. Occasionally the trailing buffer car was different, but the LCC always followed the instrumentation car and ran with the A-end leading.

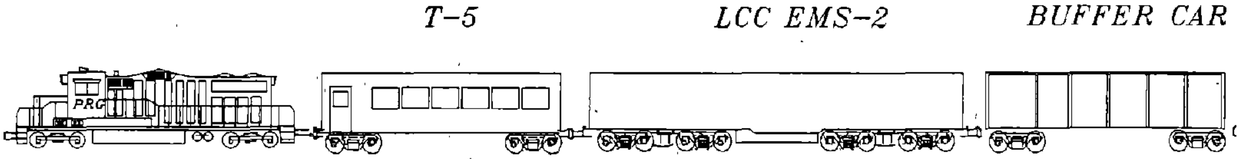


Figure 5.4 Standard Test Train Configuration

5.2 VEHICLE CHARACTERIZATION INSTRUMENTATION

Three separate lab tests were done to characterize the LCC car and suspension:

Quasi-Static Truck Characterization
Static Truck Characterization
Modal Response

5.2.1 Quasi-Static Truck Characterization Instrumentation

This test was performed on the MSU. Nineteen data channels were recorded during these tests including actuator forces, rail forces, and suspension displacements. Table 5.1 summarizes these channels. All of the measurements were collected on an HP 360 desktop computer and recorded onto an optical disk.

Table 5.1 Truck Characterization Measurements

NAME	LOCATION & DESCRIPTION	TRANSDUCER TYPE	SERIAL NUMBER	SENSITIVITY	SYSTEM EU's/VOLT
VAF1	Left Vertical Actuator Force	Interface load cell	26630	0.4054 mV/Kips	10 Kips/V
VAF2	Right Vertical Actuator Force	Interface load cell	26538	0.4097 mV/Kips	10 Kips/V
LAF1	Lateral Actuator Force	Interface load cell	26630	0.4054 mV/Kips	10 Kips/V
VRF1	Lead Left Vertical Rail Force	TTC instrumented rail	4	70.508 mV/Kips	14.617 Kips/V
VRF2	Lead Right Vertical Rail Force	TTC instrumented rail	3	73.661 mV/Kips	13.974 Kips/V
VRF3	Trail Left Vertical Rail Force	TTC instrumented rail	2	69.836 mV/Kips	13.951 Kips/V
VRF4	Trail Right Vertical Rail Force	TTC instrumented rail	1	73.324 mV/Kips	13.555 Kips/V
LRF1	Lead Left Lateral Rail Force	TTC instrumented rail	4	165.574 mV/Kips	6.04 Kips/V
LRF2	Lead Right Lateral Rail Force	TTC instrumented rail	3	183.637 mV/Kips	5.446 Kips/V
LRF3	Trail Left Lateral Rail Force	TTC instrumented rail	2	167.321 mV/Kips	5.977 Kips/V
LRF4	Trail Right Lateral Rail Force	TTC instrumented rail	1	171.257 mV/Kips	5.84 Kips/V
DZ1	Left Vertical Actuator disp.	Celesco string pot.	09934	1.1006 mV/in	0.6667 in/V
DZ2	Right Vertical Actuator disp.	Celesco string pot.	09933	1.0963 mV/in	0.6667 in/V
DZ5	Left Vertical Spring disp.	Celesco string pot.	14230	0.94524 V/in	0.4 in/V
DZ6	Right Vertical Spring disp.	Celesco string pot.	10372	0.93639 V/in	0.4 in/V
DY1	Lateral Actuator disp.	Celesco string pot.	09933	1.0963 mV/in	0.6667 in/V
DY2	Lateral Body to Truck Bolster disp.	Celesco string pot.	14235	1.9075 V/in	0.2 in/V
DY3	Left Lateral Spring disp.	Celesco string pot.	14238	4.762 V/in	0.1 in/V
DY4	Right Lateral Spring disp.	Celesco string pot.	14240	4.799 V/in	0.1 in/V

Figure 5.5 shows the transducer location for the right vertical spring displacement when characterizing the LCC trucks. This configuration was used for both sides of each truck.

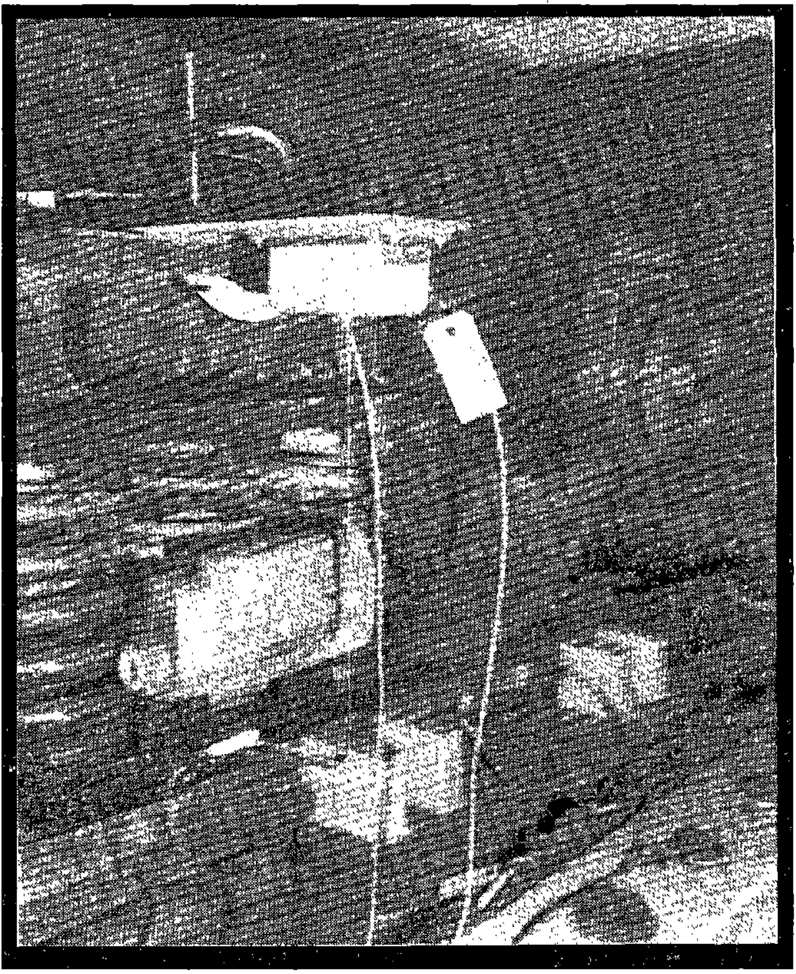


Figure 5.5 Spring Nest Vertical Displacement Transducer

Instrumented rails were used to record wheel/rail forces. Figure 5.6 shows the typical setup of a truck positioned on the instrumented rail. Each rail has a vertical and lateral signal at each wheel.

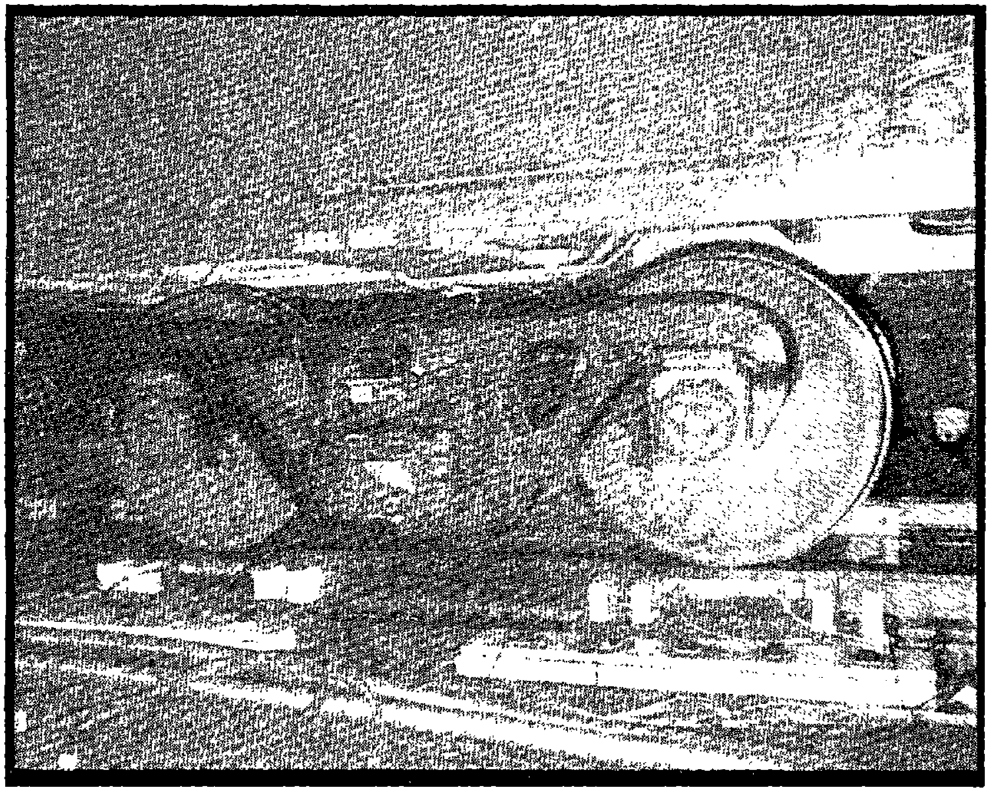


Figure 5.6 Instrumented Rails

5.2.2 Static Truck Characterization Instrumentation

Seven pieces of instrumentation were used during the six different air bearing tests. Three load cells and four string pots were used according to the test requirements. Table 5.2 lists the transducers and where they were used during the testing. All of the Air Bearing Test measurements were recorded with a Compaq 286 desktop computer equipped with a Metrabyte analog to digital converter and Lotus Measure software. The data was stored on floppy disks in Lotus 1-2-3 format.

Table 5.2 Air Table Measurements

NAME	LOCATION, DESCRIPTION, & TEST	TRANSDUCER TYPE	SERIAL NUMBER	SENSITIVITY	SYSTEM EU's/VOLT
LC1	Left Side Actuator Force	Interface load cell	10356	39.773 mV/10Kips	2 Kips/V
LC2	Right Side Actuator Force	Interface load cell	10737	40.735 mV/10Kips	2 Kips/V
LC1	Actuator Force (Inter-Axle Shear Test)	Interface load cell	22713	43.76 mV/10Kips	5 Kips/V
SP1	Left Side disp.	Celesco string pot.	22529	2.1126 in/V	2.0 in/V
SP2	Right Side disp.	Celesco string pot.	22526	2.1099 in/V	2.0 in/V
SP1	Shear disp.	RI string pot.	3680	0.2065 in/V	0.2 in/V
SP2	Distance Between Tables (Long. Stiffness Test)	RI string pot.	3684	0.2075 in/V	0.2 in/V

An interface load cell was connected to each Enerpac hydraulic actuator to record the actuator force (Figure 5.7). The same actuator and load cell remained together throughout the air bearing tests.

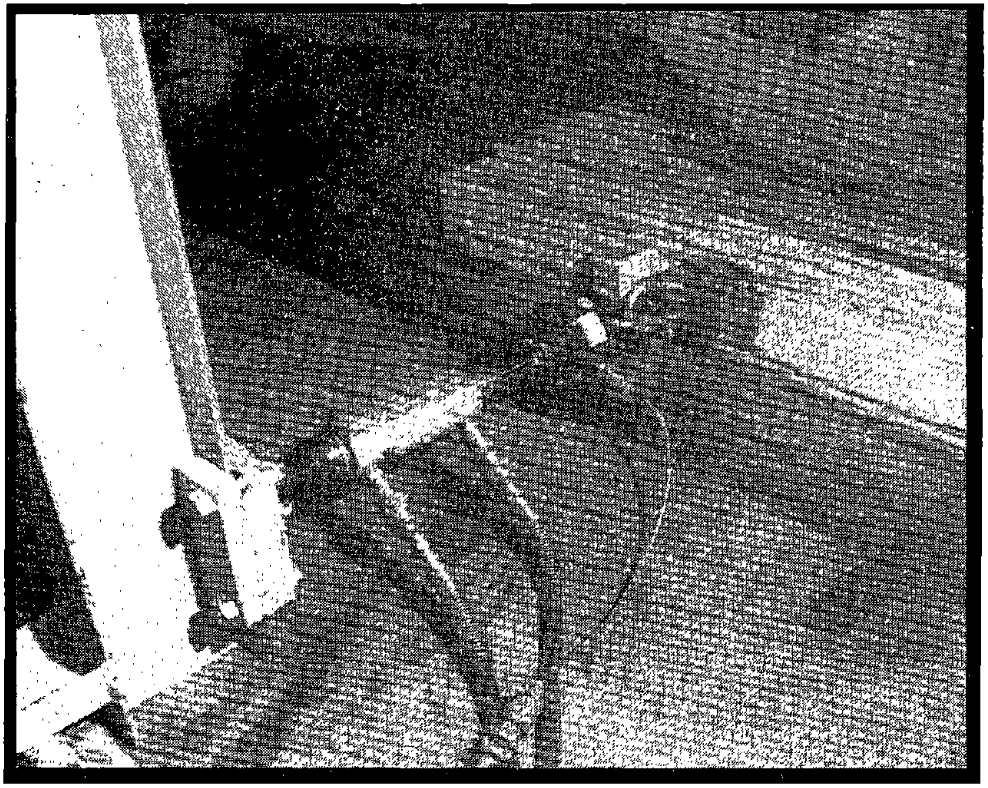


Figure 5.7 Air Table Force Transducer

The other transducers used during the air bearing tests were string pots. These transducers were located appropriately to measure the displacements of the air tables. Figure 5.8 shows the most typical setup during a truck rotation test.

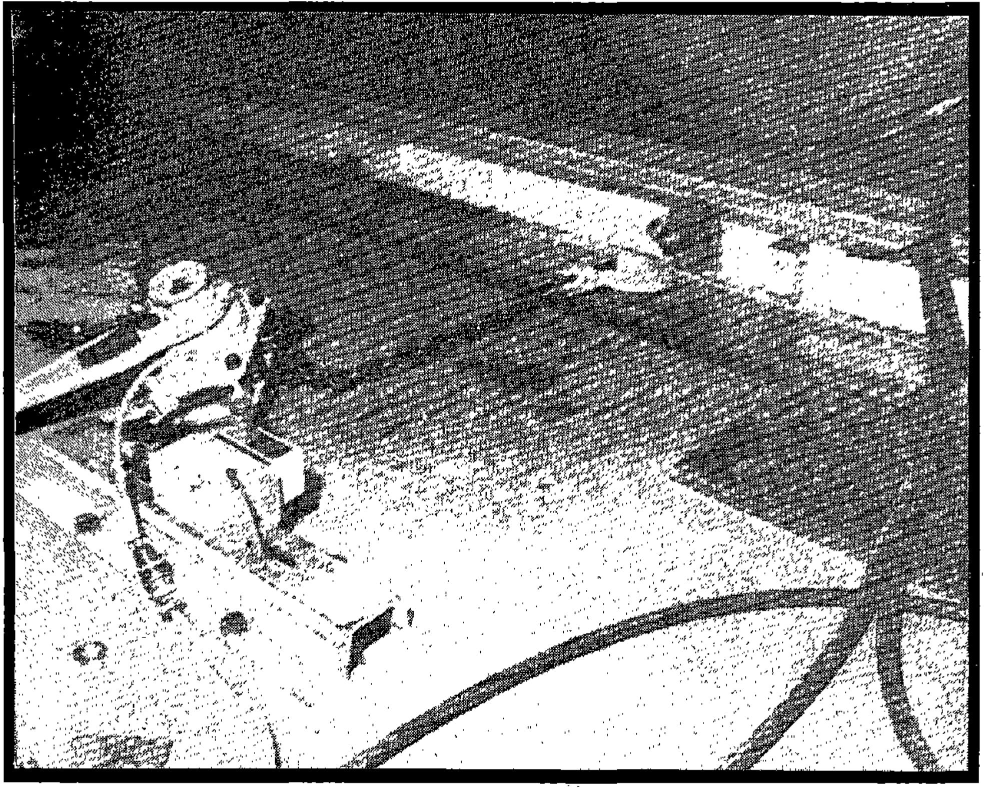


Figure 5.8 Air Table Displacement Transducer

5.2.3 Modal Response Instrumentation

The Modal Response Test was performed on the MSU in the RDL. The MSU utilized two 55 kip hydraulic actuators for vertical car body excitation. Figure 5.9 shows the MSU configured for lateral excitation testing.

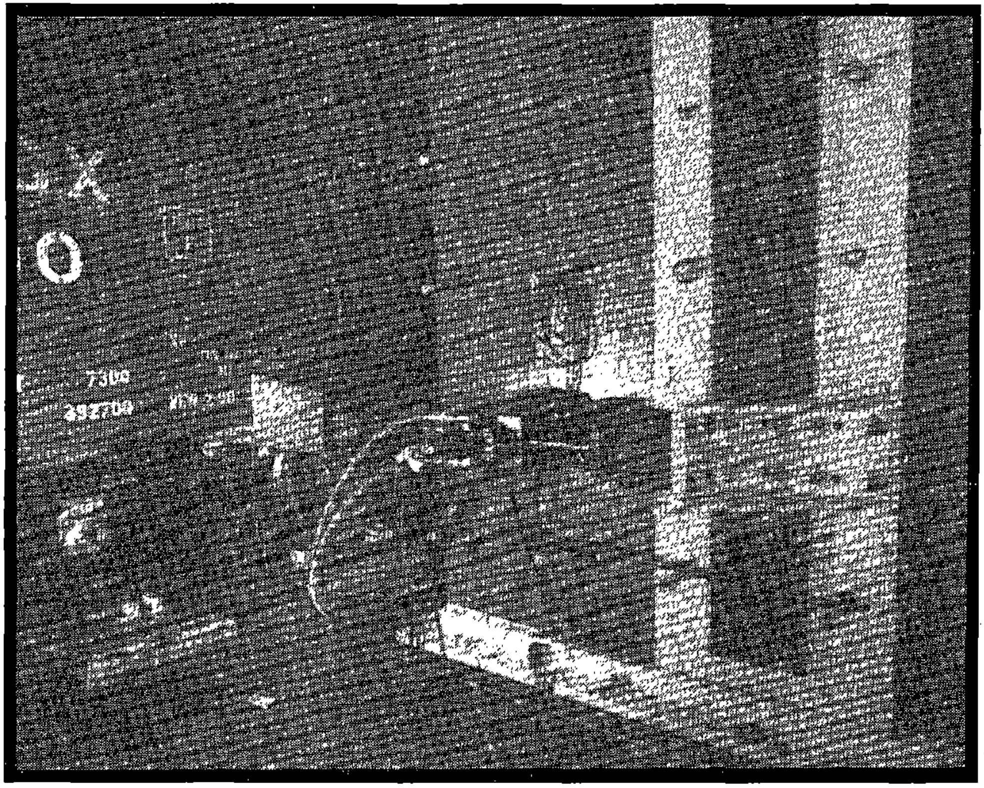


Figure 5.9 MSU in the Lateral Configuration

The relationship between car body to ground displacements measured along the car body were used to determine rigid body modes. String pots were used to obtain these measurements. Figure 5.10 shows the installation of one of the car body to ground transducers.

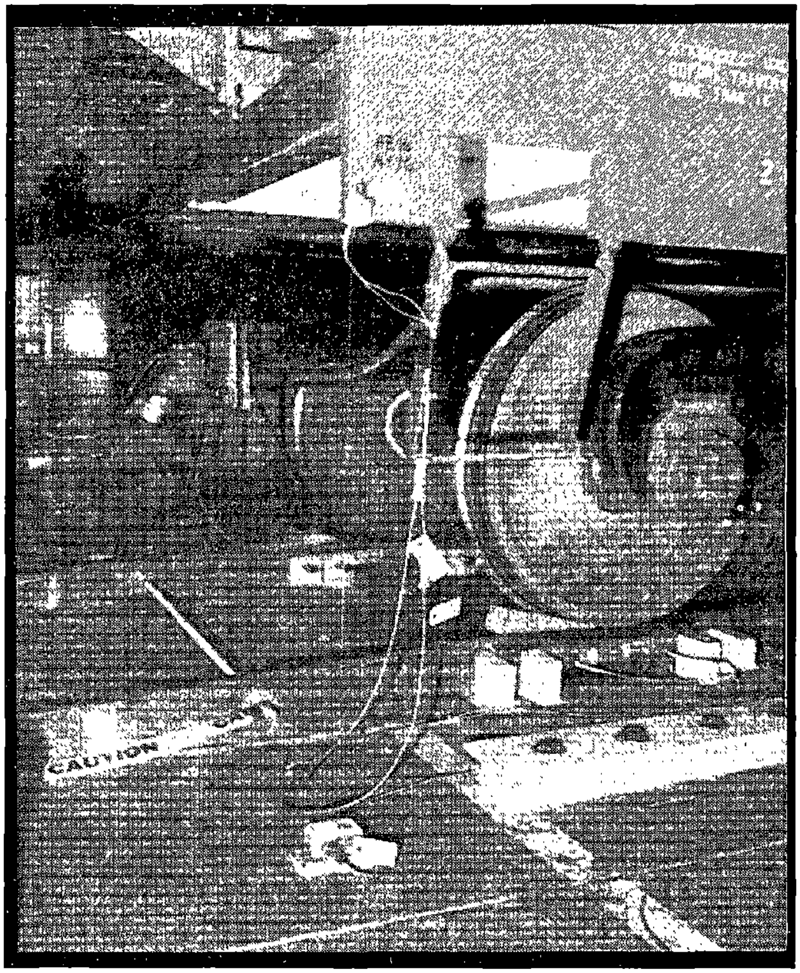


Figure 5.10 Car Body to Ground Displacement Transducer

Eight car body to ground displacement measurements were recorded. Figure 5.11 shows the location of all the displacement transducers.

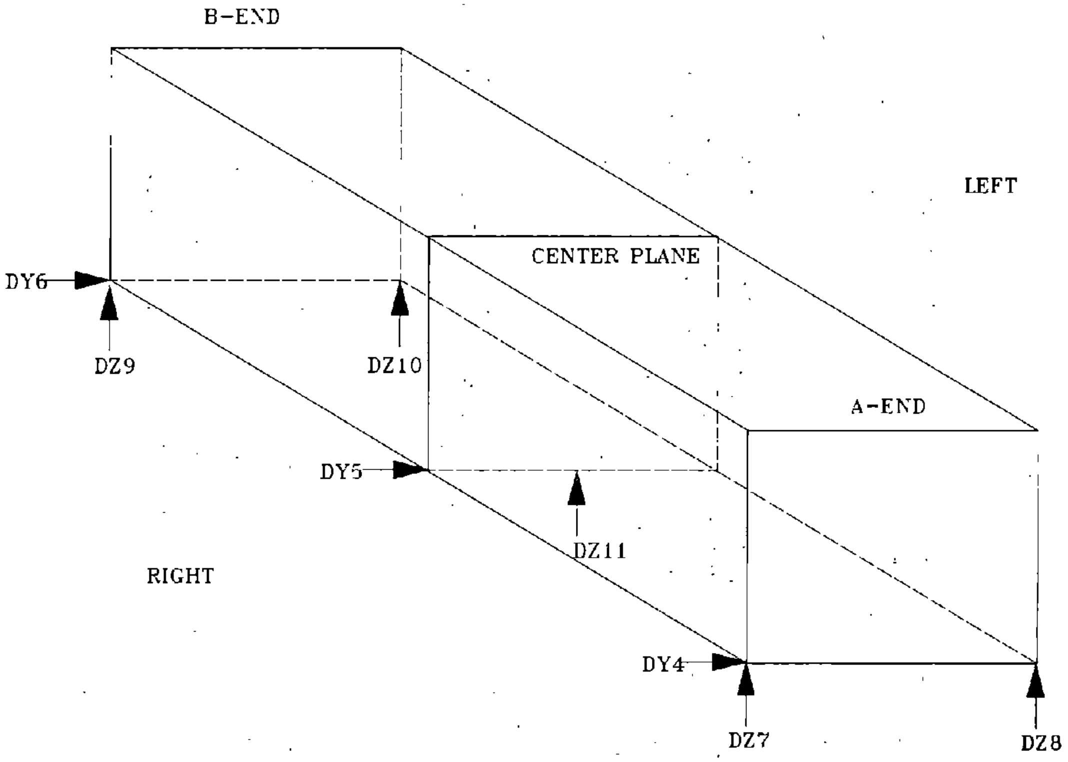


Figure 5.11 Car Body Displacement Locations

The primary source of data for the Flexible Body (Bending and Twist) Test was car body accelerometers. Thirty-two accelerometers were mounted on the LCC at specific locations with an a aluminum block and F88 adhesive (dental cement). Figure 5.12 shows a pair of accelerometers mounted on the side of the LCC. One accelerometer measures vertical movement and the other accelerometer measures lateral movement.

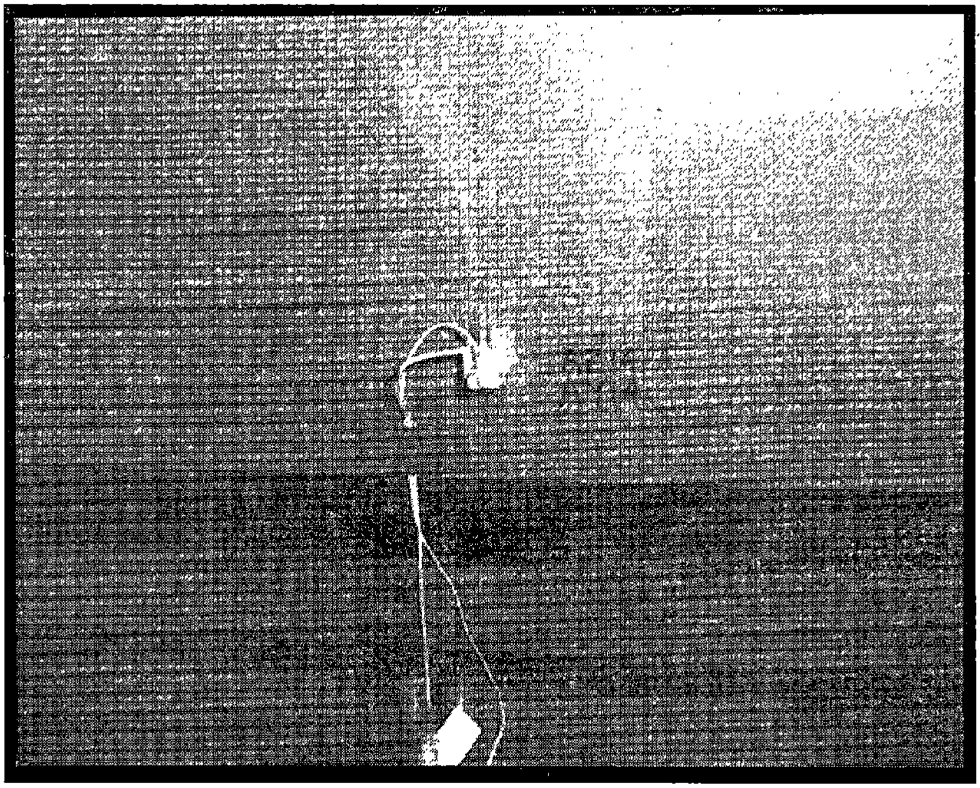


Figure 5.12 Two Car Body Accelerometers

The accelerometers were evenly spaced on the side of the LCC and at other critical locations so that various modes may be determined. Figure 5.13 shows the locations of the accelerometers.

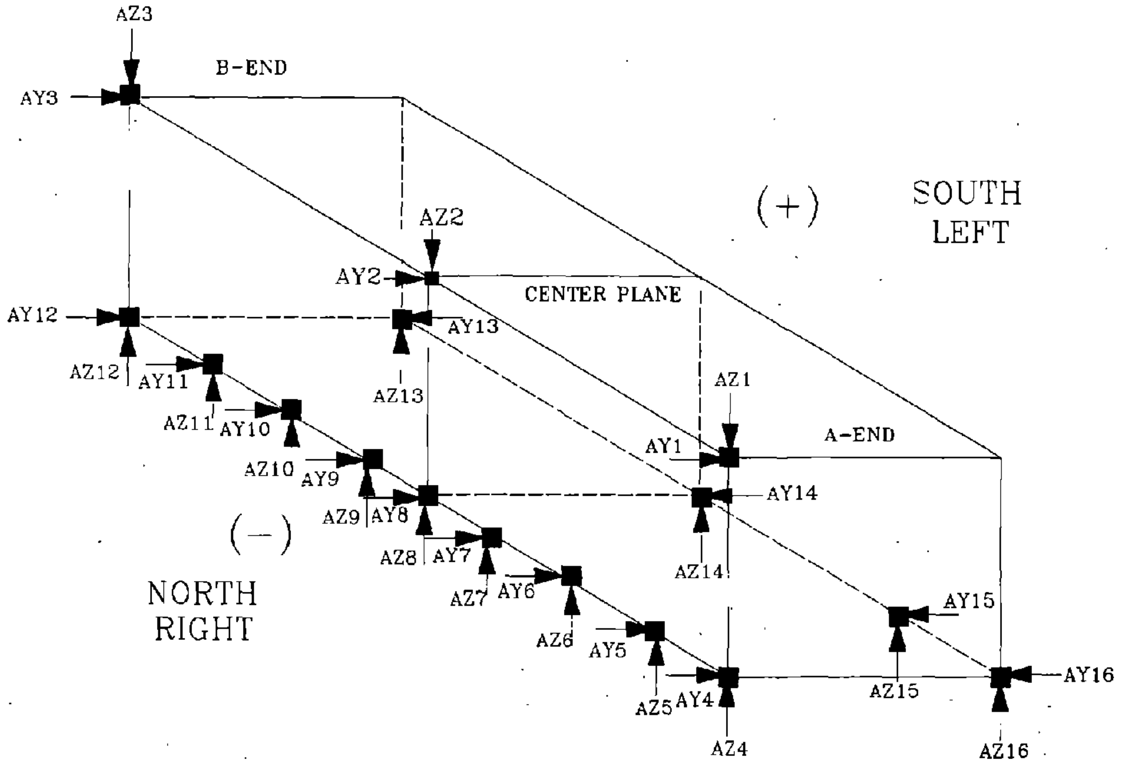


Figure 5.13 Car Body Accelerometer Locations

Vertical and lateral wheel forces were measured at each wheel on the A-end of the LCC with strain gaged rails. The setup was very similar to that presented in Section 5.2.1, except that eight rails were used instead of four. Actuator forces and displacement were also measured with load cells and LVDT's. Accelerometers and string pots were installed on the A-end trucks and span bolster to help determine if the span bolster bending mode influenced the car body resonant modes of vibration. Table 5.3 is a complete list of the modal response measurements.

Table 5.3 Modal Response Measurements

NAME	DESCRIPTION	TRANSDUCER TYPE	SERIAL NUMBER	SENSITIVITY	SYSTEM EU's/VOLT
VAF1	Left Side Actuator Force				10 Kips/V
VAF2	Right Side Actuator Force				10 Kips/V
LAF1	Lateral Actuator Force				10 Kips/V
VRF1	Lead Left Vertical Force	TTC instrumented rail	1	73.774 mV/Kips	13.555 Kips/V
VRF2	Lead Right Vertical Force	TTC instrumented rail	2	71.681 mV/Kips	13.951 Kips/V
VRF3	Trail Left Vertical Force	TTC instrumented rail	3	68.413 mV/Kips	14.617 Kips/V
VRF4	Trail Right Vertical Force	TTC instrumented rail	4	71.559 mV/Kips	13.974 Kips/V
LRF1	Lead Left Lateral Force	TTC instrumented rail	1	171.257 mV/Kips	5.839 Kips/V
LRF2	Lead Right Lateral Force	TTC instrumented rail	2	167.321 mV/Kips	5.977 Kips/V
LRF3	Trail Left Lateral Force	TTC instrumented rail	3	183.637 mV/Kips	5.446 Kips/V
LRF4	Trail Right Lateral Force	TTC instrumented rail	4	165.574 mV/Kips	6.040 Kips/V
VRF5	Lead Left Vertical Force	TTC instrumented rail	5	76.577 mV/Kips	13.059 Kips/V
VRF6	Lead Right Vertical Force	TTC instrumented rail	6	78.416 mV/Kips	12.752 Kips/V
VRF7	Trail Left Vertical Force	TTC instrumented rail	7	79.012 mV/Kips	12.656 Kips/V
VRF8	Trail Right Vertical Force	TTC instrumented rail	8	73.127 mV/Kips	13.695 Kips/V
LRF5	Lead Left Lateral Force	TTC instrumented rail	5	173.419 mV/Kips	5.766 Kips/V
LRF6	Lead Right Lateral Force	TTC instrumented rail	6	145.765 mV/Kips	6.860 Kips/V
LRF7	Trail Left Lateral Force	TTC instrumented rail	7	156.992 mV/Kips	6.370 Kips/V
LRF8	Trail Right Lateral Force	TTC instrumented rail	8	173.419 mV/Kips	5.766 Kips/V

Table 5.3 Modal Response Measurements (continued)

NAME	DESCRIPTION	TRANSDUCER TYPE	SERIAL NUMBER	SENSITIVITY	SYSTEM EU's/VOLT
DZ1	Vertical Left Actuator Disp.				0.5 in/V
DZ2	Vertical Right Actuator Disp.				0.5 in/V
DY1	Lateral Actuator Disp.				0.5 in/V
DZ3	Vertical Bolster to Side Frame Disp.	Celesco String pot.	10062	0.94305 V/in	0.5 in/V
DZ4	Vertical Bolster to Side Frame Disp.	Celesco String pot.	10063	0.9383 V/in	0.5 in/V
DZ5	Vertical Bolster to Side Frame Disp.	Celesco String pot.	10065	0.94334 V/in	0.5 in/V
DZ6	Vertical Bolster to Side Frame Disp.	Celesco String pot.	10067	0.94187 V/in	0.5 in/V
DY3	Lateral Bolster to Side Frame Disp.	Celesco String pot.	14238	4.7537 V/in	0.1 in/V
DY2	Lateral Bolster to Side Frame Disp.	Celesco String pot.	14240	4.7746 V/in	0.1 in/V
DZ7	Vertical Car Body Disp.	Celesco String pot.	10071	0.94418 V/in	0.5 in/V
DZ8	Vertical Car Body Disp.	Celesco String pot.	10075	0.94263 V/in	0.5 in/V
DZ9	Vertical Car Body Disp.	Celesco String pot.	10076	0.93878 V/in	0.5 in/V
DZ10	Vertical Car Body Disp.	Celesco String pot.	10080	0.94412 V/in	0.5 in/V
DZ11	Vertical Car Body Disp.	Celesco String pot.	10364	0.93074 V/in	0.5 in/V
DY5	Lateral Car Body Disp.	Celesco String pot.	10367	0.94576 V/in	0.5 in/V
DY6	Lateral Car Body Disp.	Celesco String pot.	10368	0.94383 V/in	0.5 in/V
DZ12	Vertical Car Body Disp.	Celesco String pot.	14230	0.94686 V/in	0.5 in/V
DZ13	Vertical Car Body Disp.	Celesco String pot.	14231	0.94757 V/in	0.5 in/V
DZ14	Vertical Span Bolster Disp.	Celesco String pot.	14232	0.94768 V/in	0.5 in/V
DZ15	Vertical Span Bolster Disp.	Celesco String pot.	10371	0.94638 V/in	0.5 in/V
DZ16	Vertical Span Bolster Disp.	Celesco String pot.	10430	0.94334 V/in	0.5 in/V
DZ17	Vertical Span Bolster Disp.	Celesco String pot.	10372	0.93639 V/in	0.5 in/V
DY4	Lateral Car Body Disp.	Celesco String pot.	10074	0.94331 V/in	0.5 in/V

Table 5.3 Modal Response Measurements (continued)

NAME	DESCRIPTION	TRANSDUCER TYPE	SERIAL NUMBER	SENSITIVITY	SYSTEM EU's/VOLT
AZ1	Vertical Car Body Accel.	Endevco Accelerometer	PA16 21026	11.14 mV/G	0.5 G/V
AY1	Lateral Car Body Accel.	Endevco Accelerometer	KR88 21025	12.90 mV/G	0.5 G/V
AZ2	Vertical Car Body Accel.	Endevco Accelerometer	MY28 21024	11.67 mV/G	0.5 G/V
AY2	Lateral Car Body Accel.	Endevco Accelerometer	PF45 21527	10.15 mV/G	0.5 G/V
AZ3	Vertical Car Body Accel.	Endevco Accelerometer	ML36 21027	12.23 mV/G	0.5 G/V
AY3	Lateral Car Body Accel.	Endevco Accelerometer	TG91 21812	12.31 mV/G	0.5 G/V
AZ4	Vertical Car Body Accel.	Endevco Accelerometer	RW99 21525	9.282 mV/G	0.5 G/V
AY4	Lateral Car Body Accel.	Endevco Accelerometer	NZ07 13738	8.613 mV/G	0.5 G/V
AZ5	Vertical Car Body Accel.	Endevco Accelerometer	NN23 12642	11.95 mV/G	0.5 G/V
AY5	Lateral Car Body Accel.	Endevco Accelerometer	MG10 12625	9.43 mV/G	0.5 G/V
AZ6	Vertical Car Body Accel.	Endevco Accelerometer	KY10 20941	12.22 mV/G	0.5 G/V
AY6	Lateral Car Body Accel.	Endevco Accelerometer	RW85 21524	9.564 mV/G	0.5 G/V
AZ7	Vertical Car Body Accel.	Endevco Accelerometer	MR84 12630	9.31 mV/G	0.5 G/V
AY7	Lateral Car Body Accel.	Endevco Accelerometer	NF15 12639	12.85 mV/G	0.5 G/V
AZ8	Vertical Car Body Accel.	Endevco Accelerometer	LD24 20936	12.06 mV/G	0.5 G/V
AY8	Lateral Car Body Accel.	Endevco Accelerometer	MR29 12627	8.95 mV/G	0.5 G/V
AZ9	Vertical Car Body Accel.	Endevco Accelerometer	EY98 13580	22.91 mV/G	0.5 G/V
AY9	Lateral Car Body Accel.	Endevco Accelerometer	EY97 8834	25.05 mV/G	0.5 G/V
AZ10	Vertical Car Body Accel.	Endevco Accelerometer	GT42 13577	28.80 mV/G	0.5 G/V
AY10	Lateral Car Body Accel.	Endevco Accelerometer	RH83 21510	20.92 mV/G	0.5 G/V
AZ11	Vertical Car Body Accel.	Endevco Accelerometer	JQ78 9991	24.17 mV/G	0.5 G/V
AY11	Lateral Car Body Accel.	Endevco Accelerometer	JQ66 9990	19.36 mV/G	0.5 G/V
AZ12	Vertical Car Body Accel.	Endevco Accelerometer	FM79 8816	21.03 mV/G	0.5 G/V
AY12	Lateral Car Body Accel.	Endevco Accelerometer	JQ54 9989	24.69 mV/G	0.5 G/V
AZ13	Vertical Car Body Accel.	Endevco Accelerometer	HF67 13575	23.82 mV/G	0.5 G/V
AY13	Lateral Car Body Accel.	Endevco Accelerometer	RG47 21511	16.04 mV/G	0.5 G/V
AZ14	Vertical Car Body Accel.	Endevco Accelerometer	RH68 21509	20.06 mV/G	0.5 G/V
AY14	Lateral Car Body Accel.	Endevco Accelerometer	CX96 7091	10.91 mV/G	0.5 G/V
AZ15	Vertical Car Body Accel.	Endevco Accelerometer	EH18 7084	9.3 mV/G	0.5 G/V
AY15	Lateral Car Body Accel.	Endevco Accelerometer	EZ36 13573	18.07 mV/G	0.5 G/V
AZ16	Vertical Car Body Accel.	Endevco Accelerometer	FP90 13582	17.24 mV/G	0.5 G/V
AY16	Lateral Car Body Accel.	Endevco Accelerometer	KE52 20942	12.44 mV/G	0.5 G/V
AZ17	Vertical Span Bolster Accel.	Endevco Accelerometer	EH16 7083	11.78 mV/G	0.5 G/V
AZ18	Vertical Span Bolster Accel.	Endevco Accelerometer	KR29 20937	12.80 mV/G	0.5 G/V
AZ19	Vertical Span Bolster Accel.	Endevco Accelerometer	RW22 21519	9.322 mV/G	0.5 G/V

5.3 SERVICE WORTHINESS INSTRUMENTATION

Service worthiness testing consisted of four separate tests. Instrumentation for each test is described in the next four sections.

5.3.1 Single Car Impact Instrumentation

Two transducers were used for the impact tests: (1) a tachometer, and (2) an instrumented coupler. The tachometer measured speed and the instrumented coupler measured the coupling force at impact. Figure 5.14 shows the instrumented coupler located on the struck end of the a loaded hopper car.

Figure 5.14 Instrumented Coupler

An Airpax tachometer was used to measure the speed of the LCC at impact. Figure 5.15 shows the tachometer mounted onto one of the axles of the LCC.

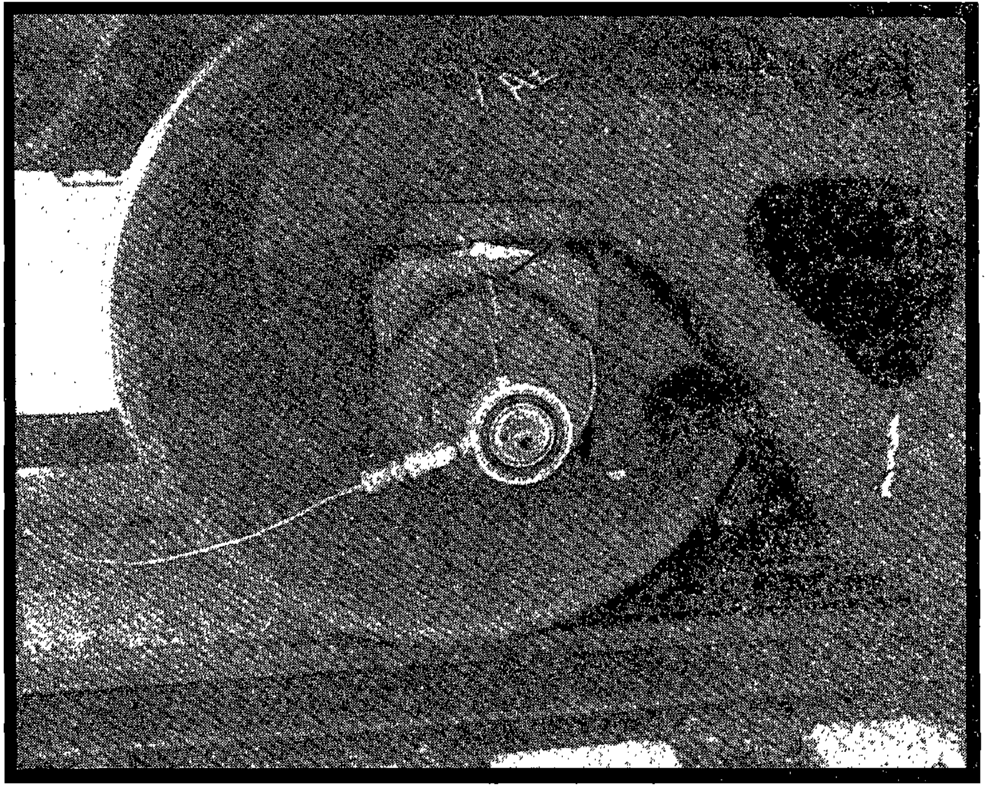


Figure 5.15 Impact Tachometer

Table 5.4 lists each measurement for the Impact Test.

Table 5.4 Impact Test Measurement

NAME	LOCATION & DESCRIPTION	TRANSDUCER TYPE	SERIAL NUMBER	SENSITIVITY	SYSTEM EU's/VOLT
LO1N	Coupler Force	Miner Instrumented coupler	25	1.5128 /V	264.4 Kips/V
SO1W	LCC Speed	Airpax Tachometer		60 P/rev	2 mph/V

5.3.2 Compressive End Load Instrumentation

The Compressive End Load Test was performed in the squeeze fixture at TTC. Figure 5.16 is a photograph looking into the squeeze fixture.

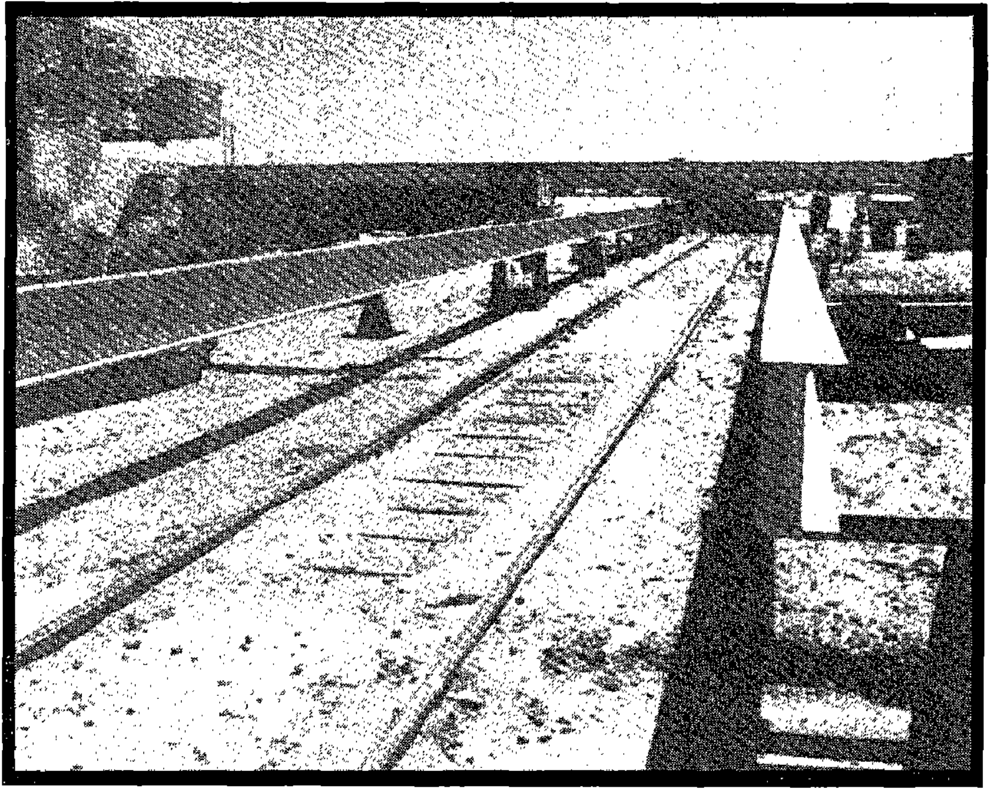


Figure 5.16 Squeeze Fixture at TTC

The LCC was placed in the squeeze fixture and a load was applied to the shanked couplers with the actuator shown in Figure 5.17.

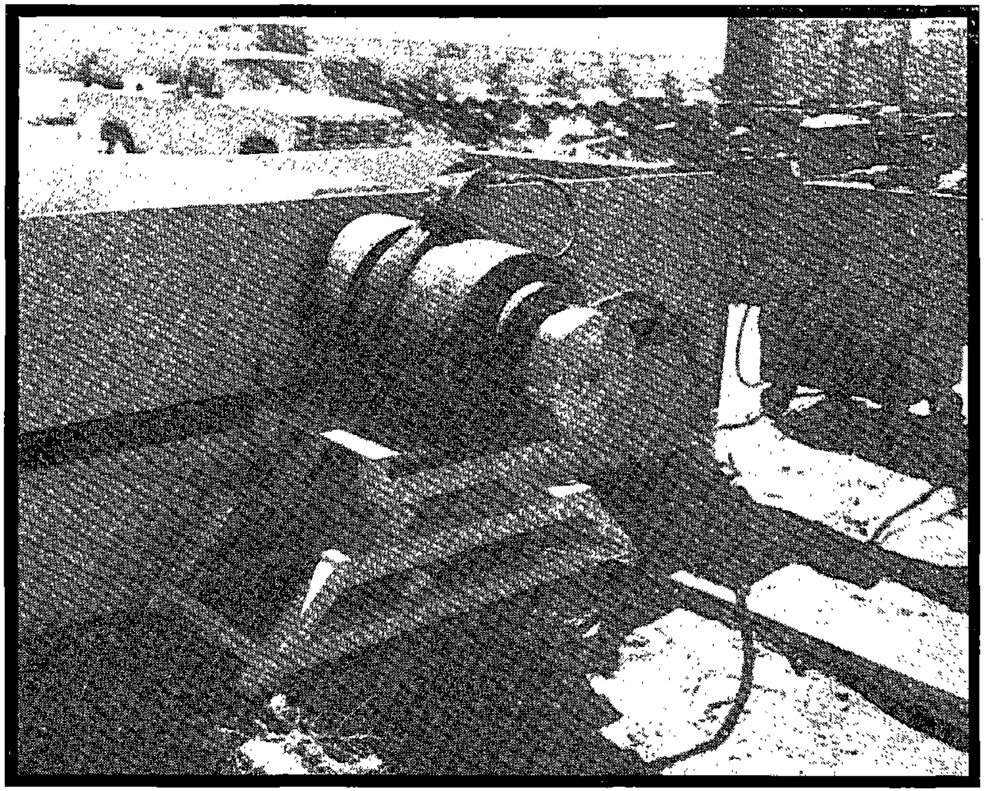


Figure 5.17 Squeeze Fixture Actuator

The force was measured with a load cell that was placed between the actuator and the LCC. Figure 5.18 shows the load cell and the digital display that was used for the output of the load cell.

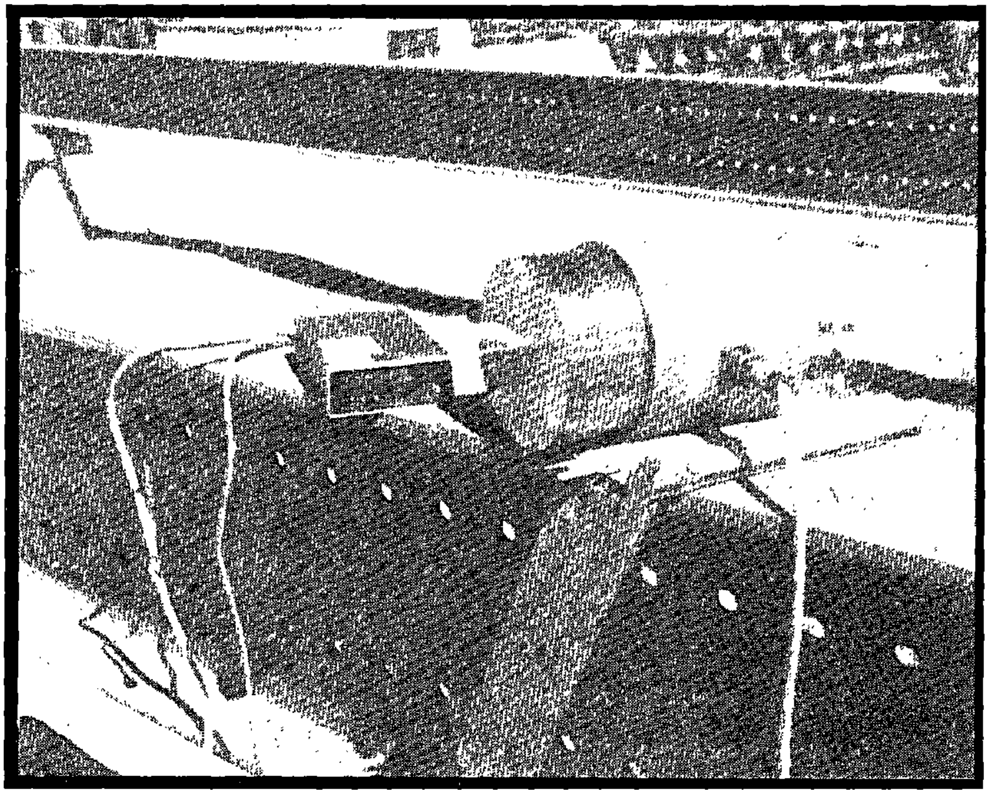


Figure 5.18 Squeeze Fixture Force Transducer

Twenty strain gages were also installed on the LCC by the AAR as part of Rockwell instrumentation requirements. Figure 5.19 shows two gages installed near a weld on two separate surfaces. The strain gages were mounted in critical locations defined by Rockwell. Table 5.5 is a complete list of the transducer locations for the Compressive End Load Test.

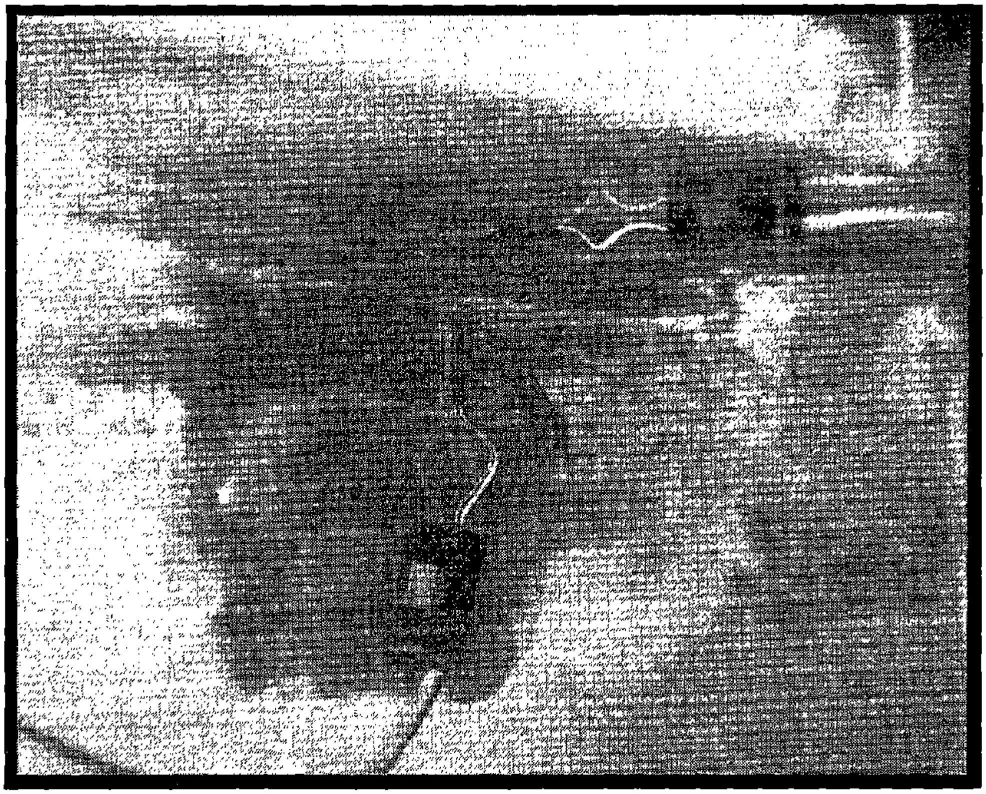


Figure 5.19 Two Rockwell Specified Strain Gages Used During The Compressive End Load Test

Table 5.5 Compressive End Load Test Measurements

NAME	LOCATION & DESCRIPTION	TRANSDUCER TYPE	SERIAL NUMBER	SENSITIVITY	SYSTEM EU's/VOLT
LO1N	Raw Force	HSI load cell	6877-001	1.9984 mV/V	400.0 Kips/V
SGX1R	Long., A-end below access door	HITEC HBWF strain gage		GF = 4.1	200µ/V
SGX2R	Long., A-end bottom corner of radome room	HITEC HBWF strain gage		GF = 4.1	200µ/V
SGX3R	Long., B-end below access door	HITEC HBWF strain gage		GF = 4.1	200µ/V
SGX4R	Long., A-end bottom center of underframe	HITEC HBWF strain gage		GF = 4.1	200µ/V
SGX5R	Long., A-end bottom center of underframe	HITEC HBWF strain gage		GF = 4.1	200µ/V
SGX6R	Long., A-end center of outside web	HITEC HBWF strain gage		GF = 4.1	200µ/V
SGX7R	Long., B-end bottom center of underframe	HITEC HBWF strain gage		GF = 4.1	200µ/V
SGX8R	Long., B-end side of long. Web	HITEC HBWF strain gage		GF = 4.1	200µ/V
SGX9R	Long., B-end bottom center of underframe	HITEC HBWF strain gage		GF = 4.1	200µ/V
SGX10	Long., B-end bottom center of underframe	HITEC HBWF strain gage		GF = 4.1	200µ/V
SGX11	Long., B-end side of long. Web	HITEC HBWF strain gage		GF = 4.1	200µ/V
SGX12	Long., B-end draft gear housing right	HITEC HBWF strain gage		GF = 4.1	200µ/V
SGX13	Long., B-end bottom center of underframe	HITEC HBWF strain gage		GF = 4.1	200µ/V
SGY1R	Lateral, B-end bottom of underframe	HITEC HBWF strain gage		GF = 4.1	200µ/V
SGY2R	Lateral, B-end bottom of underframe	HITEC HBWF strain gage		GF = 4.1	200µ/V
SGY3R	Lateral, truck 1 bottom center of bolster	HITEC HBWF strain gage		GF = 4.1	200µ/V
SGX14	Longitudinal, B-end lower left underframing	HITEC HBWF strain gage		GF = 4.1	200µ/V
SGX15	Long., B-end lower left underframing	HITEC HBWF strain gage		GF = 4.1	200µ/V
SGZ1R	Vertical, B-end center left underframing	HITEC HBWF strain gage		GF = 4.1	200µ/V
SGZ2R	Vertical, B-end center left underframing	HITEC HBWF strain gage		GF = 4.1	200µ/V

5.3.3 Jacking Instrumentation

No instrumentation was required for the Jacking Test. The LCC was jacked and inspected for any permanent damage.

5.3.4 Curve Stability Instrumentation

The only instrumentation required in the Curve Stability Test was a load cell and a feeler gage. The load cell was assembled on a coupler that was installed in a locomotive (Figure 5.20). This coupler measured the compressive or tensile force in the consist.

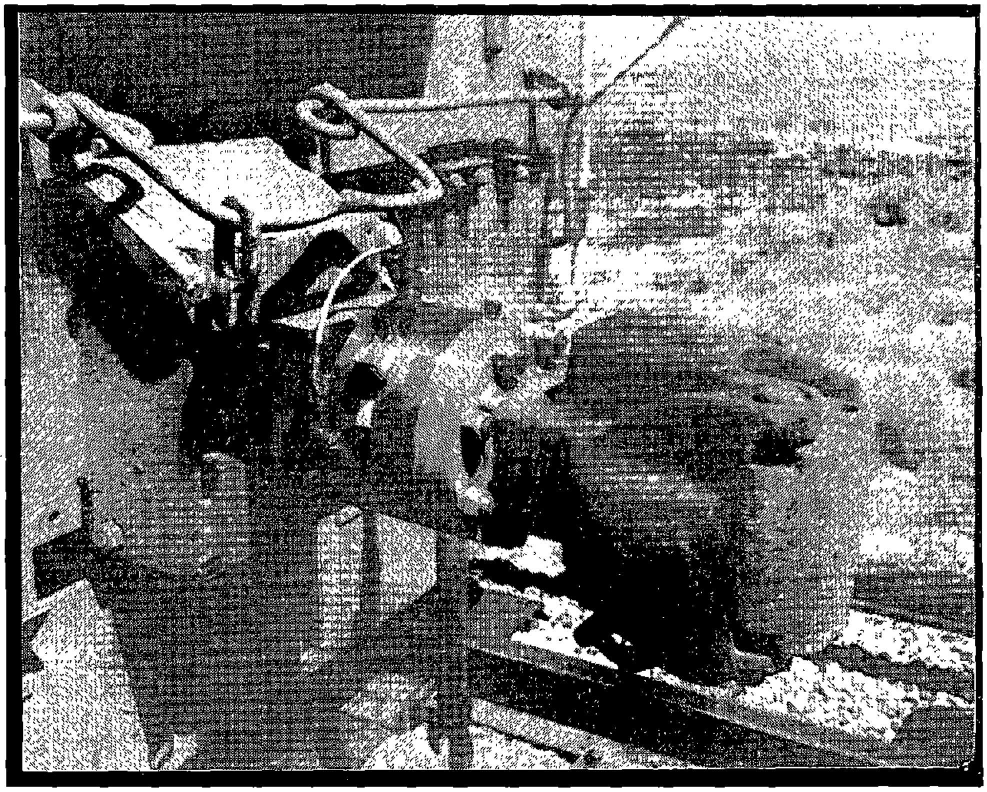


Figure 5.20 Curve Stability Instrumented Coupler

The feeler gage was a 1/8-inch steel bar that was placed under a wheel to measure wheel lift. If the feeler gage went completely under the wheel, the car was determined to have wheel lift. Figure 5.21 shows an LCC wheel being checked during a test.

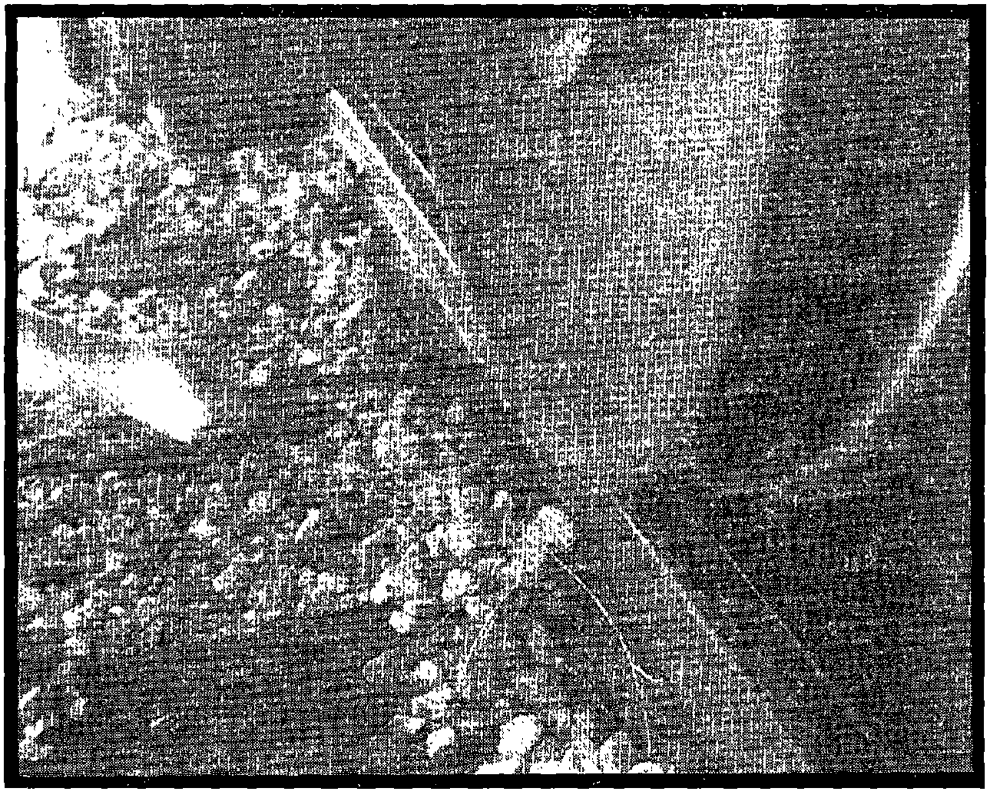


Figure 5.21 Curve Stability Wheel Lift Gage

Table 5.6 is the curve stability transducer information.

Table 5.6 Curve Stability Instrumentation

NAME	LOCATION & DESCRIPTION	TRANSDUCER TYPE	SERIAL NUMBER	SENSITIVITY	SYSTEM EU's/VOLT
LO2N	Loco. Coupler Force	BLH load cell	TTC 20999	2.9854 mV/V	66.99 Kips/V

5.4 TRACK WORTHINESS INSTRUMENTATION

The LCC, EMS-2 was equipped with instrumented wheel sets, accelerometers, roll gyros, and various Rockwell described instrumentation. The following sections describe the instrumentation.

5.4.1 Instrumented Wheel Sets

Four instrumented wheel sets were provided to TTC for the LCC track worthiness testing as Government Furnished Equipment (GFE). The wheel sets were manufactured by the Illinois Institute of Technology Research Institute (IITRI). The instrumented wheel sets were standard 36-inch wheel sets cut to a modified Huemann profile and that were machined smooth on the plate surfaces. Each wheel had six strain gage bridges. Three were used to measure vertical force, two measured lateral force, and one indicated lateral wheel tread position on the rail. The wheel sets also had instrumented axles to measure torque. The raw strain signals were acquired with a 386 based computer system and an analog to digital (AD) converter. The signals were processed to provide digital output in the form of left and right side vertical wheel force, lateral wheel force, lateral over vertical wheel force, and axle torque. The digital signals were converted back to analog, and the analog signals were displayed on strip charts and acquired on the HP data acquisition system (DAS) with outputs from the rest of the transducers on the LCC. Figure 5.22 shows the cable connections to an IITRI instrumented wheel set installed under the LCC.

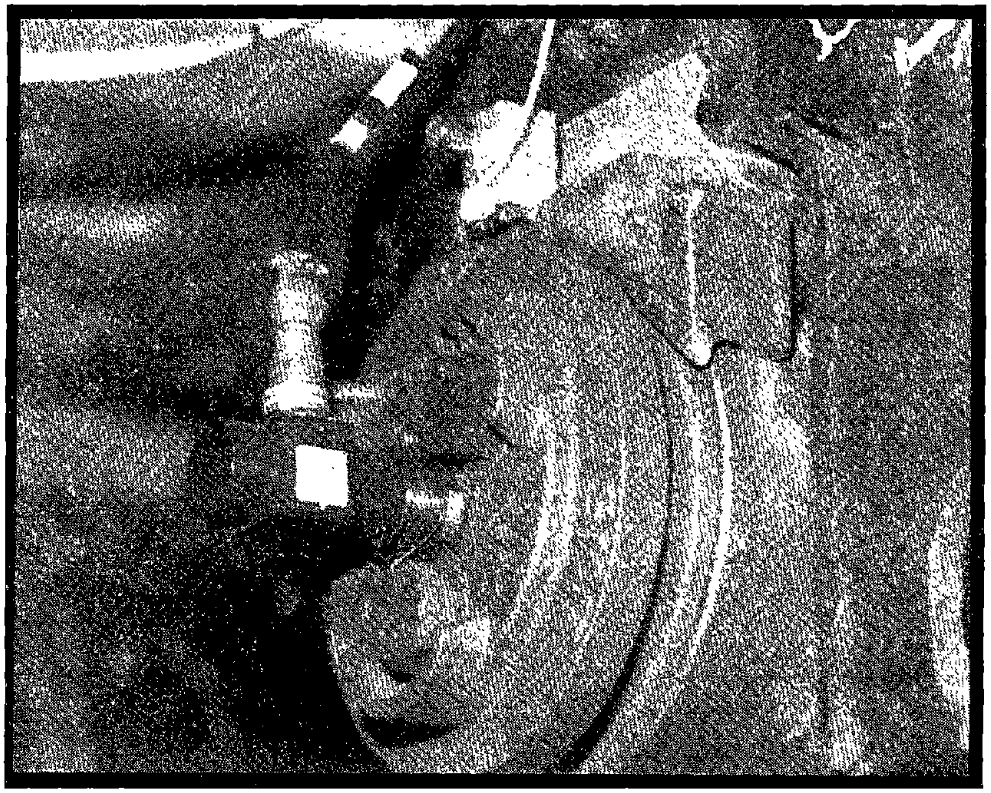


Figure 5.22 Cable Connections to an IITRI Instrumented Wheel Set

5.4.2 Lateral Accelerometers

Endevco 25 g lateral accelerometers were installed on the A- and B-ends of the LCC. They were utilized for the Hunting Test criteria; 1.0 g peak-to-peak lateral car body acceleration sustained for 20 seconds. Figure 5.23 shows a lateral accelerometer mounted to an aluminum box on the A-end of the LCC.

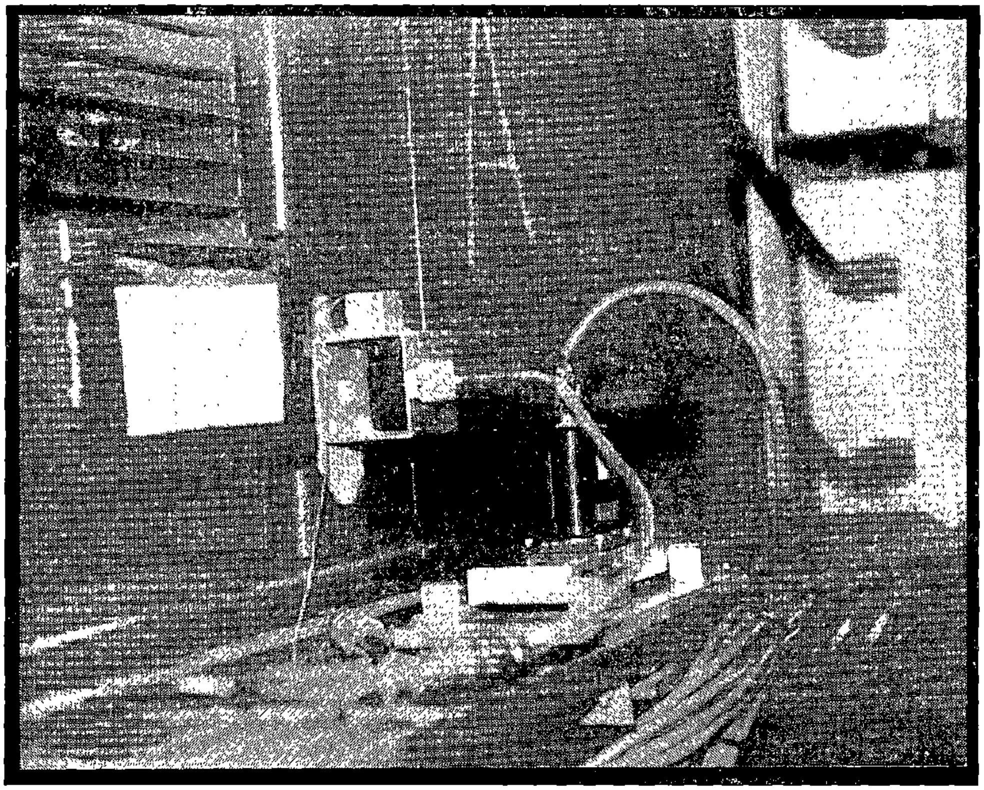


Figure 5.23 Lateral Accelerometer and Roll Gyro on A-end of LCC

5.4.3 Roll Gyros

Chapter XI requires the measurement of roll angle for certain tests. This was accomplished with two roll rate gyros. The gyros were installed on each end of the LCC at floor level as shown in Figure 5.23 (gyro located on the brake step). The output signal was roll rate. This was electrically integrated and output to the DAS as an analog roll angle.

5.4.4 Additional Measurements

A number of accelerometers were installed in vertical, lateral, and longitudinal orientations on the LCC car body and running gear for TTC. Truck spring nest displacements were also measured. These measurements were to assist the TTC analysis of ride quality and vehicle dynamics.

Twenty-three accelerometers were also installed on the LCC car body and running gear for Rockwell. These measurements were provided to Rockwell for their own analysis and to aid in the design of future cars.

The 43 measurements were recorded on the DAS along with the 111 other measurements including raw instrumented wheel set signals. Table 5.7 contains a list of the AAR Chapter XI measurements for the LCC track worthiness testing.

Table 5.7 AAR Chapter XI Measurements

NAME	LOCATION & DESCRIPTION	TRANSDUCER TYPE	SERIAL NUMBER	SENSITIVITY	SYSTEM EU's/VOLT
ALD	Automatic Location Device	Warner		20 ms/Pulse	1 event/10 V
TSPD	Speed	AirPax Tachometer		64 P/Rev	10 mph/V
FV1L	IWS truck 4 lead axle vertical left	IITRI Wheel Set	19	Processed	10.246 Kips/V
FV1R	IWS truck 4 lead axle vertical right	IITRI Wheel Set	19	Processed	10.246 Kips/V
FL1L	IWS truck 4 lead axle lateral left	IITRI Wheel Set	19	Processed	10.246 Kips/V
FL1R	IWS truck 4 lead axle lateral right	IITRI Wheel Set	19	Processed	10.246 Kips/V
LV1L	IWS truck 4 lead axle L/V left	IITRI Wheel Set	19	Processed	0.5 L/V per V
LV1R	IWS truck 4 lead axle L/V right	IITRI Wheel Set	19	Processed	0.5 L/V per V
FT1	IWS truck 4 lead axle torque	IITRI Wheel Set	19	Processed	3.4 Kips/V
FV3L	IWS truck 3 lead axle vertical left	IITRI Wheel Set	20	Processed	10.246 Kips/V
FV3R	IWS truck 3 lead axle vertical right	IITRI Wheel Set	20	Processed	10.246 Kips/V
FL3L	IWS truck 3 lead axle lateral left	IITRI Wheel Set	20	Processed	10.246 Kips/V
FL3R	IWS truck 3 lead axle lateral right	IITRI Wheel Set	20	Processed	10.246 Kips/V
LV3L	IWS truck 3 lead axle L/V left	IITRI Wheel Set	20	Processed	0.5 L/V per V
LV3R	IWS truck 3 lead axle L/V right	IITRI Wheel Set	20	Processed	0.5 L/V per V
FT3	IWS truck 3 lead axle torque	IITRI Wheel Set	20	Processed	3.4 Kips/V
FV5L	IWS truck 2 lead axle vertical left	IITRI Wheel Set	21	Processed	10.246 Kips/V
FV5R	IWS truck 2 lead axle vertical right	IITRI Wheel Set	21	Processed	10.246 Kips/V
FL5L	IWS truck 2 lead axle lateral left	IITRI Wheel Set	21	Processed	10.246 Kips/V
FL5R	IWS truck 2 lead axle lateral right	IITRI Wheel Set	21	Processed	10.246 Kips/V
LV5L	IWS truck 2 lead axle L/V left	IITRI Wheel Set	21	Processed	0.5 L/V per V
LV5R	IWS truck 2 lead axle L/V right	IITRI Wheel Set	21	Processed	0.5 L/V per V
FT5	IWS truck 2 lead axle torque	IITRI Wheel Set	21	Processed	3.4 Kips/V
FV7L	IWS truck 1 lead axle vertical left	IITRI Wheel Set	22	Processed	10.246 Kips/V
FV7R	IWS truck 1 lead axle vertical right	IITRI Wheel Set	22	Processed	10.246 Kips/V
FL7L	IWS truck 1 lead axle lateral left	IITRI Wheel Set	22	Processed	10.246 Kips/V
FL7R	IWS truck 1 lead axle lateral right	IITRI Wheel Set	22	Processed	10.246 Kips/V
LV7L	IWS truck 1 lead axle L/V left	IITRI Wheel Set	22	Processed	0.5 L/V per V
LV7R	IWS truck 1 lead axle L/V right	IITRI Wheel Set	22	Processed	0.5 L/V per V
FT7	IWS truck 1 lead axle torque	IITRI Wheel Set	22	Processed	3.4 Kips/V

Table 5.7 AAR Chapter XI Measurements (continued)

NAME	LOCATION & DESCRIPTION	TRANSDUCER TYPE	SERIAL NUMBER	SENSITIVITY	SYSTEM EU's/VOLT
ABX1	Lat. accel. above B-end center plate	Columbia accelerometer	1511	1574.9 mV/G	0.635 G/V
ABX2	Lat. accel. above A-end floor plate	Columbia accelerometer	1512	1576.5 mV/G	0.635 G/V
ABW1	Lat. accel. B-end truck 4 axle 8	Endevco accelerometer	BF79	11.0 mV/G	0.455 G/V
ABW2	Lat. accel. B-end truck 4 axle 7	Endevco accelerometer	BJ19	9.90 mV/G	0.505 G/V
ABW3	Lat. accel. B-end truck 3 axle 6	Endevco accelerometer	BK45	11.0 mV/G	0.455 G/V
AW10	Lat. accel. B-end truck 3 axle 5	Endevco accelerometer	BM98	10.32 mV/G	0.484 G/V
JBX1	Roll Angle B-end	Humphrey roll gyro	107	4.052 V/deg	1.008 deg/V
JBX2	Roll Angle A-end	Humphrey roll gyro	106	4.087 V/deg	1.018 deg/V
DBX1	Spring nest disp. truck 1 left side	Celesco sting pot.	A45607	622.6 mV/G	0.803 in/V
DBX2	Spring nest disp. truck 2 left side	Celesco sting pot.	A45608	623.0 mV/G	0.803 in/V
DBX3	Spring nest disp. truck 3 left side	Celesco sting pot.	A45609	622.4 mV/G	0.803 in/V
DBX4	Spring nest disp. truck 4 left side	Celesco sting pot.	A45610	622.4 mV/G	0.803 in/V
DBX5	Spring nest disp. truck 1 right side	Celesco sting pot.	A45611	623.4 mV/G	0.803 in/V
DBX6	Spring nest disp. truck 2 right side	Celesco sting pot.	A45612	622.6 mV/G	0.803 in/V
DBX7	Spring nest disp. truck 3 right side	Celesco sting pot.	A45613	622.6 mV/G	0.803 in/V
DBX8	Spring nest disp. truck 4 right side	Celesco sting pot.	A45614	623.4 mV/G	0.803 in/V
ABF1	Vert. accel. car center floor	Endevco accelerometer	BN70	9.74 mV/G	0.513 G/V
ABF2	Lat. accel. car center floor	Endevco accelerometer	BN42	9.90 mV/G	0.505 G/V
ABF3	Long. accel car center floor	Endevco accelerometer	BL10	11.16 mV/G	0.448 G/V
ABY1	Long. accel. car floor B-end	Endevco accelerometer	BK79	9.38 mV/G	0.533 G/V
ABY2	Lat. accel. span bolster 1 truck 1	Endevco accelerometer	BM91	11.03 mV/G	0.453 G/V
ABY3	Lat. accel. span bolster 1 truck 2	Endevco accelerometer	BK92	11.4 mV/G	0.439 G/V
ABY4	Lat. accel. span bolster 2 truck 3	Endevco accelerometer	BM52	10.13 mV/G	0.494 G/V
AB97	Lat. accel. A-end	Endevco accelerometer	AD83	196.4 mV/G	2.546 G/V
AB98	Lat. accel. B-end	Endevco accelerometer	AE36	198.6 mV/G	2.518 G/V
IRIG	IRIG time				

Table 5.8 is a list of the measurements requested by Rockwell.

Table 5.8 Rockwell Measurements

NAME	LOCATION & DESCRIPTION	TRANSDUCER TYPE	SERIAL NUMBER	SENSITIVITY	SYSTEM EU's/VOLT
AY1R	Lat. accel. truck 1 axle 1	Endevco 7290 accel.	AE38	199.5 mV/G	2.539 G/V
AZ1R	Vert. accel. Truck 1 axle 1	Endevco 7290 accel.	AE42	198.2 mV/G	2.523 G/V
AY2R	Lat. accel. truck 1 bolster	Endevco 7290 accel.	AE51	198.8 mV/G	2.515 G/V
AZ2R	Vert. accel. truck 1 bolster	Endevco 7290 accel.	AE35	203.8 mV/G	2.453 G/V
AY3R	Lat. accel. truck 1 side frame	Endevco 7290 accel.	AE54	198.2 mV/G	2.523 G/V
AZ3R	Vert. accel. truck 1 side frame	Endevco 7290 accel.	AE61	198.6 mV/G	2.518 G/V
AX1R	Long. accel. draft gear housing	Endevco 7290 accel.	AE50	196.9 mV/G	2.539 G/V
AY4R	Lat. accel. B-end draft gear housing	Endevco 7290 accel.	AE74	196.4 mV/G	2.546 G/V
AZ4R	Vert. accel. B-end draft gear housing	Endevco 7290 accel.	AE49	199.6 mV/G	2.505 G/V
AY5R	Lat. accel. span bolster 1 right	Endevco 7290 accel.	AE58	198.4 mV/G	2.520 G/V
AZ5R	Vert. accel. span bolster 1 right	Endevco 7290 accel.	AE48	209.8 mV/G	2.393 G/V
AZ6R	Vert. accel. B-end center of roof	Endevco 7290 accel.	AE37	198.3 mV/G	2.521 G/V
AZ7R	Vert. accel. center of radome	Endevco 7290 accel.	AE66	200.2 mV/G	2.498 G/V
AY6R	Lat. accel. B-end right side wall	Endevco 7290 accel.	AE70	201.7 mV/G	2.479 G/V
AZ8R	Vert. accel. B-end floor	Endevco 7290 accel.	AE71	203.9 mV/G	2.452 G/V
AX2R	Long. accel. A-end center of floor	Endevco 7290 accel.	AC55	199.0 mV/G	2.573 G/V
AY7R	Lat. accel. center of side wall	Endevco 7290 accel.	AC58	201.9 mV/G	2.476 G/V
AZ9R	Vert. accel. center of floor	Endevco 7290 accel.	AC57	199.2 mV/G	2.510 G/V
AY8R	Lat. accel. A-end side wall	Endevco 7290 accel.	AE27	199.2 mV/G	2.510 G/V
AZ10R	Vert. accel. A-end center of floor	Endevco 7290 accel.	AC97	201.8 mV/G	2.478 G/V
AY9R	Lat. accel. B-end center of floor	Endevco 7290 accel.	AC99	198.0 mV/G	2.525 G/V
AY10R	Lat. accel. B-end center of floor	Endevco 7290 accel.	AD52	200.1 mV/G	2.487 G/V
AY11R	Lat. accel. A-end center of floor	Endevco 7290 accel.	AD66	205.1 mV/G	2.438 G/V

Table 5.8 Rockwell Measurements (continued)

NAME	LOCATION & DESCRIPTION	TRANSDUCER TYPE	SENSITIVITY	SYSTEM EU's/VOLT
SGX1R	Long. A-end below access door	HITEC HBWF strain gage	GF = 4.1	200μ/V
SGX2R	Long. A-end bot. corner of radome room	HITEC HBWF strain gage	GF = 4.1	200μ/V
SGX3R	Long. B-end below access door	HITEC HBWF strain gage	GF = 4.1	200μ/V
SGX4R	Long. A-end bot. center of underframe	HITEC HBWF strain gage	GF = 4.1	200μ/V
SGX5R	Long. A-end bot. center of underframe	HITEC HBWF strain gage	GF = 4.1	200μ/V
SGX6R	Long. A-end cent. of outside web	HITEC HBWF strain gage	GF = 4.1	200μ/V
SGX7R	Long. B-end bot. center of underframe	HITEC HBWF strain gage	GF = 4.1	200μ/V
SGX8R	Long. B-end side of longitudinal web	HITEC HBWF strain gage	GF = 4.1	200μ/V
SGX9R	Long. B-end bot. center of underframe	HITEC HBWF strain gage	GF = 4.1	200μ/V
SGX10	Long. B-end bot. center of underframe	HITEC HBWF strain gage	GF = 4.1	200μ/V
SGX11	Long. B-end side of longitudinal web	HITEC HBWF strain gage	GF = 4.1	200μ/V
SGX12	Long. B-end draft gear housing right	HITEC HBWF strain gage	GF = 4.1	200μ/V
SGX13	Long. B-end bot. center of underframe	HITEC HBWF strain gage	GF = 4.1	200μ/V
SGY1R	Lat. B-end bot. of underframe	HITEC HBWF strain gage	GF = 4.1	200μ/V
SGY2R	Lat. B-end bot. of underframe	HITEC HBWF strain gage	GF = 4.1	200μ/V
SGY3R	Lat. truck 1 bot. center of bolster	HITEC HBWF strain gage	GF = 4.1	200μ/V
SGX14	Long. B-end lower left underframing	HITEC HBWF strain gage	GF = 4.1	200μ/V
SGX15	Long. B-end lower left underframing	HITEC HBWF strain gage	GF = 4.1	200μ/V
SGZ1R	Vert. B-end cent. left underframing	HITEC HBWF strain gage	GF = 4.1	200μ/V
SGZ2	Vert. B-end cent. left underframing	HITEC HBWF strain gage	GF = 4.1	200μ/V

Strain gage signals (preprocessed) were collected from the instrumented wheel sets. These signals are required for post test processing. Table 5.9 lists the raw measurements.

Table 5.9 Wheel Set Preprocessed Measurements

NAME	LOCATION & DESCRIPTION	TRANSDUCER TYPE	SERIAL NUMBER	SYSTEM EU's/VOLT
V19A	IWS raw vertical bridge	IITRI wheel set	19	1
V19B	IWS raw vertical bridge	IITRI wheel set	19	1
V19C	IWS raw vertical bridge	IITRI wheel set	19	1
L19A	IWS raw lateral bridge	IITRI wheel set	19	1
L19B	IWS raw lateral bridge	IITRI wheel set	19	1
VA19	IWS raw vertical bridge	IITRI wheel set	19	1
VB19	IWS raw vertical bridge	IITRI wheel set	19	1
VC19	IWS raw vertical bridge	IITRI wheel set	19	1
LA19	IWS raw lateral bridge	IITRI wheel set	19	1
LB19	IWS raw lateral bridge	IITRI wheel set	19	1
T19A	IWS raw torque	IITRI wheel set	19	1
P19A	IWS raw position	IITRI wheel set	19	1
V20A	IWS raw vertical bridge	IITRI wheel set	20	1
V20B	IWS raw vertical bridge	IITRI wheel set	20	1
V20C	IWS raw vertical bridge	IITRI wheel set	20	1
L20A	IWS raw lateral bridge	IITRI wheel set	20	1
L20B	IWS raw lateral bridge	IITRI wheel set	20	1
VA20	IWS raw vertical bridge	IITRI wheel set	20	1
VB20	IWS raw vertical bridge	IITRI wheel set	20	1
VC20	IWS raw vertical bridge	IITRI wheel set	20	1
LA20	IWS raw lateral bridge	IITRI wheel set	20	1
LB20	IWS raw lateral bridge	IITRI wheel set	20	1
T20A	IWS raw torque	IITRI wheel set	20	1
P20A	IWS raw position	IITRI wheel set	20	1

Table 5.9 Wheel Set Preprocessed Measurements (continued)

NAME	LOCATION & DESCRIPTION	TRANSDUCER TYPE	SERIAL NUMBER	SYSTEM EU's/VOLT
V21A	IWS raw vertical bridge	IITRI wheel set	21	1
V21B	IWS raw vertical bridge	IITRI wheel set	21	1
V21C	IWS raw vertical bridge	IITRI wheel set	21	1
L21A	IWS raw lateral bridge	IITRI wheel set	21	1
L21B	IWS raw lateral bridge	IITRI wheel set	21	1
VA21	IWS raw vertical bridge	IITRI wheel set	21	1
VB21	IWS raw vertical bridge	IITRI wheel set	21	1
VC21	IWS raw vertical bridge	IITRI wheel set	21	1
LA21	IWS raw lateral bridge	IITRI wheel set	21	1
LB21	IWS raw lateral bridge	IITRI wheel set	21	1
T21A	IWS raw torque	IITRI wheel set	21	1
P21A	IWS raw position	IITRI wheel set	21	1
V22A	IWS raw vertical bridge	IITRI wheel set	22	1
V22B	IWS raw vertical bridge	IITRI wheel set	22	1
V22C	IWS raw vertical bridge	IITRI wheel set	22	1
L22A	IWS raw lateral bridge	IITRI wheel set	22	1
L22B	IWS raw lateral bridge	IITRI wheel set	22	1
VA22	IWS raw vertical bridge	IITRI wheel set	22	1
VB22	IWS raw vertical bridge	IITRI wheel set	22	1
VC22	IWS raw vertical bridge	IITRI wheel set	22	1
LA22	IWS raw lateral bridge	IITRI wheel set	22	1
LB22	IWS raw lateral bridge	IITRI wheel set	22	1
T22A	IWS raw torque	IITRI wheel set	22	1
P22A	IWS raw position	IITRI wheel set	22	1

5.4.5 Data Acquisition System (DAS)

Analog signals from 154 signal conditioners were multiplexed and digitized with a HP6944 Multiprogrammer. Digital signals were acquired with a HP360 desktop computer located on the T-5 Instrumentation Car. AD counts were stored with their proper engineering unit conversions on 650 megabyte optical disk.

5.4.6 Chart Recorders

Six Western Graphtec MK-10 chart recorders were located on the T-5 Instrumentation Car. Four chart recorders recorded processed data from the instrumented wheel sets in real time. One recorder was used for each wheel set. Roll angle, lateral acceleration, and other pertinent measurements were displayed real time on the other two chart recorders.

5.4.7 Video System

Four video cameras were mounted under the LCC to record the leading wheel of each span bolster. The video signals were split to two monitors and then recorded on VHS video recorders. On-screen annotation and audio were recorded on each test run. The video signals were stored on a VHS format video tape.

5.5 STATIC BRAKE TEST INSTRUMENTATION

The Static Brake Test was performed in the Storage Maintenance Building (SMB) at the TTC. A locomotive was used to supply air to the LCC. A single car test device was connected between the locomotive and the LCC to control the brakes on the LCC. An air gage was installed in the brake line of the LCC to measure brake pipe pressure. Next, the brake shoes on the A-end of the LCC were removed and eight instrumented shoes were used to measure the brake shoe force. The same test was performed on the B-end of the LCC. While at the B-end, an instrumented shear pin was installed into the handbrake chain to measure the handbrake force that was applied during the test. All measurements were displayed with a digital readout. In summary, 10 transducers were used, 8 instrumented brake shoes, 1 air gage, and 1 instrumented shear pin.

6.0 RESULTS

The results of the LCC testing will be presented in four sections:

- Vehicle Characterization
- Service Worthiness
- Track Worthiness
- Static Brake Test

6.1 VEHICLE CHARACTERIZATION RESULTS

The LCC vehicle characterization consisted of these tests:

- Quasi-Static Truck Characterization
- Static Truck Characterization
- Modal Characterization

The values obtained are used to characterize the vehicle system. There is no written success criteria.

6.1.1 Quasi-Static Truck Characterization Results

Plots were made to display the spring stiffness and damping rate in the particular suspension components. The x-axis corresponds to the displacement measurements; the y-axis corresponds to the rail force measurements (the rail force, not the actuator load cell, was used for plots). The upper and lower slopes of the curve corresponds to the spring rate in kips/inch for the vertical and lateral tests, and inch-kips/radian for the roll tests. The damping corresponds to the vertical gap (hysteresis) between the upper and lower sloped lines. The value is measured at various locations of the hysteresis loop and averaged. Figure 6.1 is a typical hysteresis plot; in this case, the left vertical spring displacement versus the sum of the left vertical rail forces. Table 6.1 is a list of test runs that were analyzed for the results.

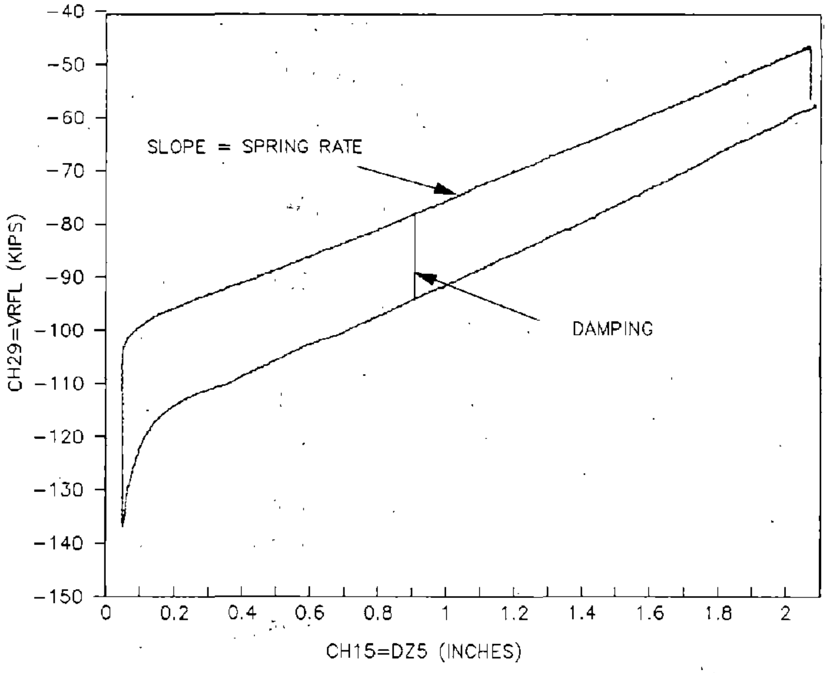


Figure 6.1 Force versus Displacement Plot Showing Spring Rate and Damping (Hysteresis) for Left Side Spring Nest

Table 6.1 Test Runs Chosen for Data Analysis

RUN NAME	DESCRIPTION	FREQUENCY	TRUCK NO.	TEST
RI01_RN003	Stroke Control± C.P*"	0.1 Hz	1	Vertical
RI01_RN006	Stroke Control± C.P"	0.25 Hz	1	Vertical
RI01_RN010	Stroke Control± 2.0"	0.1 Hz	1	Roll
RI01_RN014	Stroke Control± 2.0"	0.25 Hz	1	Roll
RI01_RN017	Force Control ± SL* kip north	0.1 Hz	1	Lateral
RI01_RN020	Force Control ± SL kip north	0.25 Hz	1	Lateral
RI01_RN023	Force Control ± SL kip south	0.1 Hz	1	Lateral
RI01_RN026	Force Control ± SL kip south	0.25 Hz	1	Lateral
RI02_RN003	Stroke Control± C.P"	0.1 Hz	2	Vertical
RI02_RN006	Stroke Control± C.P"	0.25 Hz	2	Vertical
RI02_RN010	Stroke Control± 2.0"	0.1 Hz	2	Roll
RI02_RN014	Stroke Control± 2.0"	0.25 Hz	2	Roll
RI02_RN017	Force Control ± SL kip north	0.1 Hz	2	Lateral
RI02_RN020	Force Control ± SL kip north	0.25 Hz	2	Lateral
RI02_RN023	Force Control ± SL kip south	0.1 Hz	2	Lateral
RI02_RN026	Force Control ± SL kip south	0.25 Hz	2	Lateral
RI03_RN003	Stroke Control± C.P"	0.1 Hz	3	Vertical
RI03_RN006	Stroke Control± C.P"	0.25 Hz	3	Vertical
RI03_RN010	Stroke Control± 2.0"	0.1 Hz	3	Roll
RI03_RN014	Stroke Control± 2.0"	0.25 Hz	3	Roll
RI03_RN017	Force Control ± SL kip north	0.1 Hz	3	Lateral
RI03_RN020	Force Control ± SL kip north	0.25 Hz	3	Lateral
RI03_RN023	Force Control ± SL kip south	0.1 Hz	3	Lateral
RI03_RN026	Force Control ± SL kip south	0.25 Hz	3	Lateral
RI04_RN003	Stroke Control± C.P"	0.1 Hz	4	Vertical
RI04_RN006	Stroke Control± C.P"	0.25 Hz	4	Vertical
RI04_RN010	Stroke Control± 2.0"	0.1 Hz	4	Roll
RI04_RN014	Stroke Control± 2.0"	0.25 Hz	4	Roll
RI04_RN017	Force Control ± SL kip north	0.1 Hz	4	Lateral
RI04_RN020	Force Control ± SL kip north	0.25 Hz	4	Lateral
RI04_RN023	Force Control ± SL kip south	0.1 Hz	4	Lateral
RI04_RN026	Force Control ± SL kip south	0.25 Hz	4	Lateral

* C.P = Full Compressed Spring Distance
* SL = $^1/_5$ Vertical Static Load

The LCC does not have a primary suspension. The secondary suspension rates for the chosen vertical, roll, and lateral tests were determined. The damping was calculated for the vertical and lateral test runs. The spring rates and damping values were averaged for each truck in the vertical, roll, and lateral configurations. Tests were conducted with and without the Stucki snubbers for information. Characteristics without snubbers were needed for NUCARS modelling.

Nominal values for the same type of truck that is under the LCC would be 23.1 kips/in. spring rate and 19 kips damping without hydraulic snubbers. Damping values with the Stucki HS-7 snubbers installed will be dependant on the speed that the truck bolster is travelling.

Table 6.2 gives the secondary suspension average spring rates and damping for the vertical test runs without snubbers.

Table 6.2 Average Vertical Suspension Spring Rate and Damping Without Snubbers

TRUCK NO.	LEFT SIDE AVERAGE VERTICAL DATA		RIGHT SIDE AVERAGE VERTICAL DATA	
	Spring Rate	Damping	Spring Rate	Damping
1	29.65 kips/in.	9.3 kips	28.65 kips/in.	10.1 kips
2	23.49 kips/in.	7.7 kips	25.50 kips/in.	10.5 kips
3	24.34 kips/in.	10.5 kips	25.22 kips/in.	7.5 kips
4	26.11 kips/in.	6.0 kips	27.58 kips/in.	9.0 kips

Table 6.3 lists the secondary suspension average roll spring rate for each truck in the roll test runs.

Table 6.3 Average Roll Spring Rates

TRUCK NO.	AVERAGE TRUCK ROLL SPRING RATES
1	53,962 inch-kips/radian
2	46,119 inch-kips/radian
3	52,542 inch-kips/radian
4	73,753 inch-kips/radian

Finally, Table 6.4 lists the secondary suspension average spring rates and damping for each truck in the Lateral Test runs. These results are for the entire truck. Half of the value would be used for one spring nest.

Table 6.4 Average Lateral Spring Rates and Damping

TRUCK NO.	LEFT SIDE AVERAGE LATERAL DATA		RIGHT SIDE AVERAGE LATERAL DATA	
	Spring Rate	Damping	Spring Rate	Damping
1	23.75 kips/in.	33.61 kips	24.98 kips/in.	32.81 kips
2	22.71 kips/in.	36.85 kips	22.95 kips/in.	36.49 kips
3	23.32 kips/in.	33.37 kips	22.24 kips/in.	33.39 kips
4	26.53 kips/in.	34.36 kips	29.37 kips/in.	34.29 kips

The quasi-static truck suspension results are considered reasonable, based upon experience with other types of three piece trucks.

6.1.2 Static Truck Characterization Results

Static Truck Characterization Tests were performed on truck 1 and 2 with air bearing tables. The results are separated into six categories:

Span Bolster Yaw Moment
Truck Yaw Moment
Axle Alignment
Truck Longitudinal Stiffness
Truck Inter-Axle Yaw and Bending
Inter-Axle Shear

6.1.2.1 Span Bolster Yaw Moment Results

Plots of displacement versus force were made to determine the span bolster yaw moments. Figure 6.2 shows a typical force versus displacement plot; in this case left force versus the left displacement.

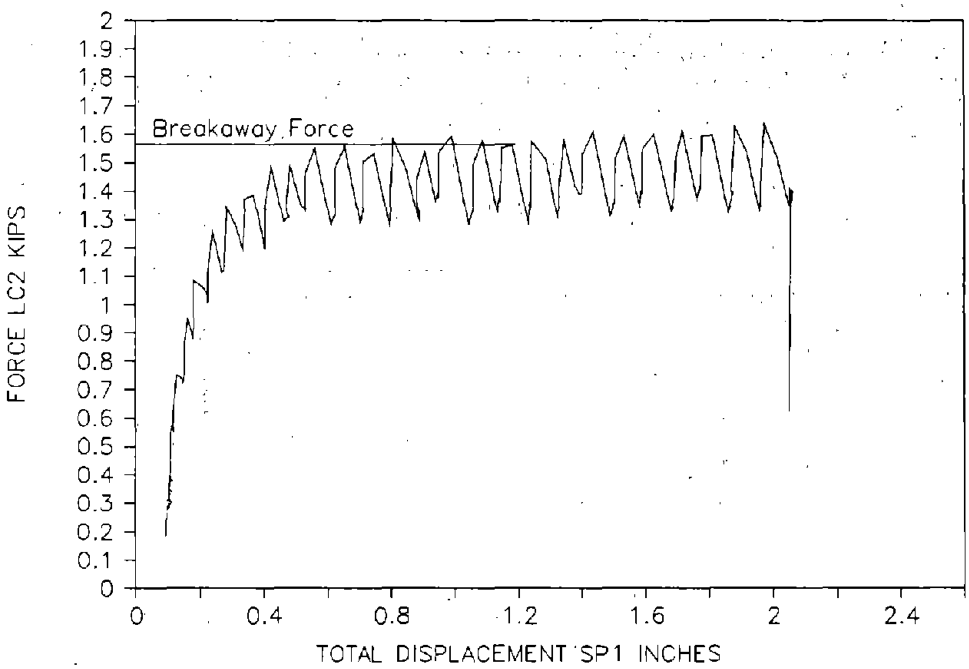


Figure 6.2 Force versus Displacement in Span Bolster Yaw Moment Test

The force increased with relatively small displacement until the static friction was overcome. At that point, the span bolster rotated with virtually no increase in force. This was called the breakaway point. Since two actuators were used, the actual breakaway torque or yaw moment was calculated by summing the two breakaway torques.

Three tests were run in a clockwise direction, and three tests were run in a counter-clockwise direction. The "sawtooth effect" in each plot was caused by pumping the actuators by hand.

The perpendicular distance from each actuator to the span bolster center pin was 107 inches. The yaw moment or breakaway force was then calculated by multiplying the sum of the two forces by the distance of 107 inches. The average span bolster yaw moment for the six runs was 350,000 in-lbs.

6.1.2.2 Truck Yaw Moment Results

The test setup for the individual three piece Truck Yaw Moment Test was identical to that for the Span Bolster Yaw Moment Test; however, the distance from the actuators to the truck center pin was 36 inches. The breakaway for the truck was less gradual than for the span bolster (Figures 6.3 and 6.4).

The force increased with almost no displacement until the truck broke away; thereafter, the displacement increased with little or no increase in force.

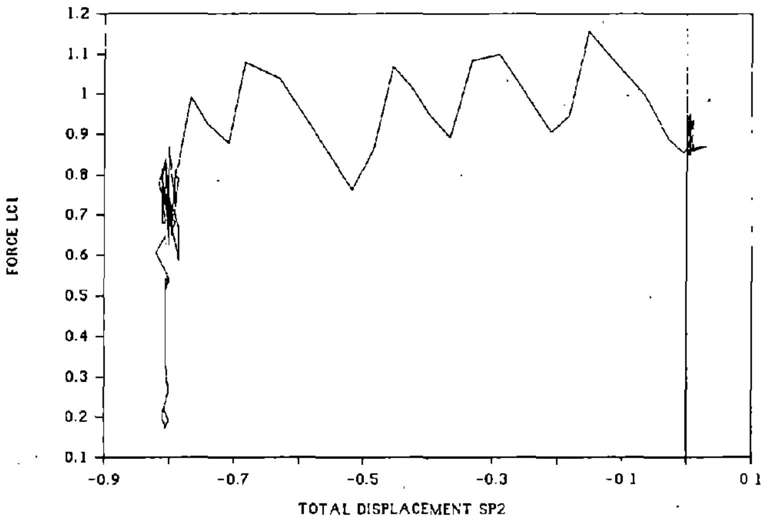


Figure 6.3 Force versus Displacement for Actuator 1-Truck Yaw Moment Test

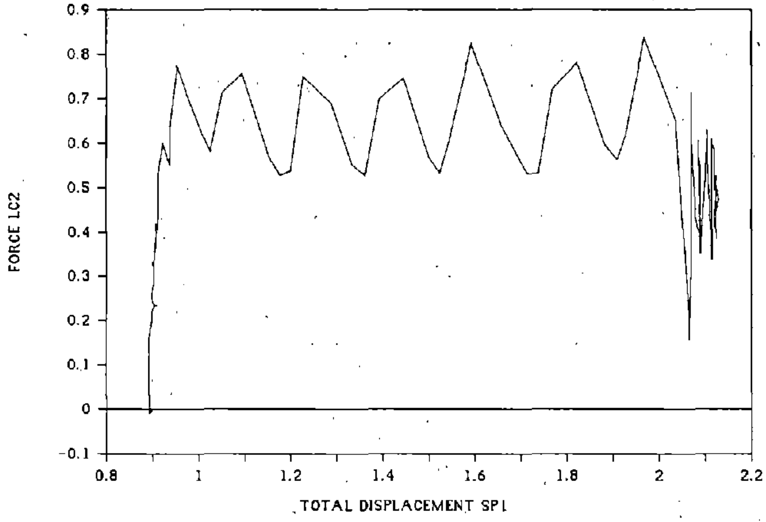


Figure 6.4 Force versus Displacement for Actuator 2-Truck Yaw Moment Test

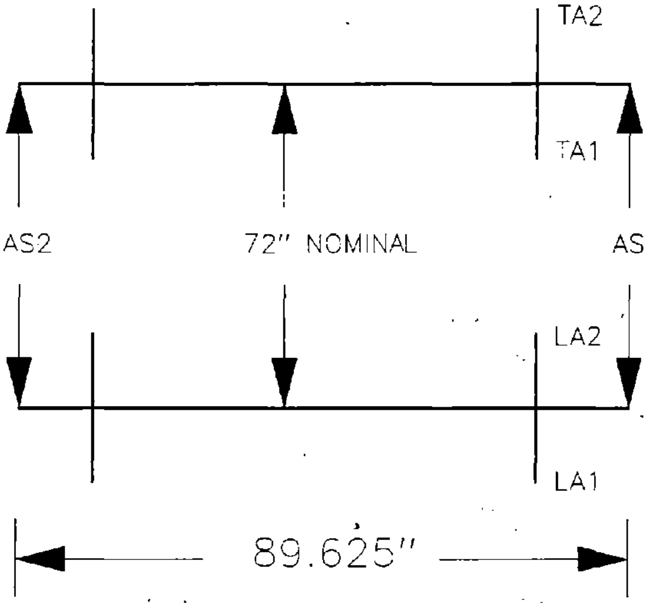
The span bolster had side bearing plates with an air gap between bolster and car body, and the individual trucks had standard roller side bearings with air gaps between the rollers and the span bolster. The center bowls of the span bolster and trucks were only slightly lubricated after a center plate repair that was completed by Rockwell.

Three clockwise and three counterclockwise tests were done on both truck 1 and 2. The average truck yaw moment was 112,500 in-lbs.

The yaw moments would be lower with better center bowl lubrication, which was done during the track worthiness testing in an attempt to improve curving results.

6.1.2.3 Axle Alignment Results

The radial misalignment, as well as the lateral misalignment, between the two axles in trucks 1 and 2 were the subject of this investigation. Six measurements were made during each test (Figure 6.5).



Radial Misalignment = (AS1 – AS2)/89.625

Figure 6.5 Axle Alignment Measurement

Axle radial misalignment was calculated with the axle spacing values AS1 and AS2 as shown in the above equation in Figure 6.5. Axle lateral misalignment was calculated with the leading axle and trailing axle measurements LA1, LA2, TA1 and TA2. Those numbers were measured from scales with a Brunson Optical Transit. The transit was first rotated until LA1 was equal to TA2. It was then translated so that LA1 and TA2 were on a round number. LA2 and TA1 were then measured; the change (delta) in LA and TA was then calculated. It was assumed that the transit was parallel to the sideframe when LA1 and TA2 were equal. The lateral misalignment could be implied from the deltas. Table 6.5 is a tabulation of alignment measurements from trucks 1 and 2.

Table 6.5 Axle Alignment Results

RUN NO.	TRUCK NO.	AS1 INCHES	AS2 INCHES	RADIAL MIS. MRAD	DELTA LA INCH	DELTA TA INCH	LATERAL MIS. INCH
1	1	69.930	69.663	2.978	-0.083	-0.198	0.115
2	1	69.875	69.700	1.953	-0.113	-0.127	0.014
3	1	69.880	69.651	2.556	-0.092	-0.133	0.041
			Average:	2.496	-0.096	-0.153	0.057
32	2	69.866	69.800	0.736	0.000	-0.041	0.041
33	2	69.631	69.545	0.959	0.000	-0.044	0.044
34	2	69.619	69.600	0.212	-0.050	-0.059	0.009
			Average:	0.636	-0.017	-0.048	0.031

The misalignments were small and fairly consistent for truck 2. They should have little or no affect on the on-track performance of the LCC. Truck 1's misalignments were large and could affect curving results. No further analysis was performed, because the axle to sideframe connection is frictional and alignment will change with operation on the track.

6.1.2.4 Longitudinal Stiffness Results

Longitudinal stiffness is a measure of the ability of the axles in a truck to move relative to each other in the longitudinal direction. In standard three piece trucks, the longitudinal stiffness is very high once the bearing adapters run up against the sideframe stops. In trucks with primary suspension components, there is some stiffness associated with the shear of the suspension components before the bearing adapters run up against the stops.

The LCC trucks used no primary suspension. Stiffness results from friction between the axle and sideframe.

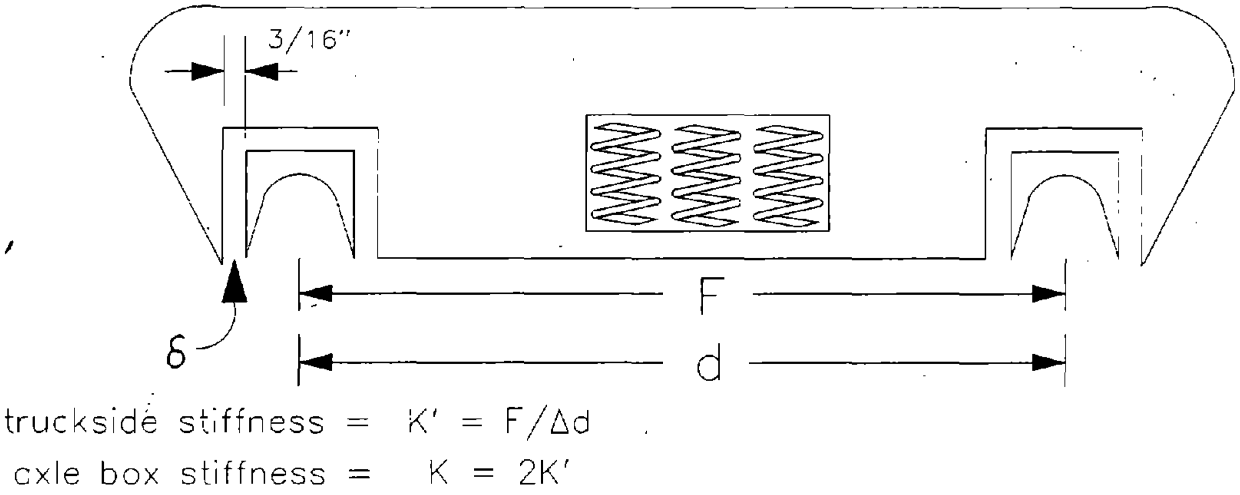


Figure 6.6 Longitudinal Stiffness Theory

NUCARS requires axle box stiffness rather than truck side stiffness. It was assumed that the truck side was symmetric. Force versus displacement plots were produced for each truck side on all test runs. Typical plots, for run 5 in this case, are shown in Figures 6.7 and 6.8.

There was one defined slope, and it was calculated with a linear regression, kips/inch. Due to the fact there is no restoring force, the stiffness resembles a friction.

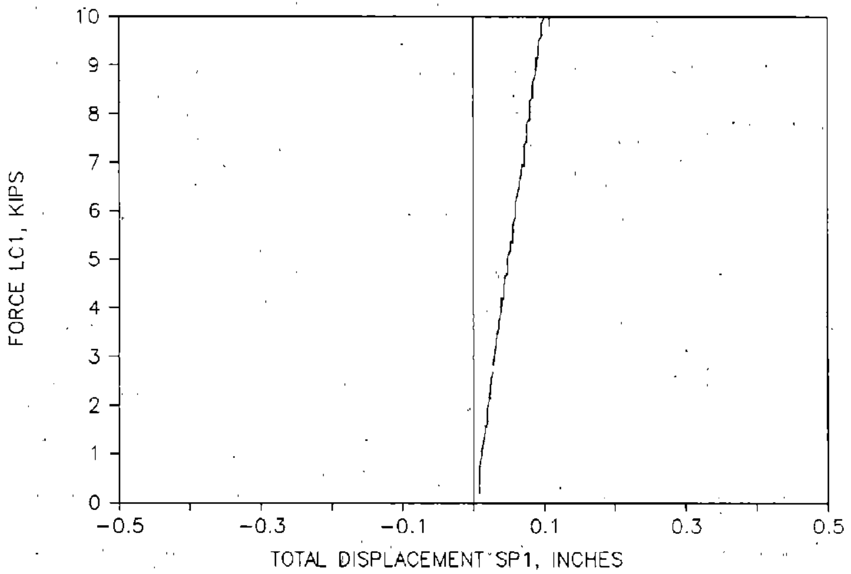


Figure 6.7 Right Truck Side Longitudinal Stiffness Plot

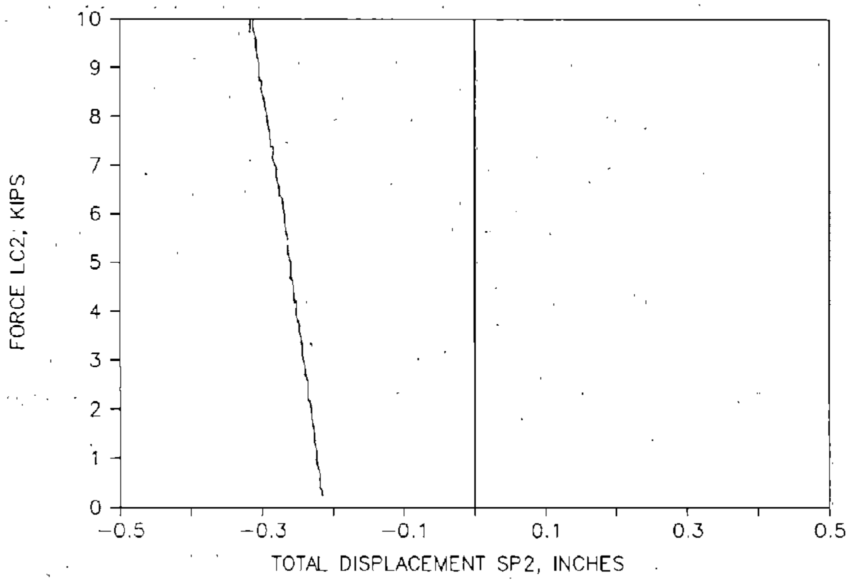


Figure 6.8 Left Truck Side Longitudinal Stiffness Plot

Table 6.6 is a tabulation of the truck side stiffness measurements. The scatter plot for all tests is shown in Figure 6.9.

Table 6.6 Truck Side Longitudinal Stiffness Measurements

RUN NO.	TRUCK NO.	DIRECTION	RIGHT SIDE SLOPE 1 (kips/in)	LEFT SIDE SLOPE 1 (kips/in)
4	1	Pulling	94.293	84.328
5	1	Pulling	94.589	95.502
6	1	Pulling	97.939	98.789
8	1	Pushing	87.974	117.539
9	1	Pushing	95.896	103.427
10	1	Pushing	103.307	113.482
		Average:	95.666	102.118
		Standard Deviation:	5.016	12.165
36	2	Pulling	83.867	78.056
37	2	Pulling	94.126	92.770
38	2	Pulling	96.403	98.438
44	2	Pushing	99.098	104.954
45	2	Pushing	88.488	109.366
46	2	Pushing	102.222	123.413
		Average:	94.034	101.166
		Standard Deviation	6.818	15.418

Note: Overall Average is 98 kips/in

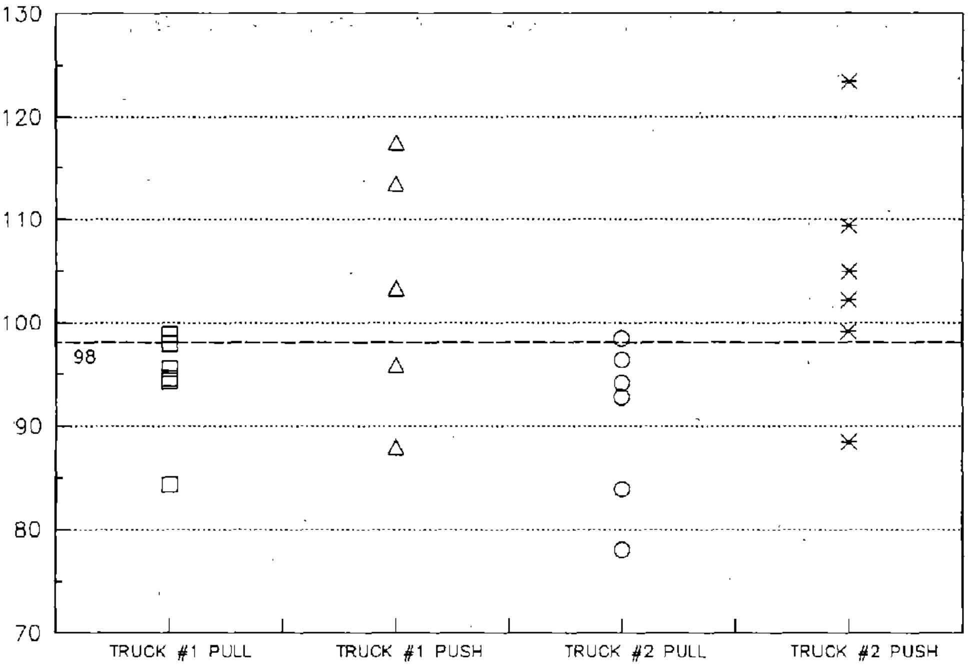


Figure 6.9 Longitudinal Stiffness Scatter

The truck side averages were doubled to give axle box stiffnesses. A final stiffness of approximately 10 ^{6} kips/in has been used in NUCARS to represent the condition when the axles are against the stops. Figure 6.10 displays the characteristic used in the model.

From the stiffness profile, a NUCARS axle box stiffness look-up table was created (Table 6.7).

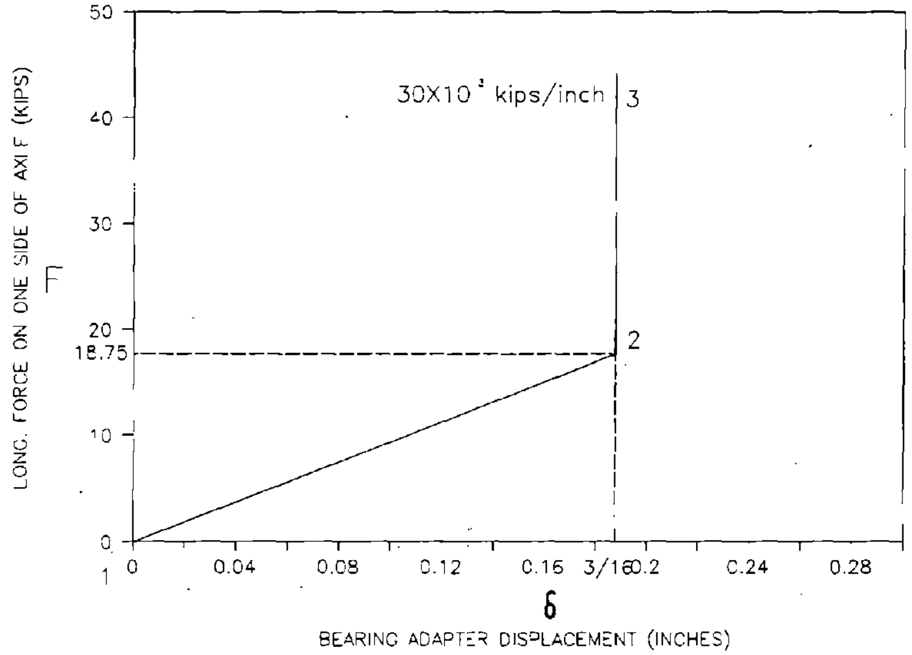


Figure 6.10 Axle Box Longitudinal Stiffness Profile

Table 6.7 NUCARS Look-up Table for Axle Box Longitudinal Stiffness

	1	2	3
F	0	18.75	16,000
δ	0	3/16"	.25"

6.1.2.5 Axle Yaw and Inter-Axle Bending Stiffness Results

In free curving, the axles would have a tendency to yaw with respect to each other (Figure 6.11).

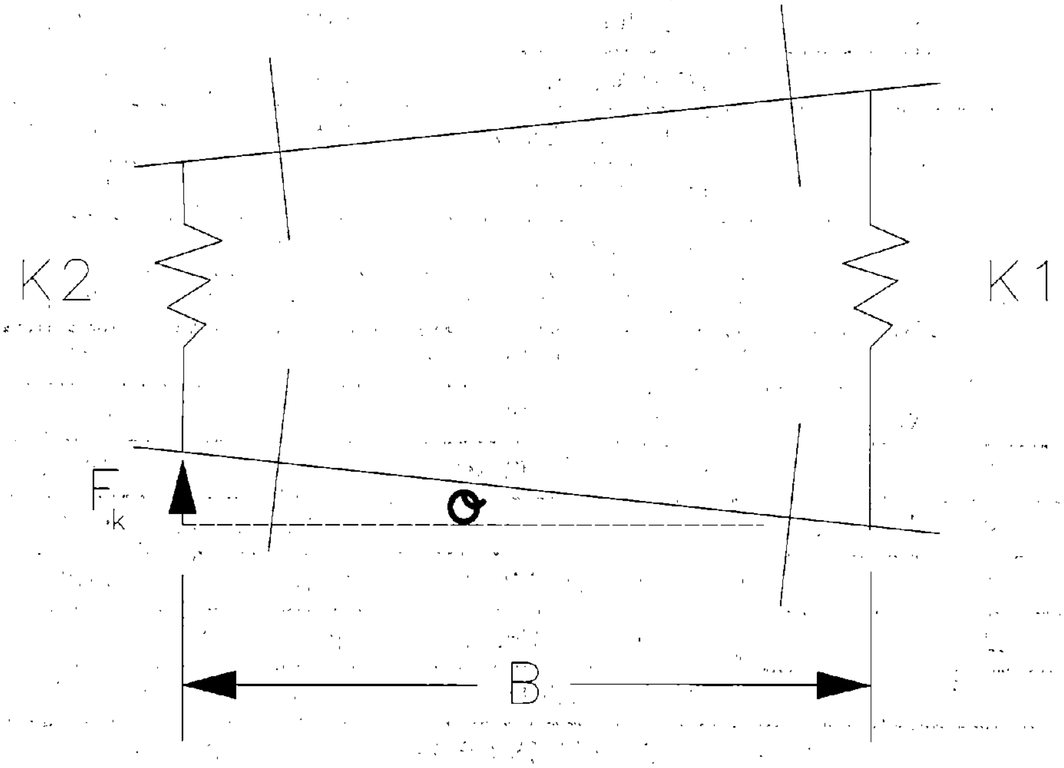


Figure 6.11 Axle Yaw Stiffness Theory

The first step in this test was to calculate the stiffnesses on each side of the truck (K1 and K2 in Figure 6.11) in the same manner as longitudinal stiffness. Linear regressions were performed on graphs similar to the longitudinal stiffness plots. Table 6.8 shows a summation of measured values for each test. It is noted that when the directions were changed, the first test usually produced lower results than the following two tests.

An axle yaw stiffness scatter plot from the summary sheet is shown in Figure 6.12.

Table 6.8 Axle Yaw Stiffness Summary Sheet

RUN NO.	TRUCK NO.	DIRECTION LC1 = RIGHT LC2 = LEFT	LC1 (RIGHT) SLOPE 1 (kips/in)	LC2 (LEFT) SLOPE 1 (kips/in)
11	1	LC2PULL/LC1PUSH	102.740	65.481*
12	1	LC2PULL/LC1PUSH	105.364	116.488*
13	1	LC2PULL/LC1PUSH	104.837	123.862*
14	1	LC2PUSH/LC1PULL	69.441*	70.665*
15	1	LC2PUSH/LC1PULL	98.198	106.111
16	1	LC2PUSH/LC1PULL	94.180	106.300
47	2	LC1PULL/LC2PUSH	90.553	89.516
48	2	LC1PULL/LC2PUSH	96.417	101.504
49	2	LC1PULL/LC2PUSH	87.017	99.967
50	2	LC1PUSH/LC2PULL	80.352*	96.735
51	2	LC1PUSH/LC2PULL	105.162	100.988
52	2	LC1PUSH/LC2PULL	94.036	97.587
AVERAGE PULL STIFFNESS: TRUCK 1 105.07 TRUCK 2 94.883				
AVERAGE PUSH STIFFNESS: TRUCK 1 96.19 TRUCK 2 98.04				

* These values were not used in average calculations.

The average axle yaw stiffness, F_k, was calculated in the following way;

$$F_k = 2(K_1 + K_2)B\theta$$

Where: K_1 is right side axle displacement and K_2 is left side axle displacement.
B is the width of the axle.
θ is the angle that the axle yaws.

$$Moment \quad M = F_k B = (K_1 + K_2)B^2\theta$$

$$K_{AY} = AXLE \quad YAW \quad STIFFNESS = \frac{M}{\theta} = (K_1 + K_2)B^2$$

Truck 1 Axle Yaw Stiffness:

$$K^1_{AY} = (105.07 + 96.19)(79)^2 = 1{,}256{,}064 \quad INCH-KIPS/RAD$$

Truck 2 Axle Yaw Stiffness:

$$K^2_{AY} = (94.883 + 98.04)(79)^2 = 1{,}204{,}032 \quad INCH-KIPS/RAD$$

To aide the vehicle dynamics modelling effort, these values were compared to those calculated by NUCARS from the longitudinal stiffness inputs.

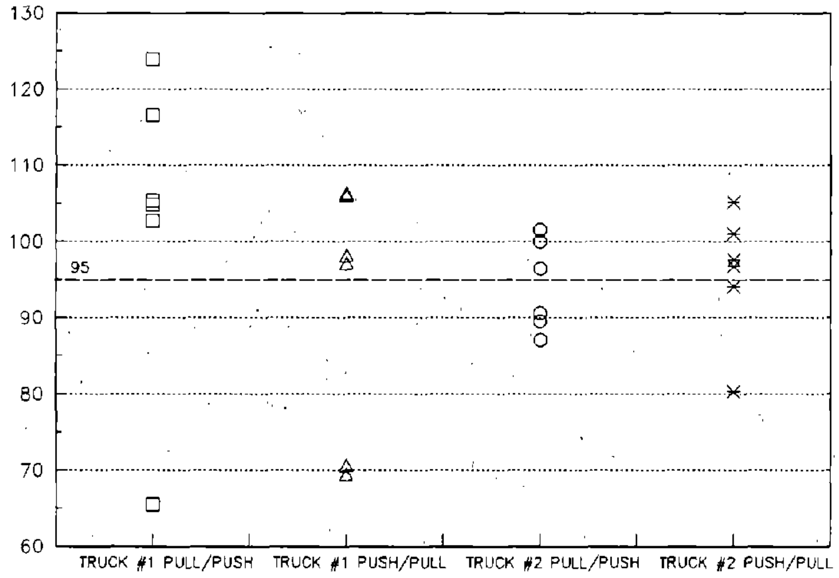


Figure 6.12 Axle Yaw Stiffness Scatter Plot

6.1.2.6 Inter-Axle Shear Stiffness Results

Two test problems were encountered during inter-axle shear stiffness testing. The first problem encountered was lateral slippage of the wheels on the wheel chocks, which were made of lead. This resulted in an unrealistic stiffness measurement. The wheels were subsequently shimmed to prevent lateral slippage.

The next problem encountered was longitudinal slippage of the wheel chocks, which enabled the tables to rotate slightly. That problem was solved by applying chocks on each wheel to prevent longitudinal slippage. Due to these problems only some of the test data is representative of inter-axle shear stiffness.

Three shear stiffness values were found from each plot. The force increased on a linear scale until the frictional snubbers broke loose; then, the force increased slightly with large displacements as the snubbers slid across the sideframe. The snubbers then ran up against the stops yielding a high stiffness. Figure 6.13 shows typical test results after the lateral slippage problem was corrected.

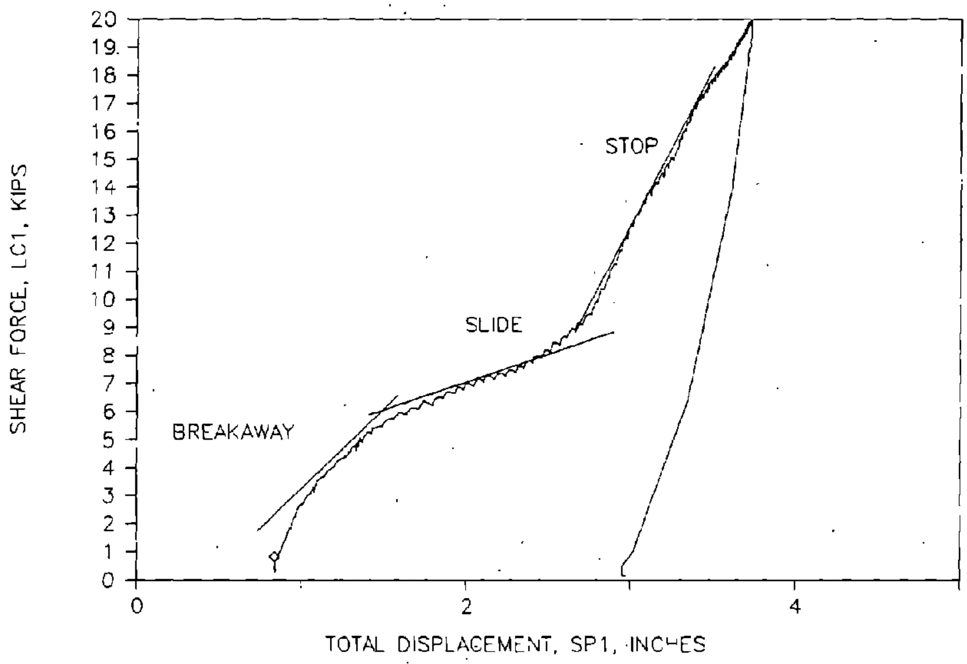


Figure 6.13 Shear Force versus Displacement for Inter-Axle Shear Test Run

Once the force was released, the truck only partially restored itself, indicating that the truck has little or no restoring force while the snubber is sliding.

6.1.3 Modal Response Results

Table 6.9 is a list of runs in the Modal Response Test matrix including the modes investigated in each run. Three of the vertical runs used only one actuator to facilitate use of a computer model.

Table 6.9 LCC Modal Test Log

RUN NAME	RUN DESCRIPTION	MODE INVESTIGATED
LCCM_RN001	+/- kip Vertical, .2 - 5 Hz	Bounce
LCCM_RN002	+/- kip Vertical, .2 - 5 Hz	and
LCCM_RN003	+/- kip Vertical, .2 - 5 Hz	Pitch
LCCM_RN004	+/- kip Vertical, .2 - 5 Hz	
LCCM_RN005	+/- kip Vertical, .2 - 5 Hz, One Actuator	
LCCM_RN006	.2 Constant G, 3 - 30 Hz, Run Aborted	Vertical
LCCM_RN007	.2 Constant G, 3 - 30 Hz, Run Aborted	Bending
LCCM_RN008	.2 Constant G, 3 - 30 Hz, Vertical, One Actuator	
LCCM_RN009	.2 Constant G, 3 - 30 Hz, Vertical, One Actuator	
LCCM_RN010	+/- 5 kip Vertical out-of-phase, .2 - 5 Hz	Roll
LCCM_RN011	+/- 10 kip Vertical out-of-phase, .2 - 10 Hz	
LCCM_RN012	+/- 15 kip Vertical out-of-phase, .2 - 10 Hz	
LCCM_RN013	.1 Constant G, 3 - 30 Hz, Vertical	Vertical
LCCM_RN014	.15 Constant G, 3 - 30 Hz, Vertical	Bending
LCCM_RN015	.2 Constant G, 3 - 30 Hz, Vertical	
LCCM_RN016	.3 Constant G, 3 - 30 Hz, Vertical	
LCCM_RN017	.4 Constant G, 5 - 30 Hz, Vertical	
LCCM_RN018	.5 Constant G, 10 - 30 Hz, Vertical	
LCCM_RN019	.1 Constant G, 3 - 30 Hz, Vertical out-of-phase	Twist
LCCM_RN020	.15 Constant G, 3 - 30 Hz, Vertical out-of-phase	
LCCM_RN021	.2 Constant G, 3 - 30 Hz, Vertical out-of-phase	
LCCM_RN022	.3 Constant G, 3 - 30 Hz, Vertical out-of-phase	
LCCM_RN023	.4 Constant G, 3 - 30 Hz, Vertical out-of-phase	
LCCM_RN024	+/- 5 kip Lateral, .2 - 5 Hz	Yaw
LCCM_RN025	+/- 10 kip Lateral, .2 - 10 Hz	And
LCCM_RN026	+/- 15 kip Lateral, .2 - 10 Hz	Sway
LCCM_RN027	+/- 15 kip Lateral, .2 - 5 Hz	
LCCM_RN028	.1 Constant G, 3 - 30 Hz, Lateral	Lateral
LCCM_RN029	.15 Constant G, 3 - 30 Hz, Lateral	Bending
LCCM_RN030	.2 Constant G, 3 - 30 Hz, Lateral	
LCCM_RN031	.3 Constant G, 10 - 30 Hz, Lateral	
LCCM_RN032	.4 Constant G, 15 - 30 Hz, Lateral	

6.1.3.1 Rigid Body Vertical and Roll Results

Data from the Vertical and Roll Tests was used to obtain pitch, bounce, and roll resonant frequencies. A transfer function between the actuator input force and the A-end upper right corner vertical acceleration is shown in Figure 6.14. Roll was found at 0.5 Hz, bounce at 4 Hz, and pitch at 7 Hz. The plot is from run LCCM_RN005 where a sine wave was applied to the actuator and swept from 2 Hz to 10 Hz.

Figure 6.15 shows the phase plots of the accelerometers located on either side of the A-end of the LCC. It can be seen that they are 188 degrees out of phase which would verify the roll frequency at 0.5 Hz.

Figure 6.16 is the phase plots of accelerometers located at both the A- and B-ends of the LCC. At 4 Hz the ends of the car are 14 degrees out of phase and at 7 Hz the ends of the car are 148 degrees out of phase, indicating the spikes in the transfer function at 4 Hz and 7 Hz (figure 6.14) correspond to bounce and pitch, respectively.

A Rockwell finite element analysis of the LCC predicted a roll frequency of 0.62 Hz, a bounce frequency of 1.78 Hz, and a pitch frequency of 9.79 Hz.

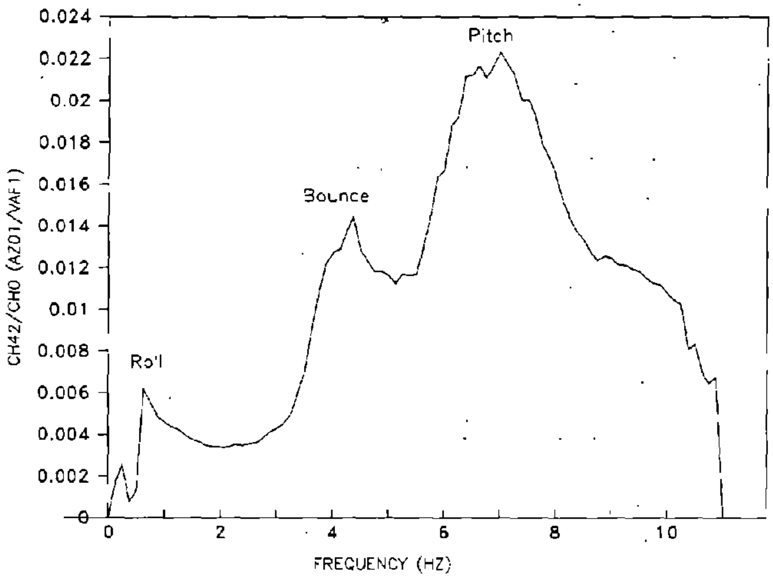


Figure 6.14 Pitch and Bounce Transfer Function

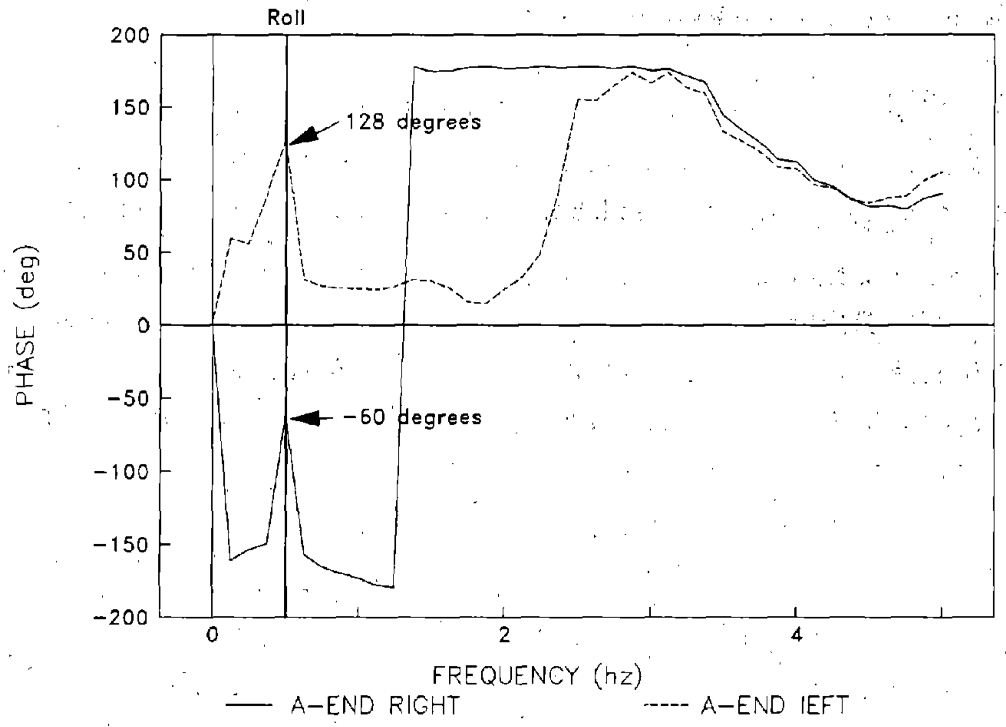


Figure 6.15 Roll Mode Phase Relationships

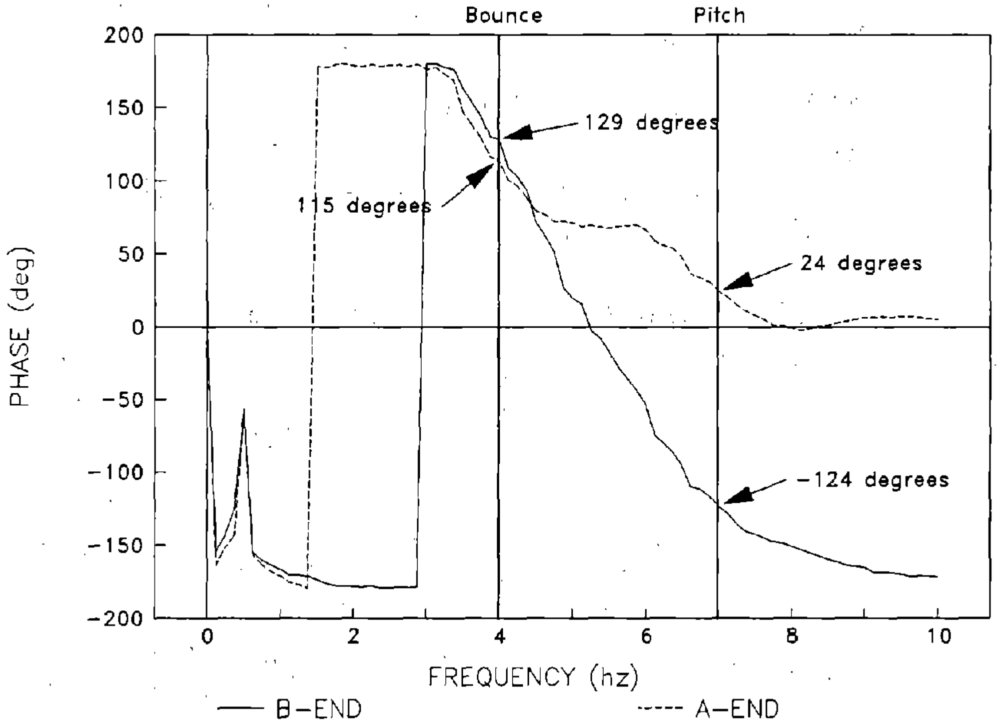


Figure 6.16 Pitch and Bounce Phase Relationships

6.1.3.2 Flexible Body Vertical Results

Data from the six vertical runs was used to obtain the first vertical bending frequency and mode shape. A constant g input was used in a sine sweep to 30 Hz. The displacement was reduced as the frequency increased, keeping the acceleration level constant.

Figure 6.17 is a transfer function from a vertical accelerometer at the middle of the car for run LCCM_RN009. The peak near 13 Hz is the vertical car body bending frequency. This peak was 149 degrees out-of-phase with the A-end of the car and 218 degrees out-of-phase with the B-end of the car (Figure 6.18). The first and second peaks in the transfer function are effects of the bounce and pitch modes.

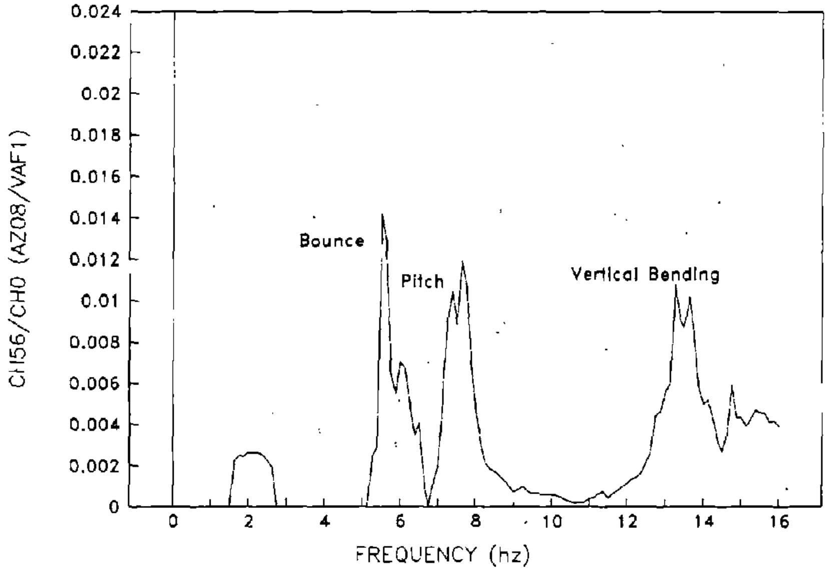


Figure 6.17 Transfer Function of AZ08 versus VAF1

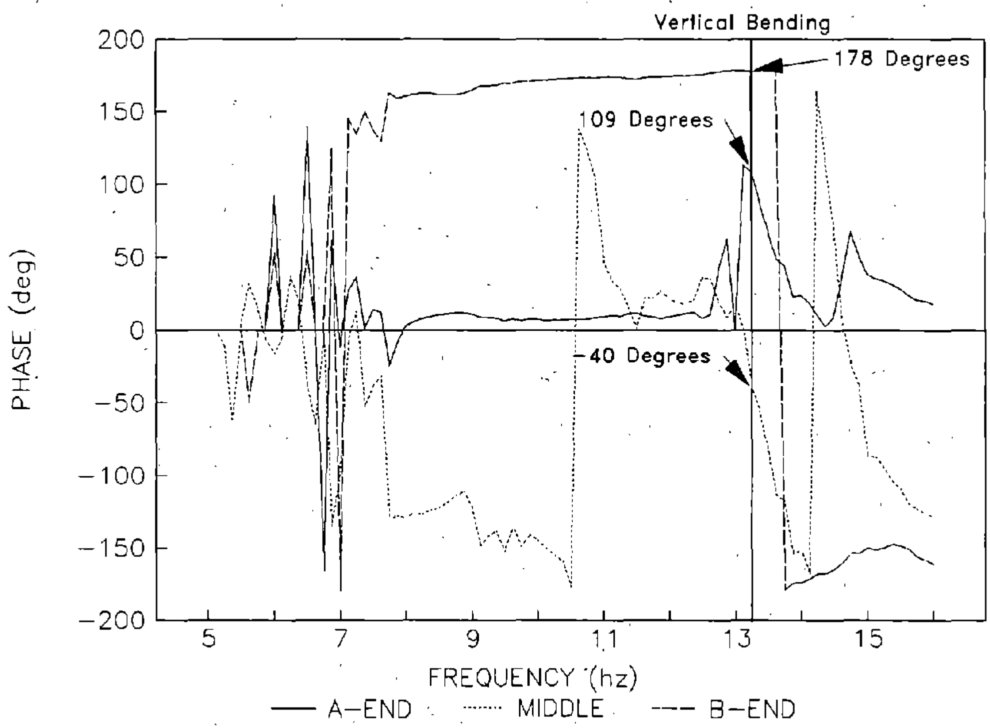


Figure 6.18 Vertical Bending Phase Relationships

Upon closer examination of the Power Spectral Densities (PSD) and transfer functions, the peak was found to be at 13.25 Hz. The transfer functions were curve fit with *Structural Measurement Systems (SMS) Modal 3.0SE* software to produce synthetic bending shapes. Figures 6.19 and 6.20 show the vertical bending in both directions. A simple structure was used and amplitudes were exaggerated to illustrate the bending shape.

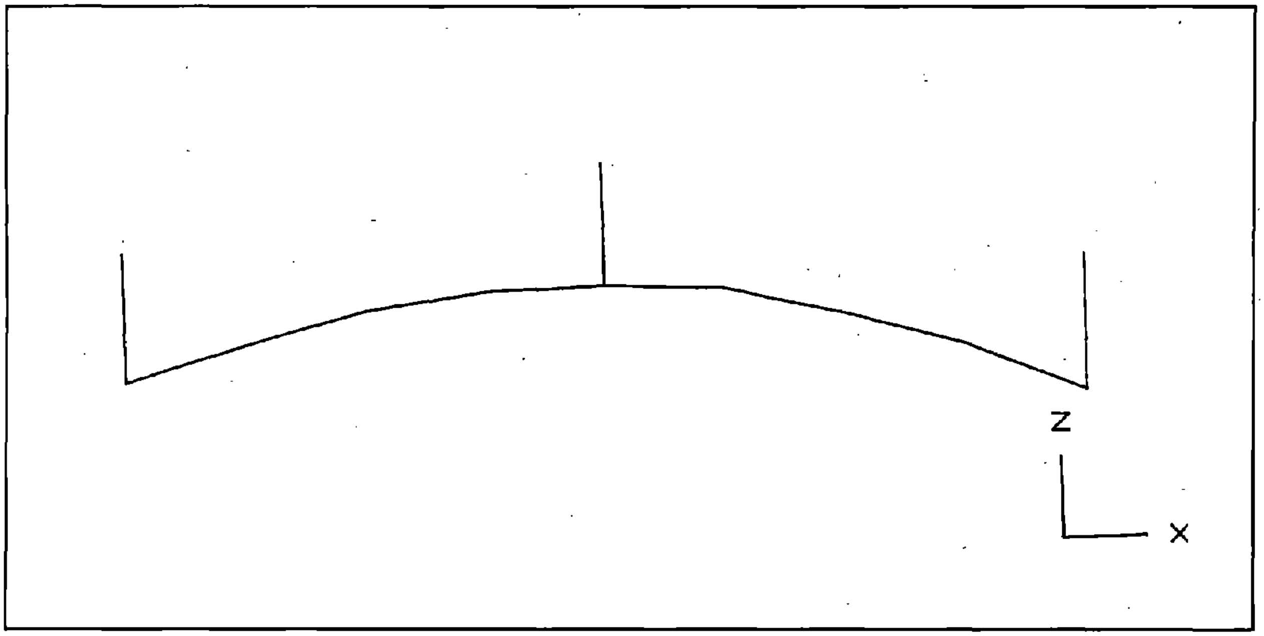


Figure 6.19 Upward Vertical Bending Shape

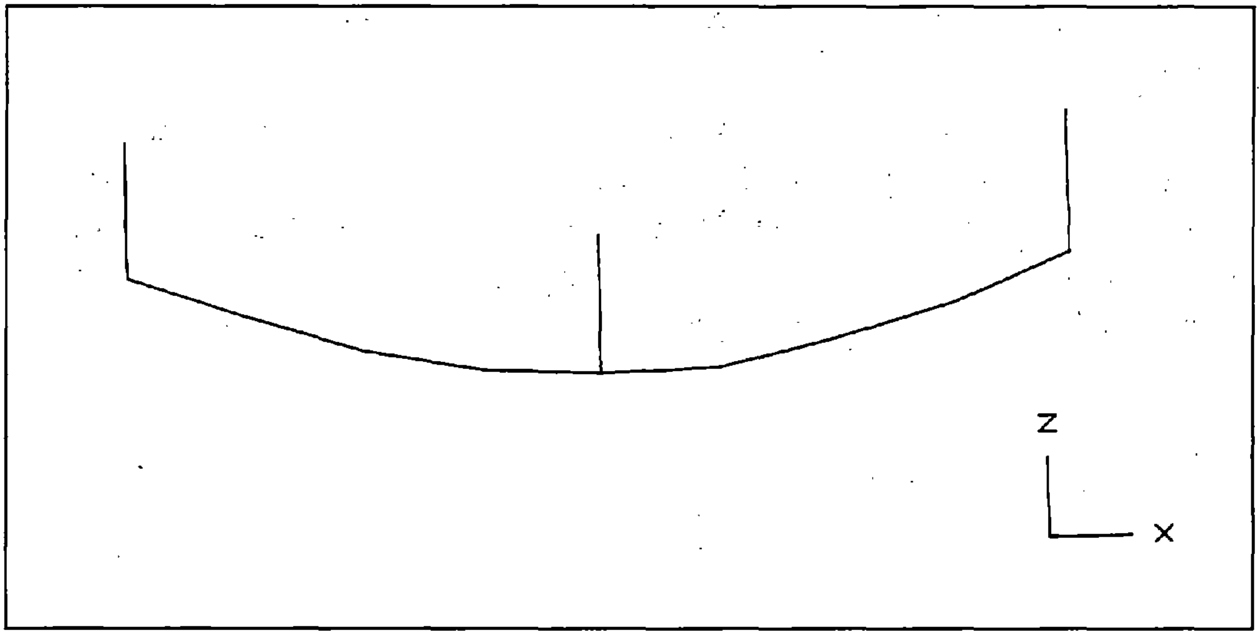


Figure 6.20 Downward Vertical Bending Shape

6.1.3.3 Flexible Body Torsion Results

The Flexible Body Torsion Test was performed in the same manner as the Flexible Body Vertical Test, with one exception. The two actuators were run 180 degrees out-of-phase with constant g sine sweeps used as input. Figure 6.21 shows a transfer function between actuator force and a corner vertical accelerometer. The spike at 20 Hz was the same amplitude but 131 degrees out-of-phase with an accelerometer located on the same side but opposite end of the car. The other corners were 139 degrees out-of-phase with each other, which would be a twisting motion. Figure 6.22 shows the phase relationships between all four corners of the LCC at 20 Hz.

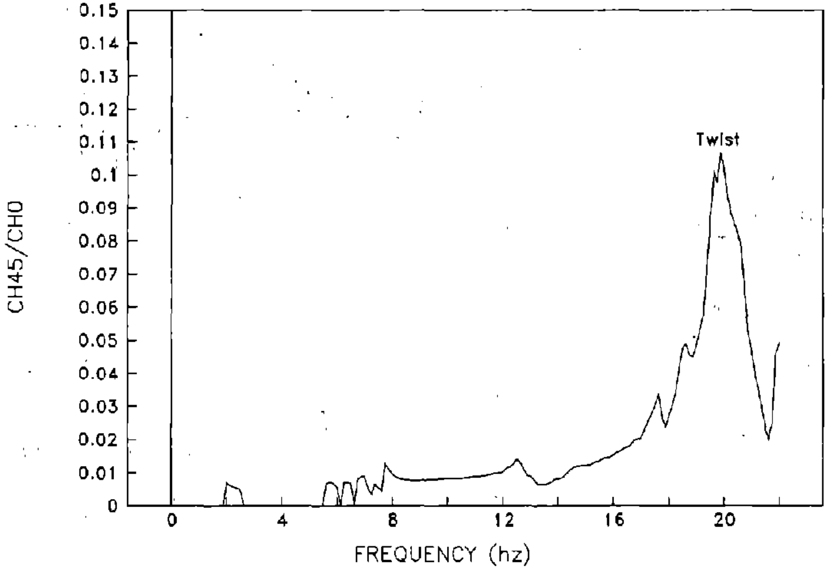


Figure 6.21 Transfer Function Showing Twist

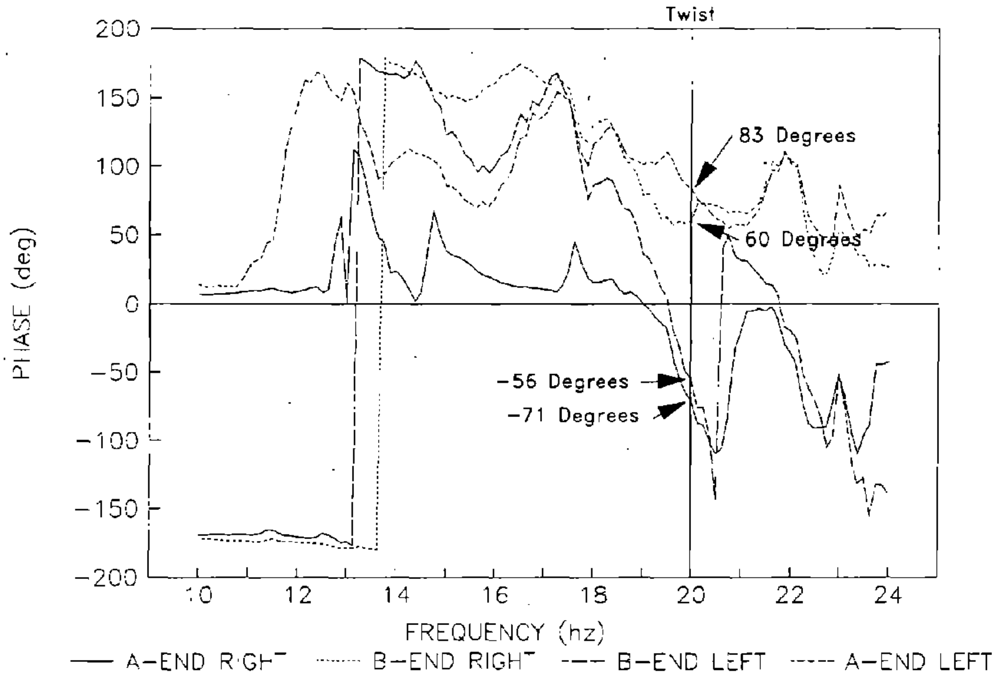


Figure 6.22 Twist Phase Relationships

Figure 6.23 shows the twisting motion near 20 Hz. The model is simplified to show twist.

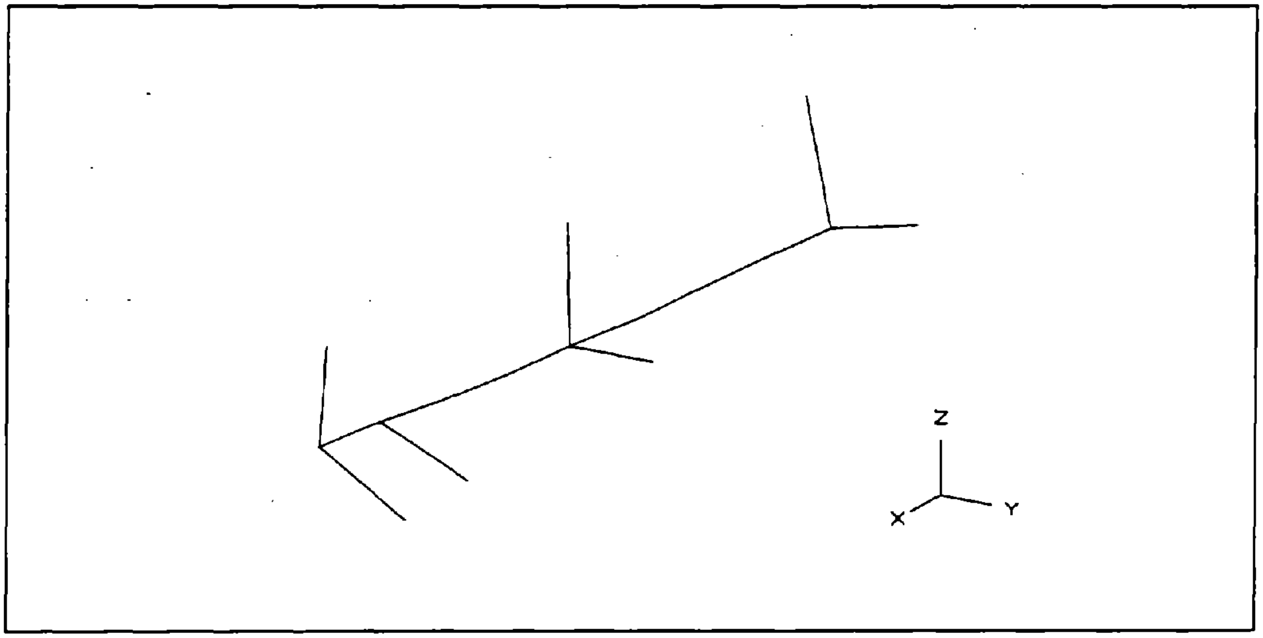


Figure 6.23 LCC Twist Mode

6.1.3.4 Rigid Body Lateral Results

The rigid body lateral runs were used to determine yaw and sway resonant frequencies. Figure 6.24 shows a transfer function between input force and the A-end lateral acceleration for run LCCM_RN030.

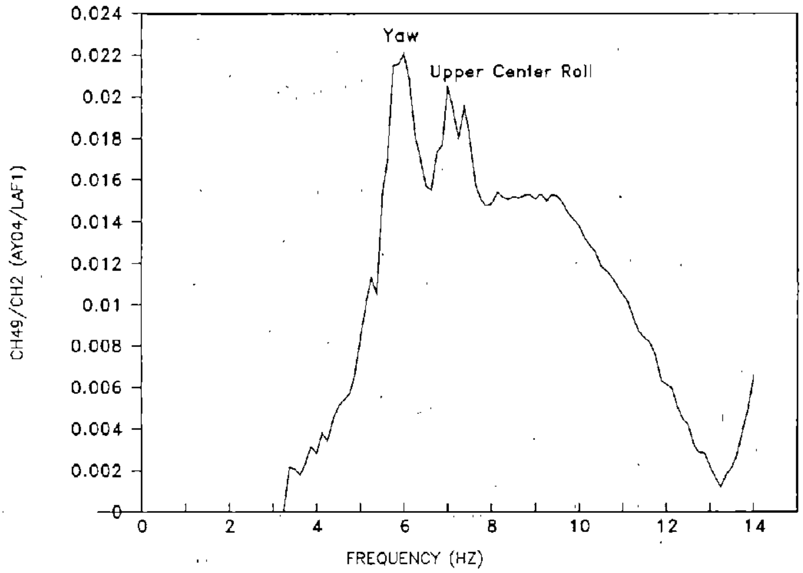


Figure 6.24 A-end Lateral Car Body Acceleration Transfer Function

The spike at 6 Hz was believed to be yaw. The transfer function at the B-end of the car showed a spike at 6 Hz as well. It was 153 degrees out-of-phase with the A-end and approximately the same amplitude (Figure 6.25). This would indicate yaw.

The next spike seen in the transfer function in Figure 6.24 is approximately 7 Hz. This spike is seen at the B-end of the LCC with the same amplitude as the A-end and only 69 degrees out-of-phase (Figure 6.25). This was believed to be sway; however, upon closer examination, the spike is found to correspond to the upper center roll frequency. A sway mode was never found.

A Rockwell finite element analysis of the LCC predicted a yaw frequency of 2.19 Hz, and a sway frequency of 1.93 Hz.

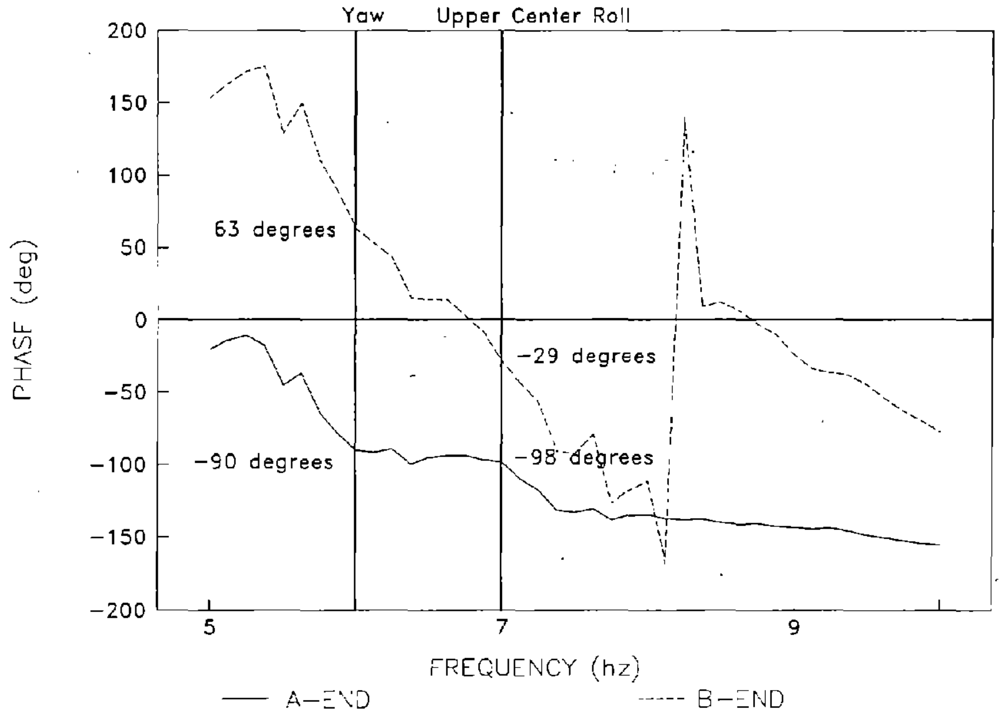


Figure 6.25 Yaw and Upper Center Roll Phase Relationships

6.1.3.5 Flexible Body Lateral Results

A lateral input of 0.2 g from 3 Hz to 30 Hz was input to the car body during run LCCM_RN030. This run was used to determine the first lateral bending mode. The first spike (around 7 Hz) in the transfer function of a lateral accelerometer located in the middle of the car, shown in figure 6.26, is the upper center roll mode. The second large spike in the transfer function between the lateral accelerometer at the center of the car and the driving force was between 15 Hz and 18 Hz (Figure 6.26). Upon closer examination with the *SMS Modal 3.0SE* software, the lateral bending frequency was found to be at 17 Hz.

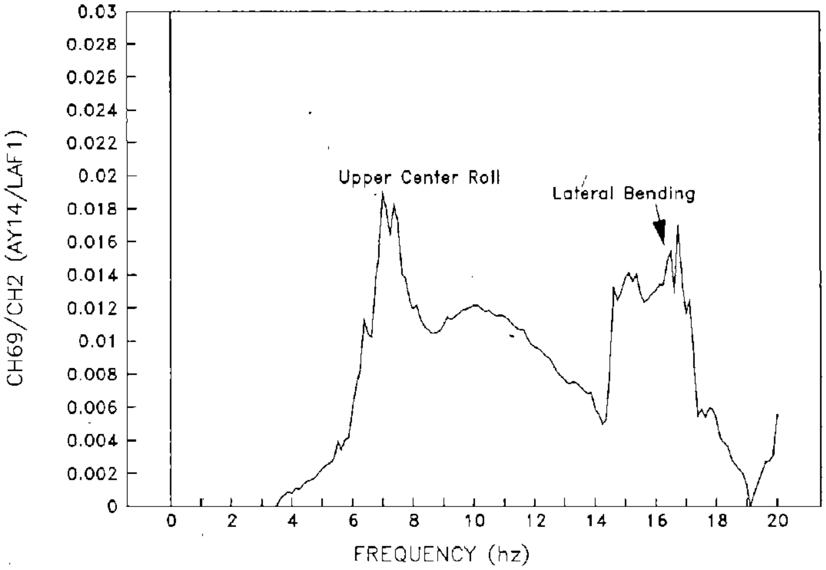


Figure 6.26 Mid-Car Lateral Acceleration Transfer Function

Transfer functions at both ends of the LCC show the same spike at 17 Hz and are approximately 176 degrees out-of-phase from the middle of the car (Figure 6.27). Figures 6.28 and 6.29 are the left and right bending shapes of the LCC.

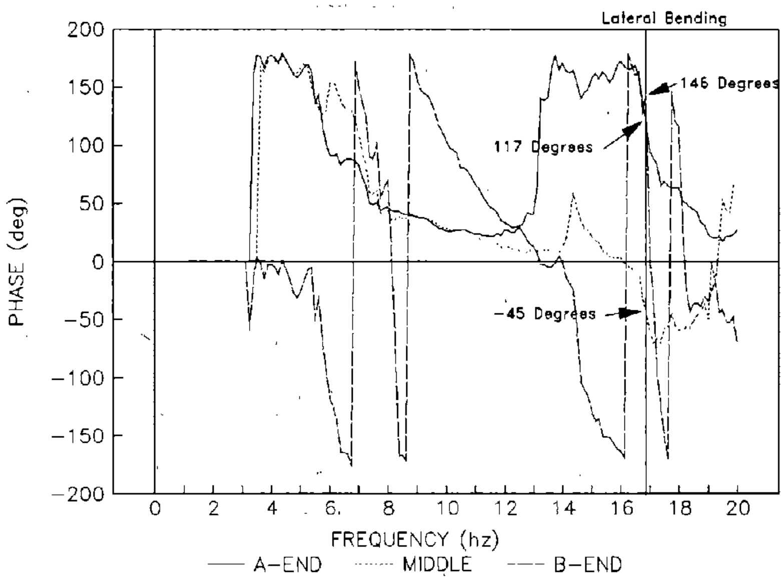


Figure 6.27 Lateral Bending Phase Relationships

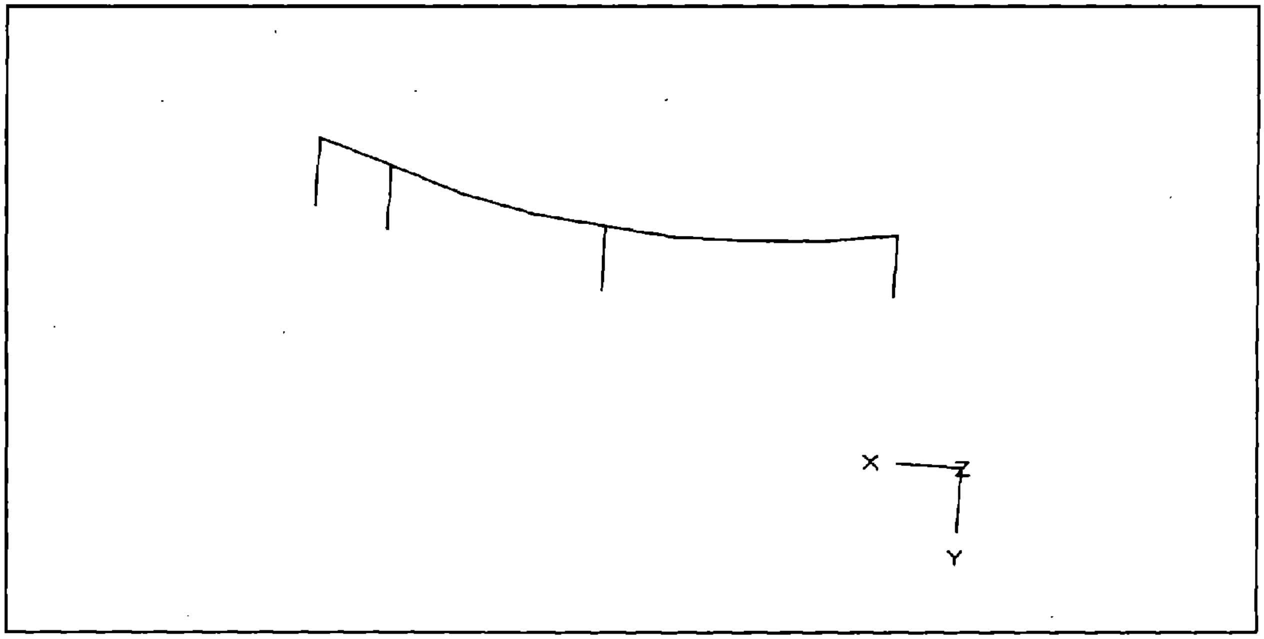


Figure 6.28 Left Bending Shape of the LCC

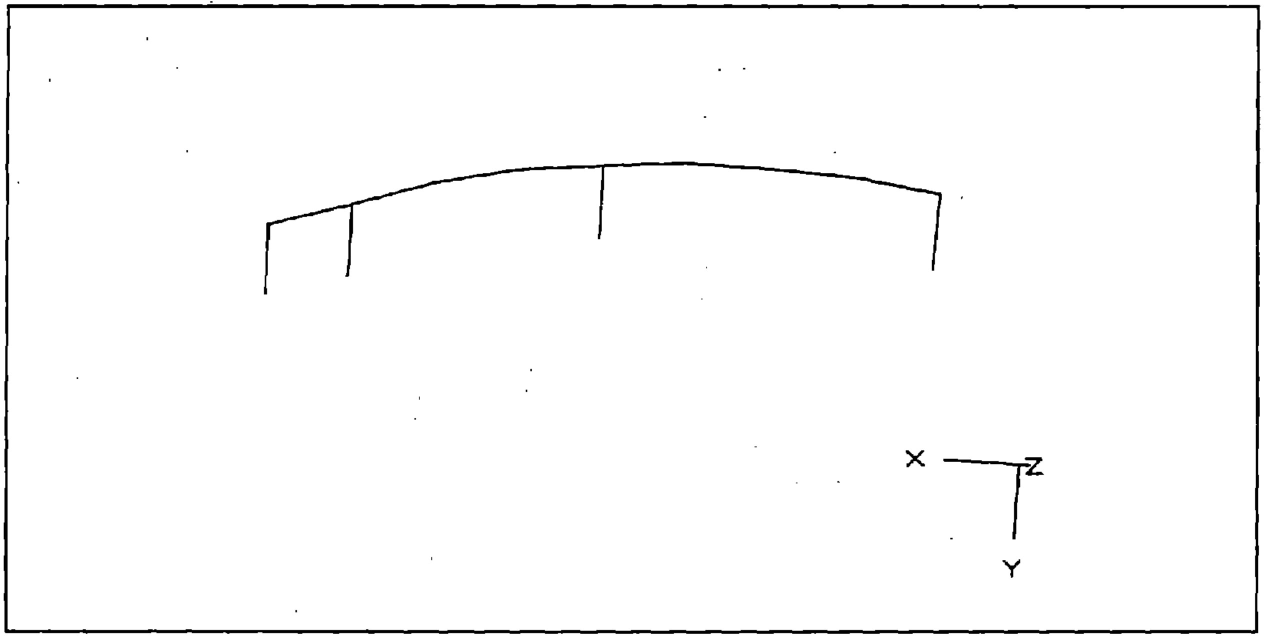


Figure 6.29 Right Bending Shape of the LCC

The LCC is a very stiff car; therefore, 17 Hz is a reasonable lateral bending frequency. No prediction was made for this mode.

6.1.4 Vehicle Characterization Results Summary

Table 6.10 presents a summary of the vehicle characterization data, which was provided for NUCARS modeling support.

Table 6.10 Air Bearing and Modal Results Summary

PARAMETER	VALUE
Vertical Spring Stiffness with snubbers	26.08 kips/in
Vertical Spring Damping with snubbers	11.61 kips
Vertical Spring Stiffness without snubbers	26.32 kips/in
Vertical Spring Damping without snubbers	8.83 kips
Truck Roll Spring Rate	56,519 in-kips/radian
Lateral Truck Stiffness	24.48 kips/in
Lateral Truck Damping	34.40 kips
Span Bolster Yaw Moment	350,000 in-lbs
Single Truck Yaw Moment	112,500 in-lbs
Axle Alignment	Truck No. 1 - 2.496 mrad Truck No. 2 - 0.636 mrad
Longitudinal Stiffness	98.5 kips/inch
Axle Yaw and Inter Axle Bending Stiffness	1,200,000 in-kips/mrad
Inter Axle Shear Stiffness	Not Used for NUCARS
Bounce Frequency	4.0 Hz
Pitch Frequency	7.0 Hz
Roll Frequency	0.5 Hz
Upper Center Roll Frequency	7 Hz
Yaw Frequency	6 Hz
First Vertical Bending Frequency	13.25 Hz
First Torsional Frequency	20.0 Hz
First Lateral Bending Frequency	17 Hz

6.2 SERVICE WORTHINESS RESULTS

The following tests were performed on the LCC during service worthiness testing:

Single Car Impact Test
Compressive End Load Test
Curve Stability Test

6.2.1 Single Car Impact Results

The LCC was impacted into three 70-ton hopper cars with the non-struck car handbrake tightly set. The purpose of this test is to observe that no permanent damage to the car structure occurred due to impact. The LCC was impacted on the A- and B-ends at speeds between 2 and 6 mph. The Air Force and Rockwell limited the maximum speed to 6 mph. Coupler forces ranged from 305 kips to 801 kips on the A-end and 272 kips to 843 kips on the B-end. Table 6.11 lists the results of the LCC Impact Test.

Chapter XI limits the coupler force to 1.25 million pounds and speed to 14 mph. Due to test restrictions, these limits were not reached. The LCC was inspected and no damage was found.

Table 6.11 LCC Impact Speeds and Coupler Forces

TRUCK END	SPEED (MPH)	COUPLER FORCE (KIPS)
A-end	2.9	305
A-end	3.6	388
A-end	4.0	565
A-end	4.6	699
A-end	5.1	685
A-end	6.3	801
B-end	2.4	272
B-end	3.0	372
B-end	3.9	382
B-end	4.9	770
B-end	6.0	843

6.2.2 Compressive End Load Results

The LCC was tested with a 1-million pound compressive force in the squeeze fixture at TTC. The force was increased from 100 kips to 1000 kips in 50 kip intervals. Once at 1-million pounds, the force was held for 60 seconds. After the test, the LCC was inspected for any permanent damage. No damage was found. Twenty strain gage measurements were collected for Rockwell.

6.2.3 Curve Stability Results

The LCC was placed in a consist on a 10-degree curve with less than 1/2 inch super-elevation. A 200,000 pound buff and draft (compress and extend) force was applied to the LCC in the consist. The LCC was monitored for wheel lift with the wheel lift gage (Figure 5.22) on the inside of the curve for buff and the outside of the curve for draft. No wheel lift occurred on the LCC during the Curve Stability Test.

The car was inspected after the test and no damage was noted.

6.3 TRACK WORTHINESS RESULTS

Pre-test predictions were made with the NUCARS model for all LCC track worthiness tests. Appropriate predictions will be noted in each subsection. The predictions were extracted from *Peacekeeper Rail Garrison, Launch Control Car (EMS-2) Pre-test Track Worthiness Predictions Report.*[1] Chapter XI criteria were used as a guideline to compare to the measured performance of the LCC and to indicate safe conduct of each test. The tests were not performed to certify the LCC. The criteria were not used as pass/fail.

---

[1] Peter Klauser, Association of American Railroads, *Peacekeeper Rail Garrison, Launch Control Car (EMS-2) Pre-Test Track Worthiness Predictions Report*, October 1990.

6.3.1 High Speed Stability Results

There were two limiting criteria for the High Speed Stability Test: maximum axle sum L/V of 1.3, and maximum peak-to-peak lateral car body acceleration of 1.0 g sustained for 20 seconds. The maximum test speed was 60 mph. Table 6.12 tabulates the high speed stability results and predictions.

Table 6.12 LCC Hunting Results

SPEED (MPH)	MAXIMUM PEAK-TO-PEAK LATERAL ACCELERATION (g)		MAXIMUM AXLE SUM L/V	
	Actual	Predicted	Actual	Predicted
30	0.20	n/a	0.31	n/a
40	0.22	0.05	0.33	0.15
50	0.50	0.29	0.46	0.29
55	1.20	n/a	0.85	n/a
57	1.30	n/a	0.96	n/a
60	1.20	0.28	1.03	0.31

The maximum lateral car body acceleration given in Table 6.12 are instantaneous. The worst speed seemed to be 57 mph. At 57 mph the LCC was unstable, but the acceleration values were never sustained for 20 seconds at 1 g peak-to-peak. Figure 6.30 shows a time history of the accelerations at the B-end of the LCC for a speed of 57 mph. The time history shows clearly that the LCC was unstable at this speed. The LCC was tested in its normal loaded condition because there is no empty condition. Should the LCC ever be empty or weigh considerably less (possibly for shipping reasons), hunting would be a problem above 50 mph.

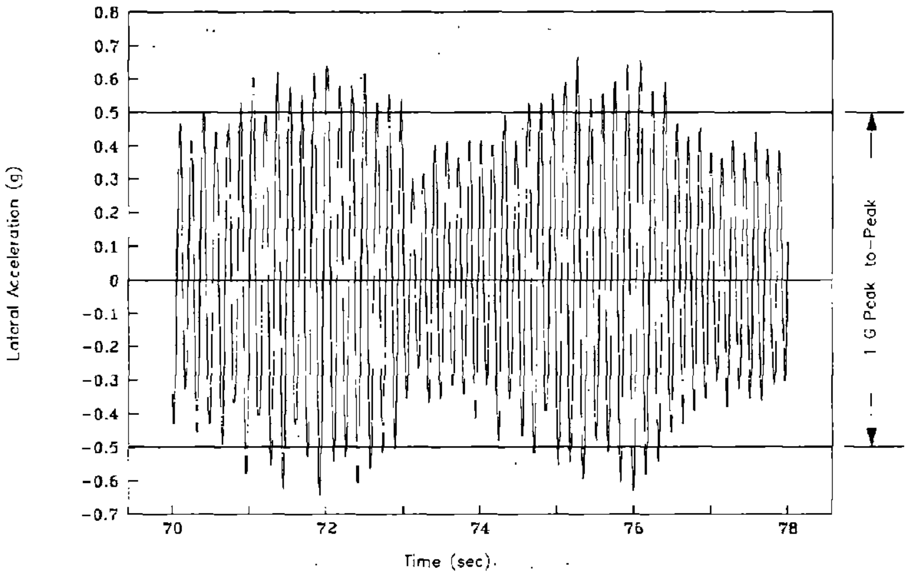


Figure 6.30 B-end Lateral Acceleration Time History

Chapter XI criteria are intended to address derailment probability for freight equipment. Ride quality, which would be poor at speeds above 55 mph is not addressed.

6.3.2 Constant Curving Results

Tests were performed in the clockwise and counterclockwise directions on the 4-, 7.5-, and 12-degree curves. A minimum of three test speeds are required by Chapter XI. These are at balance (for curve elevation) and below and above balance speed. The test speeds for each curve are shown in table 6.13. Speeds of 20 mph on the 4-degree curve, 16 and 24 mph on the 7.5-degree curve, and 14 mph on the 12-degree curve were the only speeds to be tested with the LCC.

Table 6.13 LCC Constant Curving Test Speeds

DEGREE	SUPER ELEVATION	BALANCE SPEED	ABOVE BALANCE SPEED	BELOW BALANCE SPEED
4	3	33	40	20
7.5	3	24	32	14
12	5	24	32	16

Speeds of 32 mph on the 7.5-degree curve and speeds of 24 and 32 mph on the 12-degree curve were not tested. Single occurrences above the Chapter XI limits occurred and testing was stopped by the Air Force. Since these tests, Chapter XI limits now only specify a 95th percentile limit. Single occurrences above the limit can occur as long as they occur less than 5 percent of the time.

Table 6.14 summarizes results for the 4-degree curve.

Table 6.14 LCC 4-Degree Curving Results

SPEED (MPH) AND DIRECTION	WHEEL L/V 95th PERCENTILE (.8 LIMIT)		AXLE SUM L/V 95th PERCENTILE (1.3 LIMIT)	
	Actual	Predicted	Actual	Predicted
20 cw	0.48	n/a	0.84	n/a
20 ccw	0.46	n/a	0.85	n/a
33 cw	not tested	n/a	not tested	n/a
33 ccw	not tested	n/a	not tested	n/a
40 cw	not tested	n/a	not tested	n/a
40 ccw	not tested	n/a	not tested	n/a

The results reflect the 95th percentile values and are only for the steady state condition. The steady state condition was assumed to begin when the LCC was completely in the curve and to end just before the leading end of the LCC entered the exit spiral. Curve entry and exit are covered in Section 6.3.3. The LCC performed the same clockwise as counterclockwise. No predictions are available for the tests performed in the 4-degree curve. Speeds above 20 mph were not tested in the 4-degree curve because higher speeds in adjacent curves (7.5-degree and 12-degree) could not be tested.

Table 6.15 summarizes the actual and predicted results for the 7.5-degree curve.

Table 6.15 LCC Constant 7.5-Degree Curving Results

SPEED (MPH) AND DIRECTION	WHEEL L/V 95th PERCENTILE .8 LIMIT		AXLE SUM L/V 95th PERCENTILE 1.3 LIMIT	
	Actual	Predicted	Actual	Predicted
14 cw (10)	0.56	0.5	1.04	0.95
14 ccw	0.65	n/a	1.14	n/a
24 cw	0.51	0.42	0.93	0.82
24 ccw	not tested	n/a	not tested	n/a
32 cw	not tested	0.37	not tested	0.73
32 ccw	not tested	n/a	not tested	n/a

( ) Model Speed

The counterclockwise direction yielded slightly higher 95th percentile L/V's than the clockwise direction. Figure 6.31 is a time history of the lead axle, right wheel (flanging wheel) L/V of truck 1 for a CCW 7.5 degree curve test at 14 mph. Some single occurrences above the Chapter XI criteria were observed, however, the 95th percentile value is below the Chapter XI criteria. All of the L/V values above the Chapter XI criteria for under balance and balance speeds were less than 50 milliseconds in duration for the 7.5-degree curve. Speeds above 24 mph were not tested in the 7.5-degree curve because higher speeds in the adjacent 12-degree curve could not be tested.

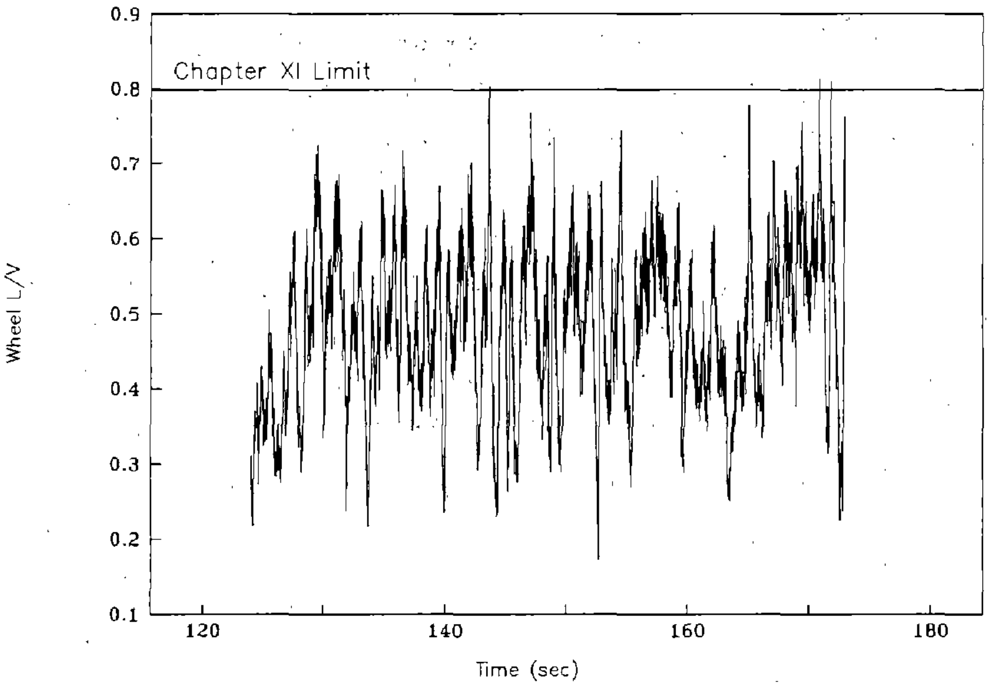


Figure 6.31 Time History of Axle 7 Right Wheel L/V for 7.5-Degree Curve

Table 6.16 summarizes the actual and predicted results for the 12-degree test.

Table 6.16 LCC Constant 12-Degree Curving Results

SPEED (MPH) AND DIRECTION	WHEEL L/V 95th PERCENTILE .8 LIMIT		AXLE SUM L/V 95th PERCENTILE 1.3 LIMIT	
	Actual	Predicted	Actual	Predicted
16 cw (15.5)	0.67	0.55	1.15	1.04
16 ccw	0.77	n/a	1.26	n/a
24 cw	not tested	0.49	not tested	0.98
24 ccw	not tested	n/a	not tested	n/a
32 cw	not tested	0.47	not tested	0.93
32 ccw	not tested	n/a	not tested	n/a

( ) Model Speed

The counterclockwise L/V results for a right hand turn on the 12-degree curve are somewhat higher than the clockwise L/V results. The values presented in Table 6.16 are within the Chapter XI 95th percentile limit; however, many exceedances above the Chapter XI limits of 0.8 for wheel L/V and 1.3 for axle sum L/V were seen in the counterclockwise direction. The center bowl was lubricated in an attempt to improve the results. The lubrication had no affect on the results. Testing was suspended at the direction of the Air Force because the exceedances still occurred. Figure 6.32 is a time history of the lead axle, left wheel (flanging wheel) L/V in the lead truck for a 12 degree curve test at 16 mph. Several occurrences above the Chapter XI criteria can be seen, some well over 50 msec, but all less than 5% of the total time.

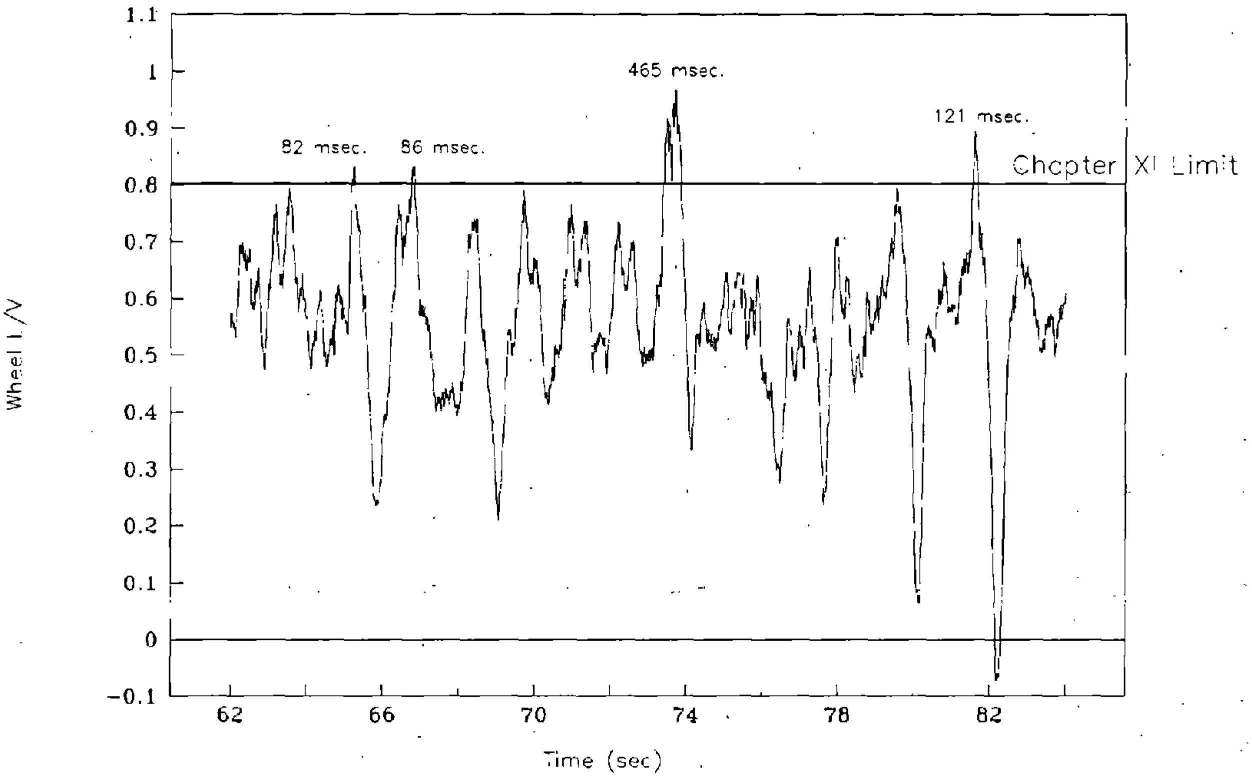


Figure 6.32 Time History of Lead Axle Flanging Wheel in 12-Degree Curve

Figure 6.33 shows the 95th percentile wheel L/V's for both clockwise and counterclockwise directions on the 12-degree curve at below balance speed (16 mph). Predicted values and the Chapter XI limit are also shown.

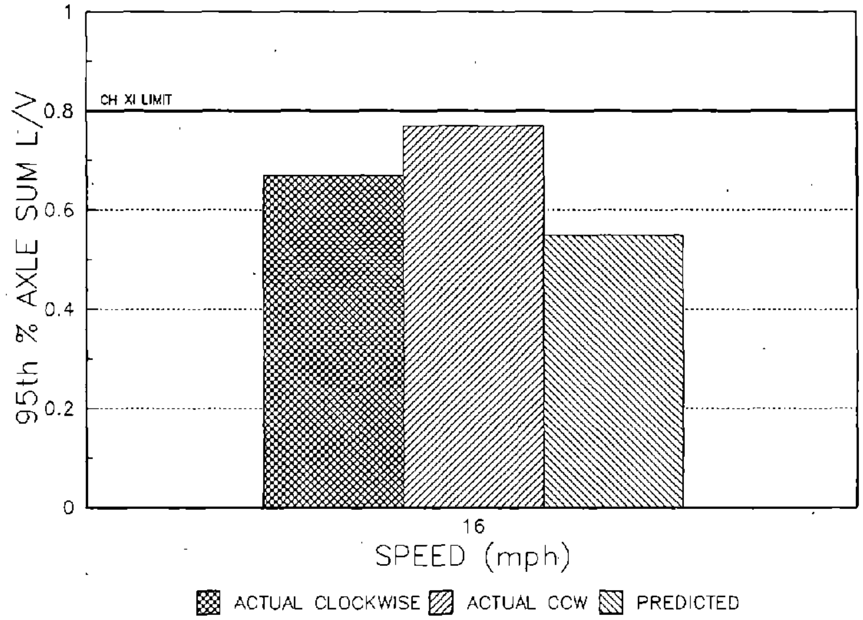


Figure 6.33 95th Percentile Wheel L/V's for the 12-Degree Curve

Figure 6.34 shows the 95th percentile axle sum L/V's for both directions on the 12-degree curve. Predictions and the Chapter XI limitations are also shown.

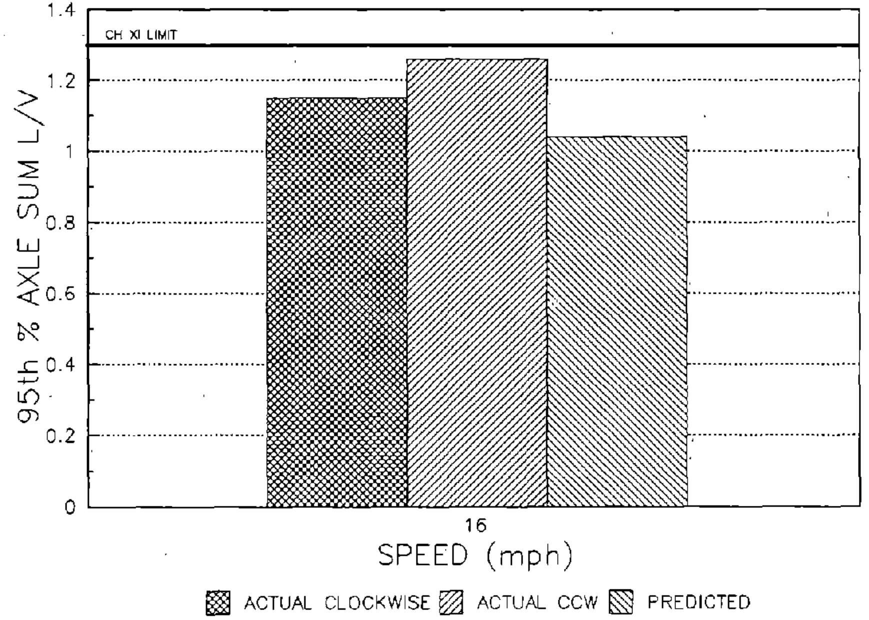


Figure 6.34 95th Percentile Axle Sum L/V's for the 12-Degree Test

Three things are evident in the two previous figures. First, steady state performance is slightly worse for a right turn than a left turn in a 12-degree curve. Second, the fact that the wheel L/V trends were very similar to the axle sum L/V trends indicates a good test for a three-piece truck performance. On dry curved track with a coefficient of friction of 0.5, a 0.8 wheel L/V should be accompanied by a 0.5 L/V on the opposite wheel barring any large longitudinal force. This would yield a 1.3 axle sum L/V. The L/V for the wheel that is not flanging should not exceed the static coefficient of friction of that interface. The data yielded an average coeffiecient of friction of 0.5 indicating dry track. Finally, the vehicle performance was within Chapter XI 95th percentile criteria at 16 mph even with some high single occurrences. Individual L/V's in excess of 50 msec duration are considered important in all other Chapter XI tests. The LCC was never tested at balance or above balance speeds in the 12-degree curve by the direction of the Air Force.

In summary, the LCC was tested in three curves, the 4-degree curve, the 7.5-degree curve and the 12-degree curve. The LCC performed below the Chapter XI criteria in all of the curves, however; single occurrences above the Chapter XI L/V limits over 50 msec in duration were noted in the 12-degree right hand curve while at a speed of 16 mph. The 50 msec duration criteria is used in other Chapter XI tests as an indicator of safe performance. The new Chapter XI standard for constant curving allows 50 msec exceedances if they occur less than 5% of the time. As seen in Figure 6.23, the exceedances were above the Chapter XI limit much more than 50 msec. Although the total duration was less than 5% of the time, the Constant Curving Tests were stopped. Above balance speeds were never tested on any curve and balance speeds were never tested on the 12-degree curve.

6.3.3 Curve Exit and Curve Entry Results

Curve entry and exit performance was measured during the Constant Curving Tests. The 7.5-degree curve had standard spirals at each end that were 200 feet long. A standard spiral is the section of track which makes the transition from tangent to curve with constant changes in curvature and superelevation with distance. The 12-degree curve has a bunched spiral at one end. The bunched spiral was curve exit for clockwise runs and a curve entry for counterclockwise runs. Chapter XI only specifies the bunched spiral for the official curve entry test. The bunched spiral makes the change in curvature throughout the spiral but the change in superelevation is bunched in the middle 100 feet of the spiral. The limiting criteria for spiral negotiation were 10 percent minimum vertical wheel load and a maximum wheel L/V of 0.8.

Table 6.17 summarizes the 7.5-degree curve entry and exit results on a standard spiral. The predictions are for a bunched spiral. Curve exit L/V values were slightly higher than curve entry results for both clockwise and counterclockwise tests.

Table 6.17 7.5-Degree Curve Entry and Exit Results

SPEED (MPH)	CURVE ENTRY				CURVE EXIT			
	Actual Wheel L/V .8 Limit	Predicted Wheel L/V	Wheel Load Percent of Static 10% Min. Limit		Actual Wheel L/V .8 Limit	Predicted Wheel L/V	Wheel Load Percent of Static 10% Min. Limit	
			Act.	Pred.			Act.	Pred.
14 (10)	0.64	0.55	58	52	0.78	0.61	58	49
24	0.55	0.56	68	51	0.65	0.50	63	50
32	not tested	0.57	not tested	40	not tested	0.45	not tested	41

( ) Model Speed

Table 6.18 is a summary of the 12-degree curve entry and exit results. Results are shown for both directions for entry or exit. Again, all predictions are for a bunched spiral.

Table 6.18 12-Degree Spiral Negotiation Summary

SPEED (MPH) AND DIR.	CURVE ENTRY				CURVE EXIT			
	Actual Wheel L/V .8 Limit	Predicted Wheel L/V	Actual Min. Wheel % 10% Limit	Predicted Min. Wheel %	Actual Wheel L/V .8 Limit	Predicted Wheel L/V	Actual Min. Wheel % 10% Limit	Predicted Min. Wheel %
16 cw (15.5)	0.92	n/a	46	n/a	0.78	3.58	52	14
16 ccw (15.5)	0.83	1.42	45	21	0.87	n/a	46	n/a
24 cw	not tested	n/a	not tested	n/a	not tested	* 6.66	not tested	* 13
24 ccw	not tested	1.10	not tested	10	not tested	n/a	not tested	n/a
32 cw	not tested	n/a	not tested	n/a	not tested	* 3.37	not tested	* 14
32 ccw	not tested	1.15	not tested	13	not tested	n/a	not tested	n/a

( ) Model Speed

* Incomplete NUCARS simulation ending in predicted derailment, results intended for comparative purposes only.

WHERE:
1. Curve Entry Clockwise .... Standard Spiral
2. Curve Entry CCW................................ Bunched Spiral
3. Curve Exit CW..................................... Bunched Spiral
4. Curve Exit CCW .... Standard Spiral

As a curve entry, the bunched spiral was slightly less severe than the standard spiral. The highest wheel L/V observed was 0.92 in the standard spiral and 0.83 in the bunched spiral. These values both exceeded the Chapter XI limits. The vertical wheel load for curve entry was 46 percent and 45 percent of the static vertical load in the standard spiral and bunched spiral, respectively. Both values are four times higher (better) than the Chapter XI minimum criteria of 10 percent.

As a curve exit, the bunched spiral also produced lower L/V's than the standard spiral. The bunched spiral exit L/V results were less than the Chapter XI limit at 0.78, but the standard spiral exit L/V was higher than the Chapter XI criteria at 0.87. The LCC performed better in the bunched spiral than in the standard spiral at 16 mph. Higher speeds were not tested at the direction of the Air Force because of the high L/V values found in the Constant Curving Test. The computer model predicted derailment at speeds above 18 mph in the 12-degree curve bunched spiral exit.

Figure 6.35 shows a comparison of the maximum wheel L/V's from the 12-degree curve entry and exit tests on the bunched spiral.

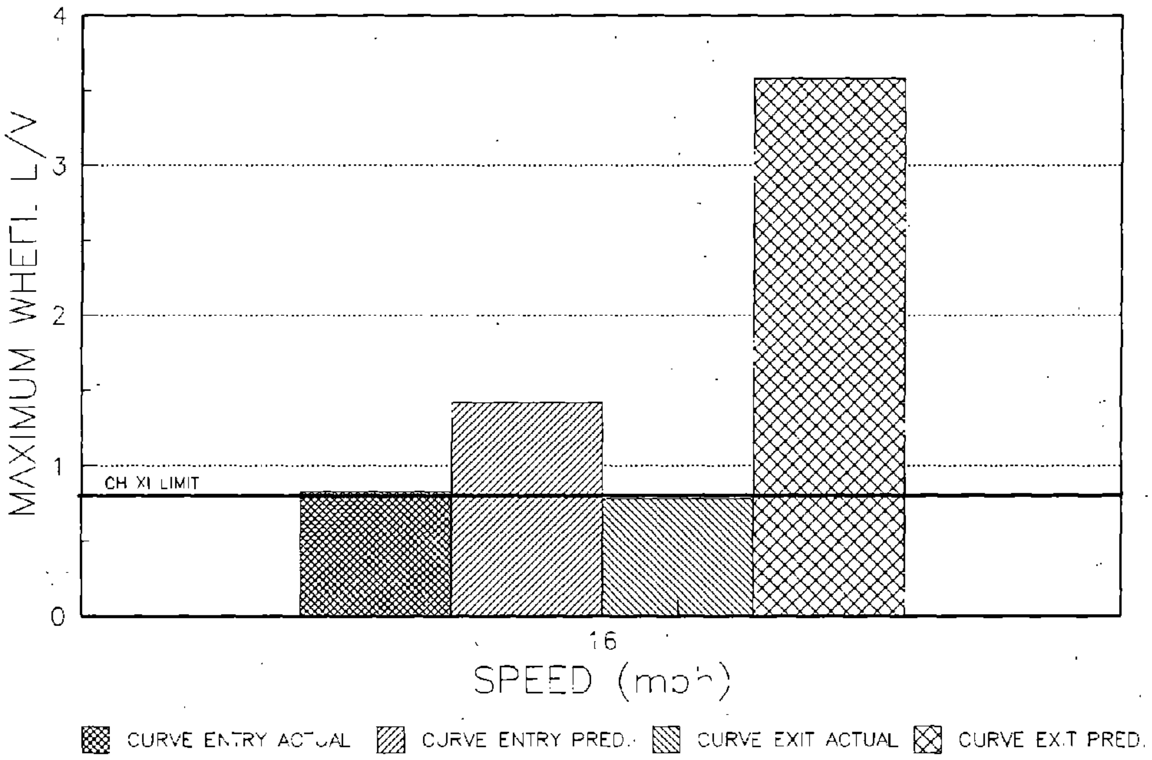


Figure 6.35 LCC Bunched Spiral Wheel L/V Results

In summary, three curves were tested, the 4-degree curve, the 7.5-degree curve and the 12-degree curve. Curve entry and curve exit results were tabulated for the 7.5- and 12-degree curve spirals. The LCC performed below the Chapter XI criteria in the 7.5 degree standard curve entry and curve exit spirals. However; the L/V results exceeded the Chapter XI criteria in both the standard and bunched spirals at either end of the 12-degree curve. Since the Constant Curving Tests were stopped, above balance speeds were never tested on any curve and balance speeds were never tested on the 12-degree curve, therefore no additional data is available for curve entry or curve exit.

6.3.4 Pitch and Bounce Results

The safety criterion listed in Chapter XI for pitch and bounce is in reference to minimum vertical wheel load. The limit is 10 percent of the static vertical wheel load.

The first step in the pitch and bounce data analysis was to determine the static vertical wheel load for each instrumented wheel. Fifteen runs were analyzed to determine the rolling vertical wheel load. The entrance zone to the twist and roll testing section was used as this is well maintained tangent track. The resultant average vertical wheel load was used for all of the minimum vertical wheel load calculations.

Table 6.19 is a tabulation of the actual and predicted minimum vertical wheel loads for the Pitch and Bounce Test.

Table 6.19 Pitch and Bounce Test Results

SPEED (MPH)	ACTUAL MINIMUM VERTICAL WHEEL LOAD PERCENT 10% LIMIT	PREDICTED MINIMUM VERTICAL WHEEL LOAD PERCENT
30	74	88
35	76	88
40	76	88
45	74	88
50	70	87
55	70	85
57	67	n/a
60	70	84

Figure 6.36 shows a comparison of actual, predicted , and limiting values. The lowest vertical wheel load was 67 percent of the static vertical wheel load at 57 mph. This is much higher than the Chapter XI limit of 10 percent.

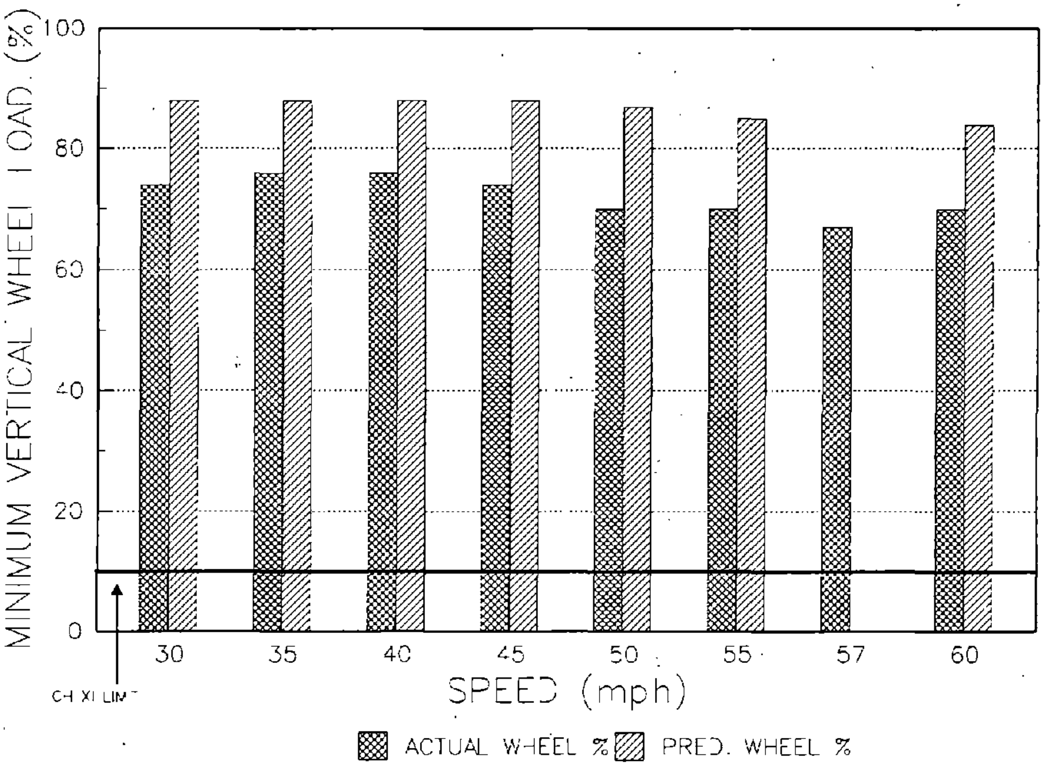


Figure 6.36 Pitch and Bounce Test Results

6.3.5 Twist and Roll Results

Chapter XI specifies three limiting criteria for twist and roll. The first is a 10 percent minimum vertical wheel load. The second is a maximum axle sum L/V of 1.3 and the third is a maximum car body roll angle of 6 degrees peak-to-peak. Table 6.20 summarizes the test data and predictions for each criterion.

Table 6.20 Twist and Roll Results

SPEED (MPH)	MINIMUM VERTICAL WHEEL LOAD PERCENT 10% LIMIT	MINIMUM VERTICAL WHEEL LOAD PERCENT	ROLL ANGLE DEGREE *P-T-P 6-DEGREE LIMIT	ROLL ANGLE DEGREE *P-T-P	AXLE SUM L/V 1.3 LIMIT	AXLE SUM L/V
	Actual	Predicted	Actual	Predicted	Actual	Predicted
10	67	n/a	0.80	n/a	0.35	n/a
15 (16)	67	65	1.40	0.8	0.30	.024
18	50	62	1.60	1.0	0.39	0.22
20	46	60	1.60	1.1	0.44	0.24
22	46	49	1.60	1.5	0.42	0.26
24	50	66	1.68	0.7	0.42	0.28
26	54	67	1.68	0.7	0.44	0.30
30	54	66	1.60	0.8	0.42	0.31
35	54	n/a	1.60	n/a	0.46	n/a
40	55	65	0.88	0.7	0.53	0.34
45	58	n/a	0.80	n/a	0.46	n/a
48 (50)	58	60	0.80	0.6	0.51	0.41
55	58	n/a	0.60	n/a	0.58	n/a
58	46	n/a	0.60	n/a	0.75	n/a
60	50	61	0.60	0.5	0.92	0.52

( ) Model Speed

* Peak-To-Peak

The minimum vertical wheel load was 46 percent of the static vertical wheel load at 20 and 22 mph, which is much higher than the Chapter XI 10 percent minimum limit. Figure 6.37 shows a comparison of actual versus predicted vertical wheel unloading for the Twist and Roll Test.

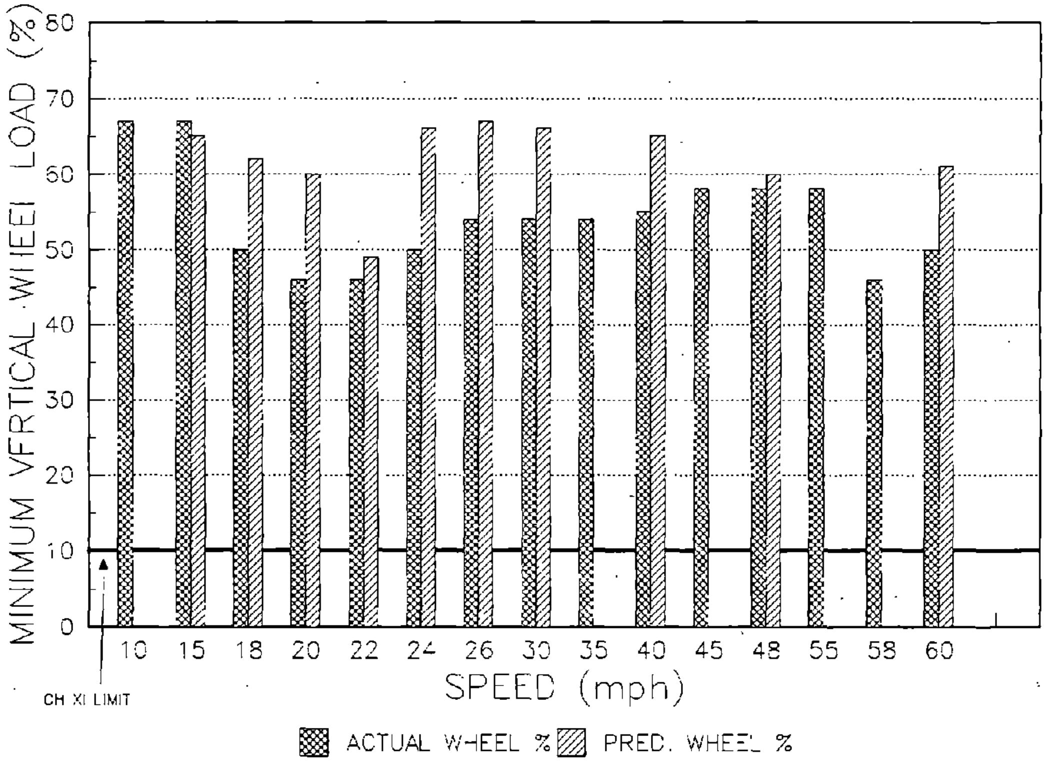


Figure 6.37 Twist and Roll Minimum Vertical Wheel Load Results versus Predictions

The largest peak-to-peak roll, 1.68 degrees, was at 24 mph and 26 mph. This was below the 6-degree Chapter XI maximum limitation. Figure 6.38 shows a comparison of actual versus predicted roll angles.

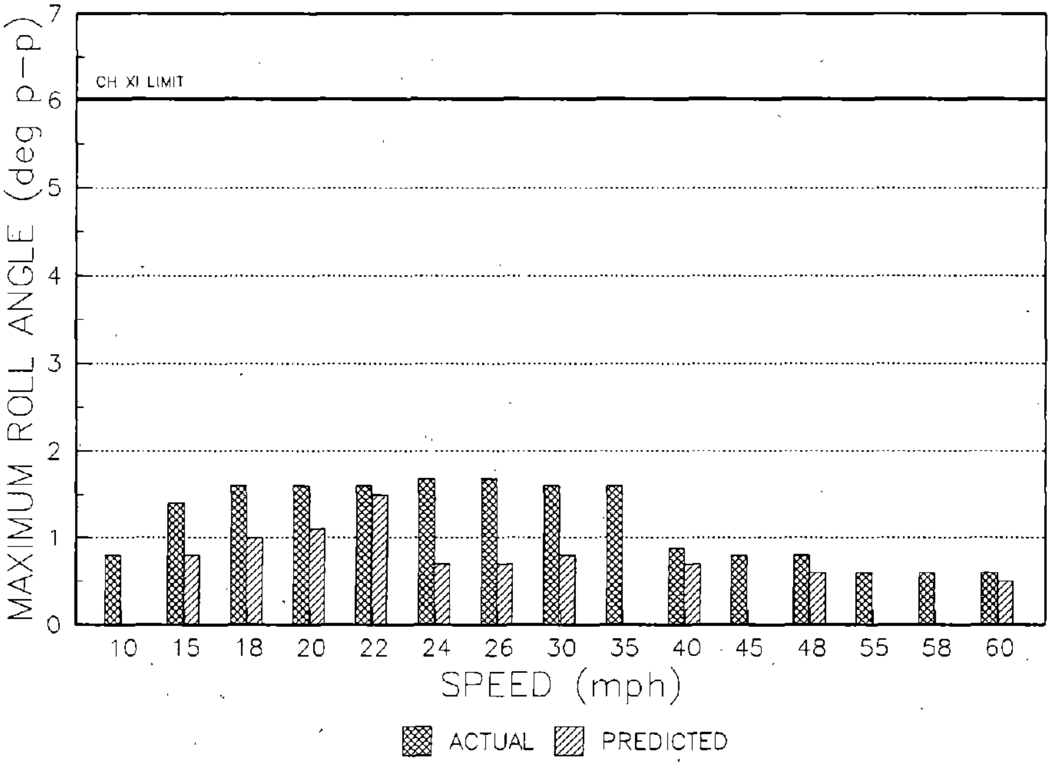


Figure 6.38 Twist and Roll Actual versus Predicted Roll Angle

The highest axle sum L/V was below the 1.3 limit. It measured 0.92 at 60 mph. This speed was well above the expected twist and roll resonant speed and may just reflect a measure of high speed instability. Figure 6.39 shows the axle sum L/V results.

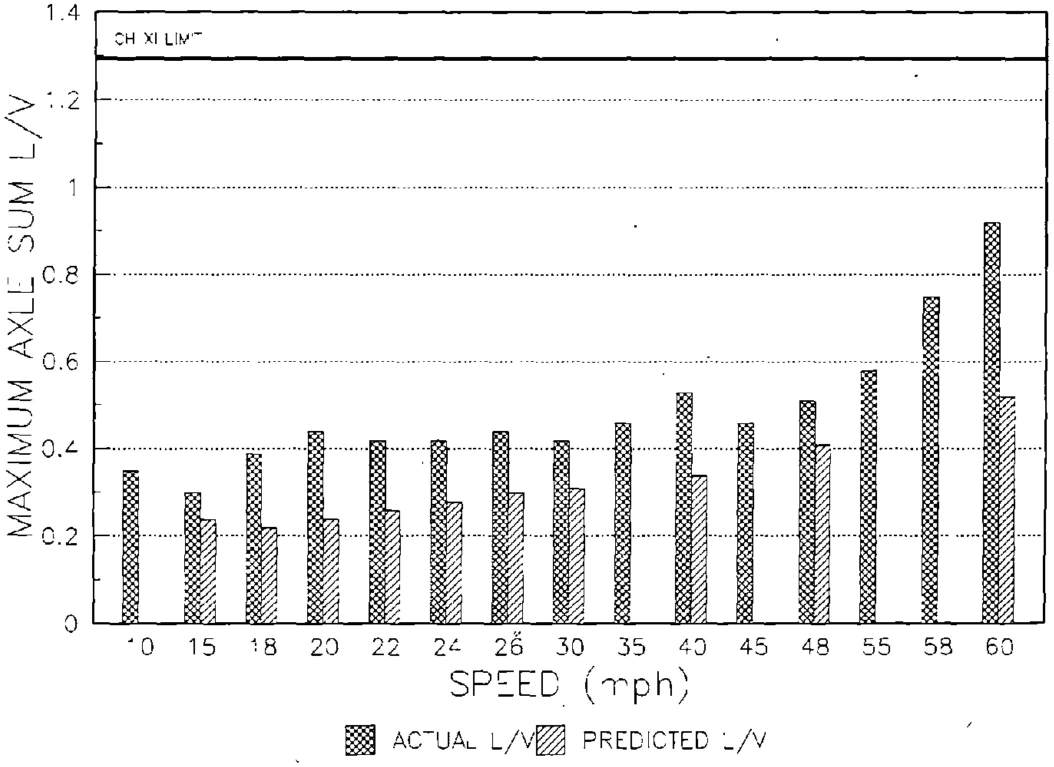


Figure 6.39 Twist and Roll Axle Sum L/V Actual versus Predictions

6.3.6 Dynamic Curving Results

The Dynamic Curve Test was conducted on the 10-degree curve of the WRM track. The 10-degree curve is shimmed similar to the twist and roll zone to provide a maximum cross level perturbation of 0.5 inch combined with lateral perturbations giving a maximum gage of 57.5 inches and a minimum gage of 56.5 inches (Figure 4.23).

Chapter XI specifies four limiting parameters for dynamic curving: a maximum wheel L/V of 0.8, a maximum axle sum L/V of 1.3, a maximum roll angle of 6 degrees peak-to-peak, and a minimum vertical wheel load of 10 percent for the static vertical wheel load.

The Dynamic Curving Test was performed only in the counterclockwise direction. Testing started at 6 mph and incremented at 2 mph for each test. This low test speed was requested by the Air Force. Normal test speeds would begin at a speed below the lower center roll resonance of the test car (12 mph in this case) and increase in 2 mph increments until a 3 inch overbalance speed is achieved (32 mph in this case). Table 6.21 is a summary of the dynamic curving results. Predictions started at 12 mph. At that speed the axle sum L/V was 1.31. The highest prediction of axle sum L/V is 1.4 at 22 mph.

Table 6.21 Dynamic Curving Results

SPEED (MPH)	MIN. VERT. WHEEL LOAD PERCENT 10% LIMIT	MIN. VERT. WHEEL LOAD PERCENT	ROLL ANGLE DEGREE *P-T-P 6-DEGREE LIMIT	ROLL ANGLE DEGREE *P-T-P	AXLE SUM L/V 1.3 LIMIT	AXLE SUM L/V	WHEEL L/V .8 LIMIT	WHEEL L/V
	Actual	Predicted	Actual	Predicted	Actual	Predicted	Actual	Predicted
6	59	n/a	0.40	n/a	1.11	n/a	0.66	n/a
8	61	n/a	0.44	n/a	1.46	n/a	0.90	n/a
10	not tested	n/a	not tested	n/a	not tested	n/a	not tested	n/a
12	not tested	63	not tested	0.8	not tested	1.31	not tested	n/a
16	not tested	70	not tested	0.6	not tested	1.33	not tested	n/a
18	not tested	70	not tested	0.6	not tested	1.35	not tested	n/a
20	not tested	70	not tested	0.7	not tested	1.37	not tested	n/a
22	not tested	69	not tested	0.8	not tested	1.40	not tested	n/a
24	not tested	68	not tested	0.8	not tested	1.38	not tested	n/a
26	not tested	n/a	not tested	n/a	not tested	n/a	not tested	n/a
28	not tested	n/a	not tested	n/a	not tested	n/a	not tested	n/a
30	not tested	n/a	not tested	n/a	not tested	n/a	not tested	n/a
32	not tested	60	not tested	1.1	not tested	1.36	not tested	n/a

* PEAK-TO-PEAK

Axle 7 from the A-end always yielded the highest single wheel L/V. That was the lead axle on the trailing truck, right side. The right side was the high side of the curve. Axle 7 also yielded the highest axle sum L/V. Figure 6.40 is a time plot of the axle sum L/V showing the duration of the exceedances. Since the Chapter XI criteria was exceeded, testing was suspended by direction from Rockwell and the Air Force.

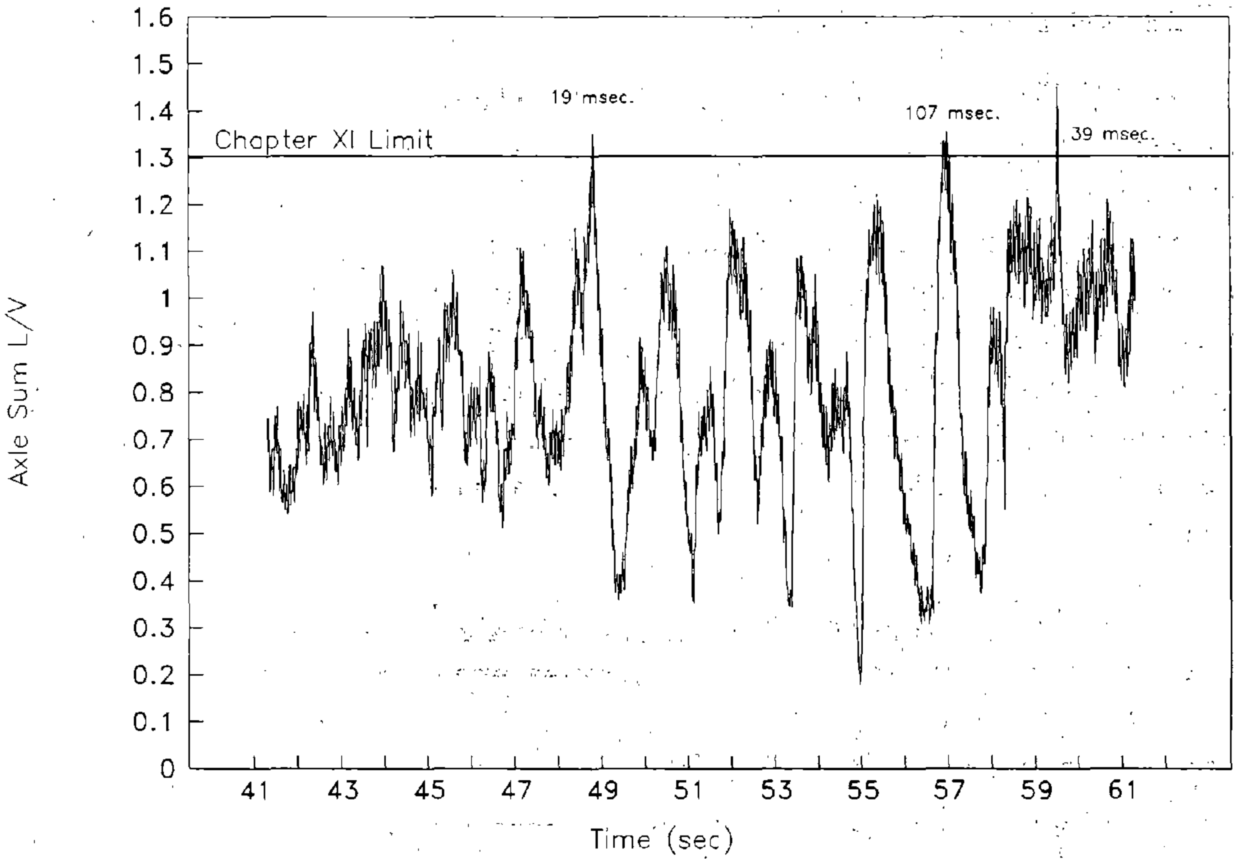


Figure 6.40 Dynamic Curving Axle Sum L/V Time Plot

6.3.7 Turnout and Crossover Results

The Turnout and Crossover Tests were conducted on a No. 8 turnout and a No. 10 crossover. The LCC was tested at the maximum speeds allowed on these switches (15 mph and 20 mph respectively). A turnout is an arrangement of a switch and a frog with closure rails, by which cars may be diverted from one track to another. A crossover is an arrangement of two turnouts with the track between the frogs arranged to allow passage between two nearby and generally parallel tracks. The wheel/rail forces determine if there is a tendency for wheel climb or to induce lateral forces into the track. Since turnout and crossover testing is not listed as an official Chapter XI test, there are no official limiting criteria. Wheel L/V of 0.8 and axle sum L/V of 1.3 were used as guidelines. Table 6.22 summarizes the results.

Table 6.22 Turnout and Crossover Results

TEST	SPEED	MAXIMUM WHEEL L/V .8 LIMIT	MAXIMUM AXLE SUM L/V 1.3 LIMIT
Turnout	10	0.63	1.26
Turnout	15	0.61	0.97
Crossover	10	0.57	0.98
Crossover	15	0.58	0.99
Crossover	20	0.66	1.14

The turnout results were somewhat move severe than the crossover results. All of the results were below Chapter XI limits of 0.8 and 1.3 for wheel L/V's and axle sum L/V's.

6.3.8 Yaw and Sway Results

The Yaw and Sway Test is conducted to determine the ability of the car to negotiate laterally misaligned track, which will excite the car in a yaw and sway motion. Track with perturbations of this type may be found where the underlying ground is unstable and allows the track to shift in the lateral direction. A section of track at the TTC has been shimmed to provide sinusoidal track alignment deviations of 39-foot wavelength and an amplitude of 1.25 inches peak-to-peak on both rails at a constant wide gage of 57.5 inches.

Chapter XI specifies two limiting criteria for yaw and sway testing. The first criteria is a maximum absolute axle sum L/V of 1.3. The second limit is a maximum truck side L/V of 0.6. In order to obtain truck side L/V's, two of the wheel sets were relocated. The leading truck of each span bolster had two instrumented wheel sets. Table 6.23 shows the yaw and sway results versus predictions.

Table 6.23 Yaw and Sway Results

SPEED (MPH)	MAXIMUM AXLE SUM L/V 1.3 LIMIT	MAXIMUM AXLE SUM L/V	MAXIMUM TRUCK SIDE L/V .6 LIMIT	MAXIMUM TRUCK SIDE L/V
	Actual	Predicted	Actual	Predicted
20	0.94	1.18	0.28	0.58
25	1.01	n/a	0.33	n/a
30	1.02	1.36	0.34	0.63
35	1.03	n/a	0.40	n/a
40	1.08	1.42	0.46	0.79
45	1.03	n/a	0.47	n/a
47	0.99	n/a	0.47	n/a
50	0.92	*3.67	0.51	*1.32
52	0.90	n/a	0.58	n/a
55	0.90	n/a	0.55	n/a
60	1.02	*3.12	0.49	*0.83

* Incomplete NUCARS simulation ending in predicted derailment, results intended for comparative purposes only.

All of the results were below both Chapter XI maximum criteria of truck side L/V and axle sum L/V. Figures 6.41 and 6.42 show actual and predicted results compared to the Chapter XI limiting criteria.

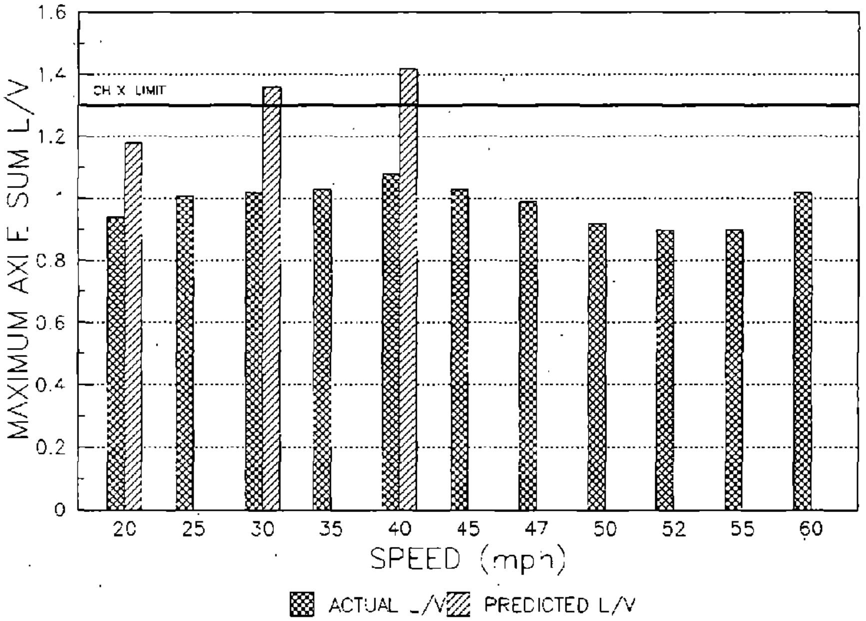


Figure 6.41 Yaw and Sway Axle Sum L/V Results

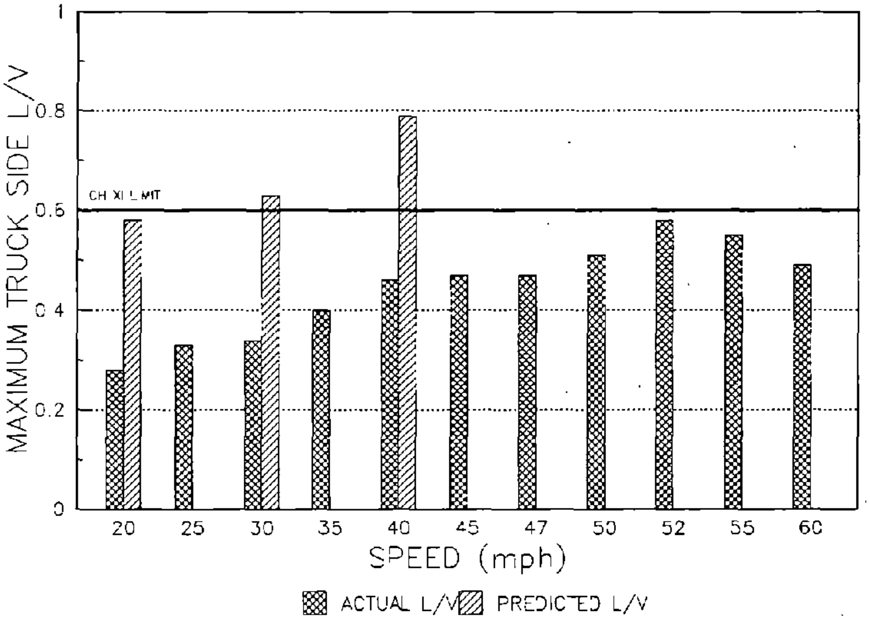


Figure 6.42 Yaw and Sway Truck Side L/V Results

6.3.9 Track Worthiness Results Summary

In Summary for Track Worthiness Testing

--- The LCC becomes unstable at 55 mph.

--- The LCC does not curve well with its present design. High wheel L/V's were encountered on the 12-degree curve. The LCC was not tested at above balance speeds for any curve during the Constant Curving Tests at Air Force direction.

--- The LCC was not tested at speeds above 8 mph for the Dynamic Curving Tests at Air Force direction. Normal test speeds range from 12 mph to 32 mph.

--- The LCC encountered high single wheel L/V's while entering and exiting the 12-degree curve through a bunched spiral. The LCC also encountered high single wheel L/V's while entering the 12-degree curve through a standard spiral. The bunched spiral was only tested at a speed of 16 mph at the direction of the Air Force.

--- The LCC performed satisfactorily in the Pitch and Bounce Test.

--- The LCC performed satisfactorily in the Twist and Roll Test.

--- The LCC negotiated a No. 8 turnout and a No. 10 crossover at their maximum speeds without difficulty.

--- The LCC performed satisfactorily in the Yaw and Sway Test.

6.4 STATIC BRAKE TEST RESULTS

The Static Brake Test preformed on the LCC included a Single Car Test, a Net Shoe Force Test, and a Handbrake Test. The tests were performed with the assistance of Blaine Consulting Services.

6.4.1 Single Car Test

Both sets of ABDW air brake equipment, one on each span bolster, passed the Single Car Test satisfactorily; however, the piston travel on the brakes was long at 3 $^3/_4$ inches when the car arrived at TTC. The distance was shortened to about 3 $^1/_4$ inches. This should have helped in obtaining a 48 psi brake cylinder pressure from a 20 psi brake pipe reduction that is required in the AAR Single Car Test Code booklet, IP No. 5039-4 Sup. 1 (AAR Standard S-486). However, the LCC only obtained a 46 psi brake cylinder pressure with the nominal piston travel of 3 $^1/_4$ inches.

6.4.2 Net Shoe Force Test

Instrumented brake shoes were installed on each truck on each span bolster. Brake shoe force data was obtained with the brake rigging rapped with a 3 lb. Blacksmith hammer, and unrapped. Since the rapped readings are felt to better represent the dynamic car rolling over the railroad conditions, these values should be considered as the test results.

Figure 6.43 shows the shoe forces on each truck for each test. Since one truck was tested at a time, the brake cylinder pressures were not exactly equal. For this reason a linear regression was performed for each truck. The four linear regression equations (also shown in figure 6.43) were summed, yielding a single equation for total car brake force.

Total Car Brake Force = 799 * Brake Cylinder Pressure - 3,678

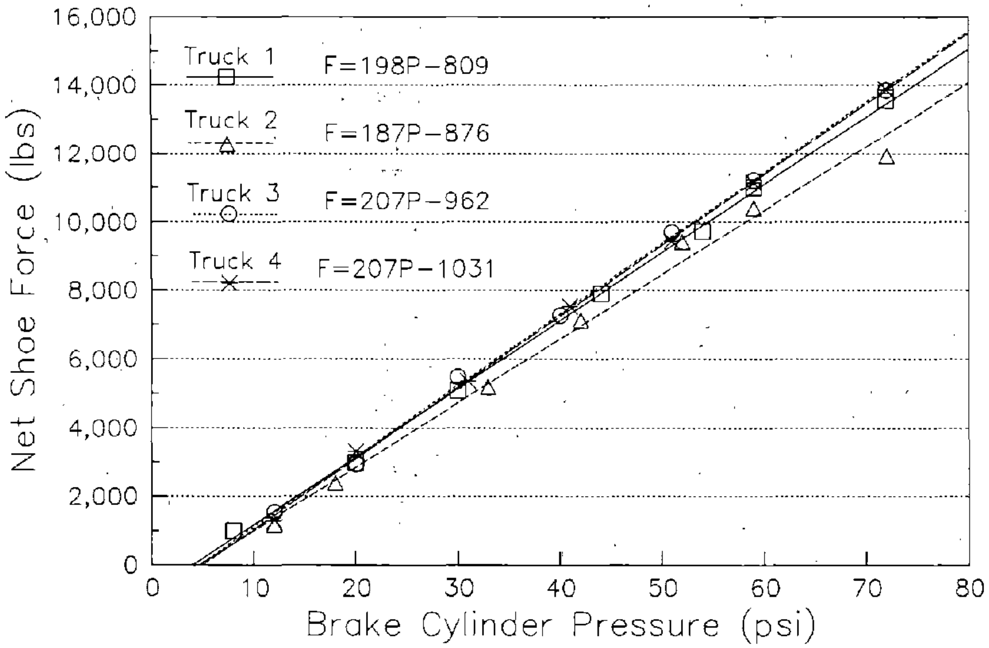


Figure 6.43 Net Shoe Force Test Results

Braking performance is based on brake shoe force and car weight. The net braking ratio, which is car brake force divided by car weight, is the parameter regulated by the AAR. The net braking ratio for the LCC was calculated with the following equation.

Net Braking Ratio = Total Car Brake Force / 392,400

The net braking ratio must be within 6.5 percent minimum and 10 percent maximum at a brake cylinder pressure of 50 psi according to AAR Standard S-486.

Brake cylinder pressure is dependent on the train line pressure and the amount of pressure bleed off (reduction). Since the operational train line pressure could be between 70 and 110 psi, Table 6.24 was developed to show brake ratios for various brake cylinder pressures.

Table 6.24 LCC Net Braking Ratio

Explanation	Brake Cylinder Pressure (psi)	Net Braking Ratio (%)
Full Service Reduction at 70 psi Train Line	50	9.2
Full Service Reduction at 90 psi Train Line	64	12.1
Full Service Reduction at 110 psi Train Line	78	14.9
Emergency at 70 psi Train Line	60	11.3
Emergency at 90 psi Train Line	77	14.7
Emergency at 110 psi Train Line	93	18.0

The brake ratio with a 50 psi brake cylinder pressure was 9.2% which is within the specifications.

6.4.3 Handbrake Net Shoe Force Test

The Handbrake Net Shoe Force Test was also performed. Handbrake chain forces ranging between 2,500 and 6,800 pounds were tested. Practically, a 4,475 pound force can be obtained in the horizontal chain after one sheave wheel with a 125 pound application at the handbrake wheel. The only location to measure the chain force was after a second sheave wheel. It is commonly said that one sheave wheel is about 95% efficient, thus approximately 4,250 pounds would be the chain force after two sheave wheels with 125 pounds applied to the handbrake wheel. Only two of the four trucks were equipped with handbrakes. Results for both trucks were plotted and linear regressions were performed. Figure 6.44 shows plotted points for truck 1 and truck 2 and the linear regression best fit lines and associated equations.

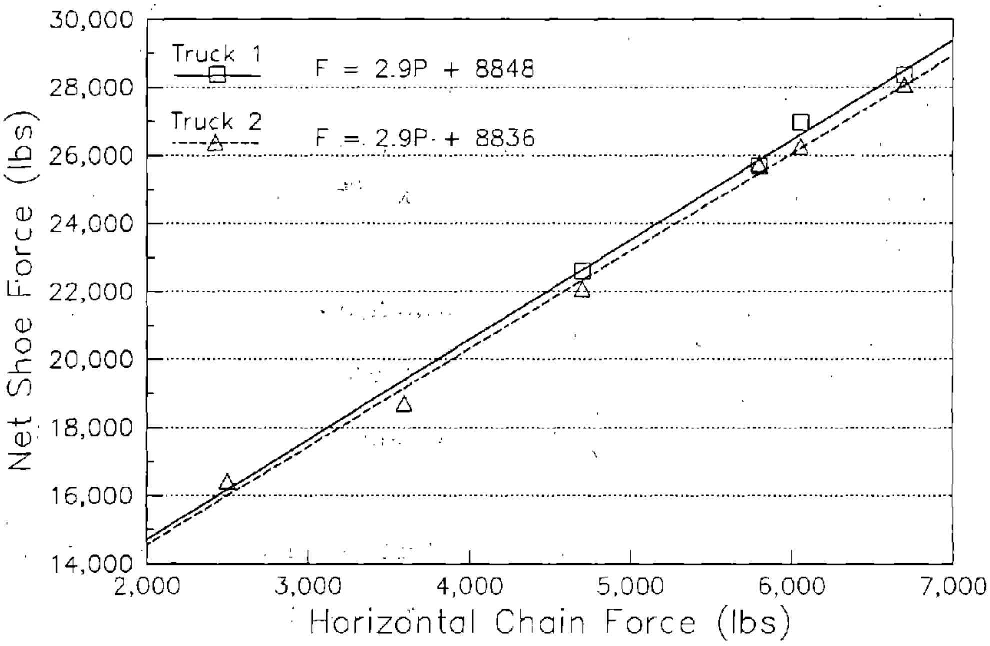


Figure 6.44 Handbrake Test Results

The linear regression equations were summed, yielding a single equation for total handbrake force.

Total Handbrake Force = 5.8 * Horizontal Chain Force + 17,684

A horizontal chain force of 4,250 pounds would have yielded a total handbrake force of 42,334 pounds and a net braking ratio of 10.79%. This value is lower than the AAR minimum of 11%.

7.0 CONCLUSIONS

Quasi-Static Truck Characterization

The Quasi-Static Truck Characterization values obtained from testing fall within those expected for a three piece truck. The following values were used in NUCARS vehicle simulations.

1. The average vertical spring rate with hydraulic snubbers is 26.08 kips/in.
2. The average vertical damping with hydraulic snubbers is 11.61 kips.
3. The average vertical spring rate without hydraulic snubbers is 26.32 kips/in.
4. The average vertical damping without hydraulic snubbers is 8.83 kips.
5. The average lateral spring rate for a truck 24.48 kips/in.
6. The average lateral damping for a truck is 34.40 kips.

Static Truck Characterization

The Static Characterization values obtained from testing fall within those expected for a three piece truck.

1. The span bolster yaw moment was 350,000 ft-lbs.
2. The truck yaw moment was 112,500 ft-lbs.
3. Axle alignment test data showed large misalignments in truck 1 and a small misalignment in truck 2.
4. The longitudinal stiffness was 98.5 kips/inch.
5. Inter-axle shear stiffness results were incomplete.
6. The axle yaw stiffness was 1,200,000 in-kips/mrad.

Modal Response

Resonant speeds were determined for the various car body modes. In addition car body bending frequency's were determined.

1. Pitch and bounce resonant frequencies were found at 7 and 4 Hz respectively. This would equate to a resonant pitch speed of 273 ft/sec or 186 mph and a resonant bounce speed of 156 ft/sec or 106 mph for the pitch and bounce test track.
2. Roll resonance was found at 0.5 Hz. This would equate to a resonance speed of 19.5 ft/sec or 13.3 mph for the Twist and Roll Test.
3. Yaw and upper center roll resonances were found at 6 and 7 Hz respectively. This would equate to a resonant upper center roll speed of 273 ft/sec or 186 mph and a yaw resonant speed of 234 ft/sec or 159.5 mph for the yaw and sway test track.
4. The first vertical bending mode was found at 13.25 Hz.
5. The twist mode was found near 20 Hz.
6. The first lateral bending mode was found at 17 Hz.
7. The Sway frequency was never found.

Service Worthiness

No problems were observed for the LCC in service worthiness testing. The following summarizes the results:

1. The LCC encountered an 843,000 pound coupler force at a 6 mph impact.
2. The LCC received no permanent damage with a 1 million pound compressive force.
3. No wheel lift occurred on the LCC while in a 200,000 pound buff or draft force in a 10-degree curve.

Track Worthiness

Track worthiness testing shows acceptable freight car performance on tangent track at speeds below 55 mph. Some instability was noted above this speed. Curving tests were limited due to Air Force request. Dynamic curving and 12-degree curving were identified as potential problem areas. The test results show:

1. The LCC becomes unstable above 55 mph, although the lateral accelerations are still below the Chapter XI criteria for freight cars.
2. The LCC does not curve well with its present design. High wheel L/V's were occasionally encountered in the 12-degree curve; however, the results were below the Chapter XI 95th percentile limit at under balance speeds. Balance and above balance speeds were never tested.

   The LCC performed satisfactorily on the 7.5-degree and 4-degree curves at speeds up to the balance speed. No curve was tested at above balance speeds because these speeds could not be accomplished without entering the 12-degree curve at a speed higher than desired.
3. The LCC exceeded Chapter XI criteria in the Dynamic Curving Test. The test started at 6 mph by request of the Air Force and axle sum values above 1.3 were obtained at 8 mph. Higher speeds were not tested.
4. The LCC encountered wheel L/V's above 0.8 while entering and exiting the 12-degree curve through a bunched spiral. The LCC also encountered wheel L/V's above 0.8 while entering the 12-degree curve in a standard spiral.
5. The LCC performed satisfactorily in the Pitch and Bounce Test.
6. The LCC performed satisfactorily in the Twist and Roll Test.
7. The LCC negotiated the turnouts and crossovers within the Chapter XI guidelines.
8. The LCC performed satisfactorily in the Yaw and Sway Test.

Static Brake Test

1. The LCC did not obtain an equalization pressure between 48 psi and 52 psi with a 20 pound reduction from a 70 psi brake pipe pressure, and therefore failed to meet the requirements of AAR Standard S-486.
2. The handbrake net braking ratio was 10.79 percent which is lower than the AAR's 11 percent minimum.

8.0 RECOMMENDATIONS

Curving:

1. Curving tests should be completed. Curving tests were not performed at balance and above balance speeds at Air Force direction. Poor performance in the 12-degree curve may indicate potential problems in other curving situations.
2. Post test modeling should be performed to examine car performance in dynamic curving. Possible design changes may be considered and modeled for improvements in performance.

Ride Quality:

1. Ride quality measurements were not taken but high speed stability performance needs closer examination for personal comfort and ride quality reasons.

Braking:

1. The handbrake should be redesigned to give a higher net braking ratio.
2. The air brake system needs closer examination. Equalization pressure of 48 to 52 psi in the brake cylinder was never obtained.

APPENDIX A

CHAPTER XI

From

MANUAL OF STANDARDS
AND
RECOMMENDED PRACTICES

Section C - Part II

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CHAPTER XI
SERVICE-WORTHINESS TESTS AND ANALYSES FOR NEW FREIGHT CARS

Adopted 1987

11.1. PURPOSE AND SCOPE

This chapter presents guidelines for testing and analysis to ascertain the interchange-service worthiness of freight cars. The regimes of vehicle performance to be examined are divided into two sections. Section 1 covers structural static and impact requirements. Section 2 covers vehicle dynamic performance, with the following regimes to be examined: hunting, car body twist and roll, pitch and bounce, yaw and sway and longitudinal train action.

Braking performance, structural fatigue life, car handling, and other design considerations must be considered in accordance with requirements outlined by other chapters of this specification.

The methods presented provide acceptable approaches to the analysis and measurement of car parameters and performance. Other rational methods may be proposed at the time of submission for design approval. Their use and applicability must be agreed to by the Car Construction Committee.

11.2. STATIC AND IMPACT TEST REQUIREMENTS

Application for approval of new and untried types of cars, along with supporting data specified in paragraph 1.2.3, shall be submitted to the Director—Technical Committees Freight Car Construction prior to initiation of official AAR testing. A proposed testing schedule and testing procedures will be submitted sufficiently in advance of tests to permit review and approval of the proposal and assignment of personnel to witness tests as AAR observers. Tests will be in conformity with the following and all costs are to be borne by the applicant, including observers.

11.2.1. TEST CONDITIONS

11.2.1.1.

A car of the configuration proposed for interchange service must be utilized for all tests. Deviation from such configuration is only permitted with the explicit permission of the Car Construction Committee.

During impact tests, the test car will be the striking car and shall be loaded to AAR maximum gross rail load for the number and size of axles used under car (see 2.1.5.17). Exceptions to this procedure will be considered by the Car Construction Committee when justified by the applicant.

Cars designed for bulk loading shall have a minimum of 85% of the total volume filled.

Cars designed for general service, other than bulk loading, shall be loaded so that the combined center of gravity of car and loading is as close as practicable to the center of gravity computed in accordance with the requirements of 2.1.3, except that general service flat cars may be loaded by any practicable method. The loads shall be rigidly braced where necessary, and various types of loads should be used to test each component to its maximum load.

The test car may be equipped with any AAR-approved draft gear or any AAR-approved cushioning device for which the car was designed.

11.2.1.2.

The cars, other than the test car, shall be of seventy ton nominal capacity, loaded to the allowable gross weight on rails prescribed in 2.1.5.17. A high density granular material should be used to load cars to provide a low center of gravity, and the load should be well braced to prevent shifting. Such cars shall be equipped with draft gears meeting the requirements of AAR Specification M-901, except at the struck end where M-901E rubber friction gear shall be used.

Free slack between cars is to be removed, draft gears are not to be compressed. No restraint other than handbrake on the last car is to be used.

11.2.2. INSTRUMENTATION

The coupler force shall be measured by means of a transducer complying with AAR Specification M-901F, or other approved means. Instrumentation used for recording of other data shall be generally acceptable type properly calibrated and certified as to accuracy.

Speed at impact shall be recorded.

11.2.3. STATIC TESTS

11.2.3.1. COMPRESSIVE END LOAD

A horizontal compressive static load of 1,000,000 lbs, shall be applied at the centerline of draft to the draft system of car/unit structure interface areas, and sustained for a minimum 60 seconds. The car/unit structure tested shall simulate an axially loaded beam having rotation free-translation fixed end restraints. (See Figure 11.2.3.1).

No other restraints, except those provided by the suspension system in its normal running condition, are permissible. Multi-unit car must have each structurally different unit subjected to such test, also two empty units joined together by their connector shall undergo this test to verify the connectors compressive adequacy and its anti-jackknifing properties.

The test is to be performed with the car subjected to the most adverse stress or stability conditions (empty and/or loaded).

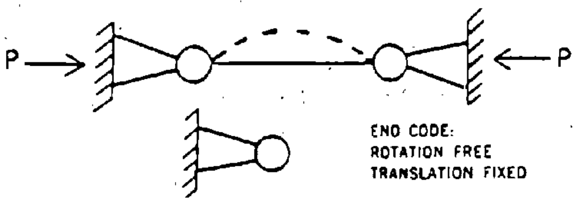

Figure 11.2.3.1

11.2.3.2. COUPLER VERTICAL LOADS

A vertical upward load shall be applied to the coupler shank immediately adjacent to the striker face or to the face of the cushion unit body at one end of the car, sufficient in magnitude to lift the fully loaded car free of the truck nearest the applied load, and held for sixty seconds. Cushion underframe cars having sliding sill are excluded from the requirements of this paragraph.

For cushion underframe cars having sliding sills, a vertical upward load shall be applied to the sliding sill in a plane as near the ends of the fixed center sills as practicable, sufficient in magnitude to lift the fully loaded car free of the truck nearest the applied load, and held for sixty seconds.

For all cars, a load of 50,000 pounds shall be applied in both directions to the coupler head as near to the pulling face as practicable and held for sixty seconds.

11.2.3.3. CURVE STABILITY

The test consist is to undergo a squeeze and draft load of 200,000 lbs. without car body-suspension separation or wheel lift. Load application shall simulate a static load condition and shall be of minimum 20 seconds sustained duration.

Cars consisting of more than two units shall be tested with a minimum of three units in the test consist. The number of units used shall generate maximum load in the critical L/V location of the car.

For the purpose of this test, wheel lift is defined as a separation of wheel and rail exceeding ⅛" when measured 2⅝" from the rim face at the inside of curve for buff and outside for draft.

Empty car shall be subjected to squeeze and draft load on a curve of not less than 10 degrees. The curve is to have ½" maximum superelevation. The test car is to be coupled to a "base car" as defined in paragraph 2.1.6.1. or a like car which ever is most severe and a "long car" having 90′ over strikers, 66′ truck centers, 60" couplers and conventional draft gear.

The test consist shall have means for measuring and recording coupler forces.

11.2.3.4. RETARDER AND "HOT BOX" DETECTION

Cars with other than conventional 3 piece trucks must be operated while fully-loaded over a hump and through a retarder. Retarder shall be operated to determine capability to brake the test cars. Such cars must also demonstrate their compatibility with hot box detection systems or be equipped with on-board hot box detection systems.

11.2.3.5. JACKING

Vertical load capable of lifting a fully loaded car/unit shall be applied at designated jacking locations sufficient to lift the unit and permit removal of truck or suspension arrangement nearest to the load application points.

11.2.3.6. TWIST LOAD

Loaded car/unit shall be supported on the side bearings or equivalent load points only. Diagonally opposite bearing or load point support shall be lowered through a distance resulting from a calculated 3" downward movement of one wheel of the truck or suspension system supporting it. No permanent deformation of car/unit structure shall be produced by this test.

11.2.4. IMPACT TESTS

These requirements apply to all cars except those exempted by other specification requirements.

11.2.4.1. SINGLE CAR IMPACT

The loaded car shall be impacted into a string of standing cars consisting of three nominal 70-ton capacity cars, loaded to maximum gross weight on rails as described in paragraph 2.1.5.17. with sand or other granular material, equipped with M-901E rubber-friction draft gear at the struck end and with the hand brake on the last car on the non-struck end of the string tightly set. Free slack between cars is to be removed; however, draft gears are not to be compressed. No restraint other than handbrake on the last car is to be used.

A series of impacts shall be made on tangent track by the striking car at increments of two miles per hour starting at six miles per hour until a coupler force of 1,250,000 pounds or a speed of fourteen miles per hour has been reached, whichever occurs first.

A car consisting of two or more units must also undergo impact testing as outlined above with the leading unit of the test car being empty for a two-unit car, or with the first two units being empty for a three (or more) unit car. No carbody-suspension disengagement or wheel lift is permitted during the partially loaded impact tests.

11.2.4.2. DYNAMIC SQUEEZE

(Optional–May be performed in lieu of or in addition to static end compression test if requested by the Car Construction Committee.)

The striking and standing car groups shall each consist of six cars, in which the test car may be the lead car in either group. All cars except the test car shall be as prescribed in 11.2.1.2. The brakes shall be set on all standing cars after all slack between cars has been eliminated. There shall be no precompression of the draft gears. The standing cars shall be on level tangent track. The striking cars, coupled together, shall be adjusted, if necessary, to restore the original conditions.

A series of impacts shall be made at increments of two miles per hour starting at six miles per hour until a coupler force of 1,250,000 pounds or a speed of fourteen miles per hour has been reached, whichever occurs first.

11.2.5. INSPECTION

A visual inspection of the test car shall be made after each static test and after each impact. Following the impact tests, the car shall be unloaded and inspected.

Any permanent damage to any major structural part of the car, found before or after all tests are completed, will be sufficient cause for disapproval of the design. Damage will be considered permanent when the car requires shopping for repairs.

11.3. TRACK-WORTHINESS ASSESSMENT

11.3.1. METHODOLOGY

Regimes are identified, representative of the performance of the car in service. Tests are defined for each regime. The results of the tests are an indication of the car's track-worthiness. In most regimes, analytic methods are also available to permit prediction to be made of the performance of the car, to the degree of accuracy required.

The characteristic properties of the car body and its suspension, required for the analysis, shall be supported by evidence of their validity. Characterization tests, such as those defined in Appendix A, are required to verify the values used in the analyses.

11.3.2. TRACK-WORTHINESS CRITERIA

The criteria applied to the analyses and tests are chosen from a consideration of the processes by which cars deviate from normal and required guidance. They are also subject to the requirement of observability in tests. Typical of these are lateral and vertical forces, the lateral over vertical force (L/V) ratios, dynamic displacements, and accelerations of the masses. These criteria are based on considerations of the processes of wheel climb, rail and track shift, wheel lift, coupler and component separation and structural integrity.

The values chosen for the criteria selected have been used in tests on cars presently in service. Those included in the body of this chapter are shown in Table 11.1. Values worse than these are regarded as having a high risk of unsafe behavior. Values better than these are regarded as indicating the likelihood of safe car performance.

Table 11.1 Criteria for Assessing the Requirements for Field Service

Regime	Section	Criterion	Limiting Value
Hunting (empty)	11.5.2	minimum critical speed (mph)	70
		maximum lateral acceleration (g)	1.0
		maximum sum L/V axle	1.3*
Constant curving (empty and loaded)	11.5.3	95th percentile maximum wheel L/V	0.8
		or	
		95th percentile maximum sum L/V axle	1.3
Spiral (empty and loaded)	11.5.4	minimum vertical load (%)	10 **
		maximum wheel L/V	0.8*
Twist, Roll (empty and loaded)	11.6.2	maximum roll (deg)***	6
		maximum sum L/V axle	1.3
		minimum vertical load (%)	10 **
Pitch, Bounce (loaded)	11.6.3	minimum vertical load (%)	10 **
Yaw, Sway (loaded)	11.6.4	maximum L/V truck side	0.6*
		maximum sum L/V axle	1.3*
Dynamic curving (loaded)	11.6.5	maximum wheel L/V	0.8*
		or	
		maximum sum L/V axle	1.3*
		maximum roll (deg) **	6
		minimum vertical load (%)	10 **
Vertical curve	11.7.2	to be added****	
Horizontal curve	11.7.3	to be added****	

* Not to exceed indicated value for a period greater than 50 milliseconds per exceedence

** Not to fall below indicated value for a period greater than 50 milliseconds per exceedence

*** Peak-to-peak

**** See the introduction to section 11.7.1

11.4. GLOSSARY OF TERMS

Radial misalignment of axles in a truck or car is the difference in yaw angle in their loaded but otherwise unforced condition. It causes a preference to curving in a given direction.

Lateral misalignment is the difference in lateral position between axles. It causes both axles to be yawed in the same direction on straight track.

Inter-axle shear stiffness, equivalent to the lozenge or tramming stiffness in 3-piece trucks, is the stiffness between axles in a truck or car found by shearing the axles in opposite directions along their axes, and measuring the lateral deflection between them.

Inter-axle bending stiffness is the stiffness in yaw between axles in a truck or car.

Bounce is the simple vertical oscillation of the body on its suspensions in which the car body remains horizontal.

Pitch of the body is the rotation about its transverse axis through the mass center.

Body yaw is the rotation of the body about a vertical axis through the mass center.

Body roll is the rotation about a longitudinal axis through the mass center.

Upper and lower center roll are the coupled lateral motion and roll of the body center of mass. They combine to give an instantaneous center of rotation above or below the center of mass. When below the center of mass, the motion is called lower center roll. When above, the motion is called upper center roll.

Sway is the coupled body mode in roll and yaw and it occurs where the loading is not symmetrical.

Unbalance is used in this chapter to mean the additional height in inches, which if added to the outer rail in a curve, at the designated car speed, would provide a single resultant force, due to the combined effects of weight and centrifugal force on the car, having a direction perpendicular to the plane of the track. Thus, the unbalance (U) is defined as:

$$\text{Unbalance } U = \frac{V^2 D}{1480} - H$$

where,
D is the degree of the curve.
V is the vehicle speed in mph.
H is the height, in inches, of the outer rail over the inner rail in the curve.

Effective conicity, E, of a wheel on a rail is its apparent cone angle used in the calculation of the path of the wheel on the rail. It is defined as:

$$E = A\left(\frac{R_w}{R_w - R_R}\right)$$

where,
A is the angle of the contact plane, between the wheel and rail, to the plane of the track.
R_w is the transverse profile radius of the wheel.
R_R is the transverse profile radius of the rail.

The effective conicity of the modified Heumann wheel of Figure 8.1 on AREA 132 lb rail, under conditions of tight gage, is between 0.1 and 0.3.

Three ratios of lateral (L) to vertical (V) forces are used as criteria in the assessment of car performance. These are:

(1) **The individual wheel L/V, (or wheel L/V).** This is defined as the ratio of the lateral force to the vertical force between the wheel and rail on any individual wheel. It is used to assess the proximity of the wheel to climbing the rail.

(2) **The instantaneous sum of the absolute wheel L/V's on an axle, (or sum L/V axle).** This is defined as the sum of the absolute values of the individual wheel L/V's on the same axle, as given in the following algebraic equation. They must be measured at the same time.

$$\text{Sum L/V axle} = \left| \text{L/V (left whl)} \right| + \left| \text{L/V (right whl)} \right|$$

It is used to assess the proximity of the wheel to climbing the rail and is more appropriate where the angle of attack of the flanging wheel to the rail does not result in full slippage at the area of contact.

(3) **The truck side L/V, (or L/V truck side).** This is defined as the total sum of the lateral forces between the wheels and rails on one side of a truck divided by the total sum of the vertical forces on the same wheels of the truck, as given in the following algebraic expression.

$$\text{Truck side L/V} = \frac{\Sigma \text{L (truck side)}}{\Sigma \text{V (truck side)}}$$

It is used to indicate the proximity to moving the rail laterally.

11.5. SINGLE CAR ON UNPERTURBED TRACK

11.5.1. GENERAL

The regimes described in this section are chosen to test the track-worthiness of the car running on premium track. They are required to establish the safety of the car from derailment under conditions basic to its performance in service and are carried out under operating conditions similar to those found in normal service, but without the effects of dynamic variations due to adjacent cars or large perturbations associated with poor track.

The parameters used in the analysis shall be confirmed in characterization tests described in Appendix A. The results of the following analyses and tests shall be included for the consideration of approval by the Car Construction Committee.

11.5.2. LATERAL STABILITY ON TANGENT TRACK (HUNTING)

This requirement is designed to ensure the absence of hunting, which can result from the transfer of energy from forward motion into a sustained lateral oscillation of the axle between the wheel flanges, in certain car and suspension designs. The analyses and tests are required to show that the resulting forces between the wheel and rail remain within the bounds necessary to provide an adequate margin of safety from any tendency to derail.

11.5.2.1. PREDICTIONS AND ANALYSES

An analysis shall be made of the critical speed at which continuous full flange contact is predicted to commence, using a validated mathematical model and the parameters measured for the empty test car. This analysis shall include predictions on tangent and on 1/2 and 1 degree curves.

The analytic requirement is that no hunting be predicted for the empty car below 70 miles per hour assuming a coefficient of friction of 0.5 and an effective conicity of 0.15, for the modified Heumann wheel profile given in Figure 8.1 of Chapter VIII, on new AREA 136 lb. rail, for axle lateral displacements up to +/− 0.2 in. on track with standard gauge.

11.5.2.2. TEST PROCEDURE AND CONDITIONS

The empty test car shall be placed at the end of the test consist, behind a stable buffer car, and operated at speeds up to 70 miles per hour on tangent class 5 or better track, with dry rail.

All axles of the lead unit or car shall be equipped with modified Heumann profile wheels as shown in Figure 8.1 of Chapter VIII, with the machining grooves worn smooth on the tread.

The rail profile shall be new AREA 136 lb. or an equivalent which, with the Heumann wheel specified, gives an effective conicity of at least 0.15 for lateral axle displacements of +/− 0.2 inch from the track center. The track gage may be adjusted in order to achieve this minimum effective conicity. If hunting is predicted for curved track in section 11.5.2.1, a special hunting test in shallow curves may be requested.

11.5.2.3. INSTRUMENTATION AND CRITERIA

The leading axle of both trucks on an end unit or car, or each axle on an end unit or car with single-axle trucks, shall be equipped with instrumented wheelsets, and each truck location on the end unit or car shall be equipped with a lateral accelerometer on the deck above the center of the truck.

Sustained truck hunting shall be defined as a sustained lateral acceleration greater than 1 g peak-to-peak for at least 20 consecutive seconds. No occurrences of greater than 1.5 g peak-to-peak are permitted within the same time period. The instantaneous sum of the absolute values of the L/V ratios shall not exceed 1.3 on any instrumented axle. Components of the measured accelerations and forces having frequencies above 15 hertz are to be filtered out.

The car shall not experience sustained truck hunting during the test. A record of maximum lateral acceleration and the wheel L/V's on the same axle, against speed, at the worst location, shall be submitted as required test data.

11.5.3. OPERATION IN CONSTANT CURVES

This requirement is designed to ensure the satisfactory negotiation of track curves. The analyses and tests are required to show that the resulting forces between the wheel and rail are safe from any tendency to derail and to confirm other predictions of the car behavior relating to the guidance of the car and absence of interferences.

11.5.3.1. PREDICTIONS AND ANALYSES

An analysis shall be made of the wheel forces and axle lateral displacements and yaw angles on a single car, empty and fully loaded, using a validated mathematical model. The model shall include a fundamental representation of the rolling contact forces using the geometry of the profiles of the wheel and rail, and car parameters from the measurements described in Appendix A.

Either the individual wheel L/V shall be less than 0.8 on all wheels measured, or the instantaneous sum of the absolute wheel L/Vs on any axle shall be less than 1.3, for any curve up to 15 degrees. The range of unbalance assumed shall be −3 inches to +3 inches, with a coefficient of friction of 0.5 and modified Heumann profiled wheels on new AREA 132 lb. or 136 lb. rail.

11.5.3.2. TEST PROCEDURE AND CONDITIONS

The test car shall be operated at constant speeds equivalent to unbalances of −3, 0, and +3 inches. The tests shall be run with the test car in both empty and fully loaded conditions, between two heavy buffer cars, one of which may be replaced by an instrumentation car. A complete set of tests shall be carried out in both directions and with the test consist turned in each direction, on dry rail.

The wheels of the test car shall have less than 5000 miles wear on the new profiles specified for production, except that those on instrumented wheelsets shall have modified Heumann profiles. The rail profiles shall have a width at the top of the head not less than 95 percent of the original value when new. The test curve shall be of not less than 7 degrees with a balance speed of 20 to 30 mph, and with class 5 or better track.

11.5.3.3. INSTRUMENTATION AND CRITERIA

The leading axle of both trucks on an end unit or car, or each axle on an end unit or car with single-axle trucks, shall be equipped with instrumented wheelsets. The lateral and vertical forces and their ratio, L/V, shall be measured for the length of the body of the curve, which must be at least 500 ft., and their maxima and means computed. Measured force components having frequencies above 15 hertz are to be filtered out.

Either the individual wheel L/V shall be less than 0.8 on all wheels measured, or the instantaneous sum of the absolute wheel L/Vs on any axle shall be less than 1.3. A record of L/V on both wheels of the instrumented axles, for each test run, shall be submitted as required test data.

11.5.4. SPIRAL NEGOTIATION AND WHEEL UNLOADING

This requirement is designed to ensure the satisfactory negotiation of spirals leading into and away from curves. The analyses and tests are required to show that the resulting forces between the wheel and rail show an adequate margin of safety from any tendency to derail, especially under reduced wheel loading, and to confirm other predictions of the car behavior.

11.5.4.1. PREDICTIONS AND ANALYSES

An analysis shall be carried out of the lateral and vertical wheel forces on a single car, with the car loaded asymmetrically, consistent with AAR loading rules, to give maximum wheel unloading.

The analysis shall be made for a speed equivalent to a mean unbalance at the car center of −3 inches to +3 inches with a coefficient of friction of 0.5 and modified Heumann wheel and new AREA 132 lb. or 136 lb. rail profiles.

The predicted lateral-to-vertical force ratio shall not exceed 0.8, and no vertical wheel load shall be less than 10 percent of its static value, in a bunched spiral, with a change in superelevation of 1 inch in every 20 ft. leading into a curve of at least 7 degrees and a minimum of 3 inches superelevation.

11.5.4.2. TEST PROCEDURE AND CONDITIONS

This test may be carried out concurrently with the previous test, paragraph 11.5.3.2. The test car shall be operated, empty and fully loaded, between two heavy buffer cars, one of which may be an instrumentation car, at constant speeds equivalent to an unbalance of −3, 0, and +3 inches at the maximum curvature.

The wheels of the test car shall have less than 5000 miles wear on the new profiles specified for production, except that those on instrumented wheelsets shall have modified Heumann profiles. The rail profiles shall have a width at the top of the head not less than 95 percent of the original value when new.

The maximum curvature shall be not less than 7 degrees, with a minimum of 3 inches superelevation. A bunched spiral, with a change in superelevation of not less than 1 inch in every 20 ft., is required. The track shall be class 5 or better and dry. Tests shall be run in both directions and with the consist turned.

11.5.4.3. INSTRUMENTATION AND CRITERIA

The leading axle on both trucks on an end unit or car, or each axle on an end unit or car with single-axle trucks, shall be equipped with instrumented wheelsets.

The lateral and vertical forces and their ratio, L/V, shall be measured continuously through the bunched spiral, in both directions, and their maxima and minima computed. Measured force components having frequencies above 15 hertz are to be filtered out.

The maximum L/V ratio on any wheel shall not exceed 0.8, and the vertical wheel load shall not be less than 10 percent of the measured static value. A record of L/V's and vertical forces on both wheels of the two worst axles in a car, and car body roll angle, for each test, shall be submitted as required test data.

11.6. SINGLE CAR ON PERTURBED TRACK

11.6.1. GENERAL

The analyses and tests described in this section are designed to establish the trackworthiness of the car under conditions associated with variations in the track geometry. They include the dynamic response due to perturbations in the track but exclude the dynamic effects due to coupling with adjacent cars.

The investigations are designed to demonstrate that the car design provides an adequate margin of safety from structural damage and from any tendency to derail.

The tests shall be completed and their results found satisfactory by the AAR observers. The results identified shall be added as required data for the consideration of the Car Construction Committee.

11.6.2. RESPONSE TO VARYING CROSS-LEVEL (TWIST AND ROLL)

This requirement is designed to ensure the satisfactory negotiation of oscillatory cross-level excitation of cars, such as occurs on staggered jointed rail, which may lead to large car roll and twist amplitudes. The analyses and tests are required to show that the resulting forces between the wheel and rail show an adequate margin of safety from any tendency to derail.

11.6.2.1. PREDICTIONS AND ANALYSES

A review shall be made of any tests and analyses for the natural frequency and damping of the car body, in the roll and twist modes, in the empty and fully loaded conditions, and an estimate made of the speed of the car at each resonance.

The maximum amplitude of the carbody in roll and twist, the maximum instantaneous sum of the absolute values of the wheel L/V ratios on any axle, the minimum vertical wheel load, and the number of cycles to reach them, shall be predicted at resonant speed of 70 mph or below, on tangent track, with staggered jointed rails of 39 ft. length, and a maximum cross-level at the joints of 0.75 in. as shown in Fig. 11.1.

The instantaneous sum of the absolute values of the wheel L/V ratios on any axle shall be less than 1.3, the predicted roll angle of the carbody shall not exceed 6 degrees peak-to-peak, and the vertical wheel load shall not be less than 10 percent of its static value, within 10 rail lengths of the start, at any speed at or below 70 mph.

11.6.2.2. TEST PROCEDURE AND CONDITIONS

The test car shall be between two cars chosen for their stable performance. Tests shall be carried out with the test car empty and fully loaded.

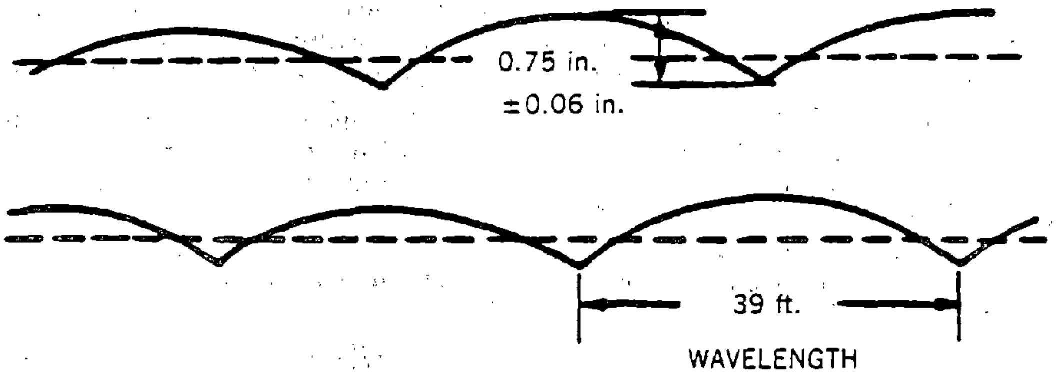

Figure 11.1.

TRACK CROSS LEVEL FOR THE TWIST AND ROLL TEST

The test shall be on tangent track with staggered 39 ft. rails on good ties and ballast, shimmed to a cross level of 0.75 in., low at each joint as shown in Fig. 11.1, over a test zone length of 400 ft., but otherwise held to class 5 or better.

The test shall be carried out at constant speed, increasing in 2 mph steps from well below any predicted resonance until it is passed, or approaching it from a speed above that expected to give a resonant condition. The test shall be stopped if an unsafe condition is encountered or if the maximum of 70 mph is reached. It shall be regarded as unsafe if a wheel lifts or if the car body roll angle exceeds 6 degrees, peak-to-peak.

11.6.2.3. INSTRUMENTATION AND CRITERIA

The leading axle of both trucks on an end unit or car, or each axle on an end unit or car with single-axle trucks, shall be equipped with instrumented wheelsets. The car body roll angle shall also be measured at a minimum of each end of an end unit.

The wheel forces, the mean roll angle and difference in roll between ends for each unit, shall be measured continuously through the test zone. Measured force components having frequencies above 15 hertz are to be filtered out.

The sum of the absolute values of wheel L/V on any instrumented axle shall not exceed 1.3, the roll angle of the carbody of any unit shall not exceed 6 degrees peak-to-peak and the vertical wheel load shall not be less than 10 percent of its static value at any speed tested.

A record of the vertical loads measured at the axle with the lowest measured vertical load, and the roll angles measured at each end of the most active unit of the car, taken at the resonant speeds for each car load, shall be submitted as required test data.

11.6.3. RESPONSE TO SURFACE VARIATION (PITCH AND BOUNCE)

This requirement is designed to ensure the satisfactory negotiation of the car over track which provides a continuous or transient excitation in pitch and bounce, and in particular the negotiation of grade crossings and bridges, where changes in vertical track stiffness may lead to sudden changes in the loaded track profile beyond those measured during inspection. The analyses and tests are required to show that the resulting forces between the wheel and rail show an adequate margin of safety from any tendency for the car to derail, to uncouple, or to show interference either between subsystems of the car or between the car components and track.

11.6.3.1. PREDICTIONS AND ANALYSES

A review shall be made of any tests and analyses for the natural frequency and damping of the car body, fully loaded, in the modes of pitch and bounce, and an estimate made of the resonant speed of the car when excited by a track wavelength of 39 feet.

The vertical wheel load shall be predicted at these speeds or at 70 mph, whichever is greater, for a continuous near sinusoidal excitation with a vertical amplitude to the track surface of 0.75 inches peak-to-peak and a single symmetric vertical bump in both rails, of the shape and amplitude shown in Fig. 11.2, predicted vertical wheel load shall not be less than 10 percent of its static value at any resonant speed at or below 70 mph, within 10 rail lengths of the start of the continuous sinusoid or following the single bump.

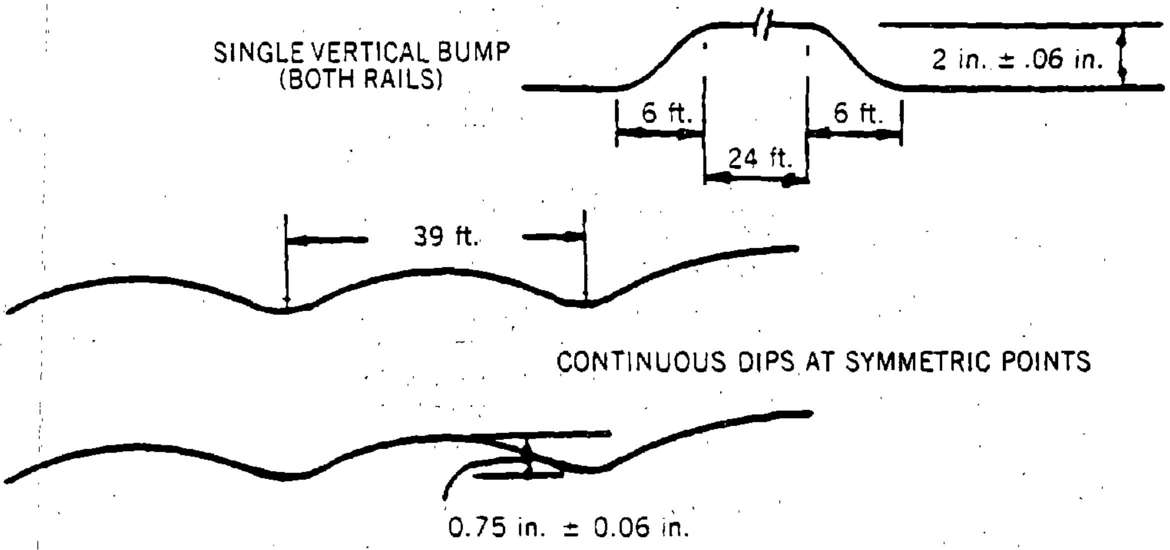

Figure 11.2.

TRACK SURFACE VARIATION FOR PITCH AND BOUNCE

11.6.3.2. TEST PROCEDURE AND CONDITIONS

The fully loaded test car shall be tested between two light cars that have at least 45 ft. truck center spacing.

Tests shall be carried out on tangent track with surface deviations providing a continuous, near sinusoidal, excitation with a vertical amplitude to the track surface of 0.75 inches peak-to-peak and a single symmetric vertical bump in both rails of the shape and amplitude shown in Fig. 11.2. These tests may be carried out separately, or together, with a separation of at least 100 feet. The track shall otherwise be held to class 5 or better.

Testing shall start at constant speed well below any predicted resonant speed, increasing in 5 mph steps until an unsafe condition is encountered, the resonance is passed, or the maximum of 70 mph is reached. The speed at which resonance is expected may be approached from a higher speed, using steps to decrease the speed. It shall be regarded as unsafe if any wheel lifts.

11.6.3.3. INSTRUMENTATION AND CRITERIA

The leading axle on both trucks on an end unit or car, or each axle on an end unit or car with single-axle trucks, shall be equipped with instrumented wheelsets. The vertical wheel forces shall be measured continuously through the test zone. Measured force components having frequencies above 15 hertz are to be filtered out.

The vertical wheel load shall not be less than 10 percent of its static value on any wheel at any speed tested. A record of the vertical loads measured on the axle with the lowest vertical load shall be submitted as required test data.

11.6.4. RESPONSE TO ALIGNMENT VARIATION ON TANGENT TRACK (YAW AND SWAY)

This requirement is designed to ensure the satisfactory negotiation of the car over track with misalignments which provide excitation in yaw and sway. The analyses and tests are required to show that the resulting forces between the wheel and rail show an adequate margin of safety from any tendency for the car forces to move the track or rail or to give interference either between subsystems of the car or between the car components and track.

11.6.4.1. PREDICTIONS AND ANALYSES

A review shall be made of the previous tests and analyses for the natural frequency and damping of the car body, fully loaded, in the yaw and roll modes. These may combine in a natural motion referred to as sway, which, if present, must be included in this analysis. Using the values for frequency and damping identified, an estimate shall be made of the resonant speed of the car, in each mode.

The car shall be assumed to be excited by a symmetric, sinusoidal track alignment deviation of wavelength 39 feet, on tangent track. The ratio of the sum of the lateral to that of the vertical forces on all wheels on one side of any truck shall be predicted at resonance or at 70 mph, whichever is greater, for a sinusoidal double amplitude of 1.25 inches peak-to-peak on both rails and a constant wide gage of 57.5 inches, as shown in Fig. 11.3.

The predicted truck side L/V shall not exceed 0.6, and the sum of the absolute values of L/V on any axle shall not exceed 1.3, at any speed at or below 70 mph, within 5 rail wavelengths of the start.

11.6.4.2. TEST PROCEDURE AND CONDITIONS

The fully loaded test car shall be placed at the end of the test consist, behind a buffer car of at least 45 feet truck center spacing, chosen for its stable performance.

Tests shall be carried out on dry tangent track, with symmetric, sinusoidal alignment deviations of wave length 39 feet, alignment amplitude 1.25 inches peak-to-peak and a constant wide gage of 57.5 inches, over a test zone of 200 feet as shown in Fig. 11.3. The track shall otherwise be held to class 5 or better.

The wheels of the test car shall have less than 5000 miles wear on the new profiles specified for production, except that those on instrumented wheelsets shall have modified Heumann profiles. The rail profiles shall have a width at the top of the head not less than 95 percent of the original value when new.

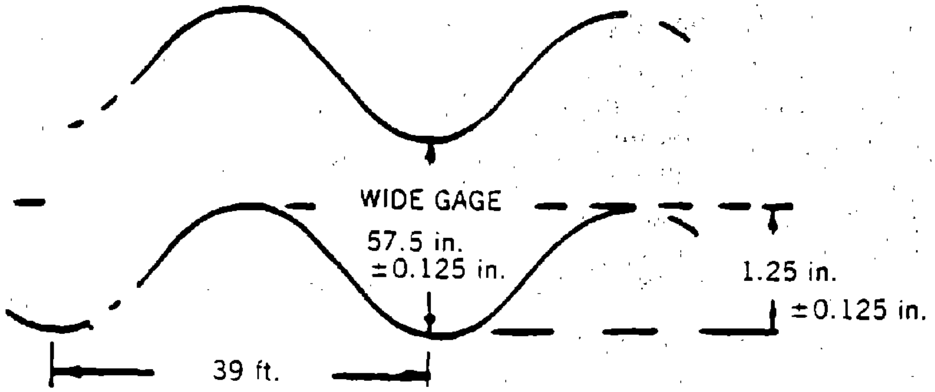

Figure 11.3.

TRACK ALIGNMENT VARIATIONS FOR YAW AND SWAY

Testing shall start at constant speed well below any predicted resonant speed, increasing in 5 mph steps until an unsafe condition is encountered, the resonance is passed, or the maximum of 70 mph is reached. It shall be regarded as unsafe if the ratio of total lateral to vertical forces, on any truck side measured, exceeds 0.6 for a duration equivalent to 6 feet of track.

11.6.4.3. INSTRUMENTATION AND CRITERIA

All axles on the truck estimated to provide the worst total truck side L/V, or each axle on an end unit or car with single-axle trucks, shall be equipped with instrumented wheelsets. The wheel forces shall be measured continuously through the test zone. Measured force components having frequencies above 15 hertz are to be filtered out.

The truck side L/V measured shall not exceed 0.6 for a duration equivalent to 6 feet of track, and the sum of the absolute values of L/V on any axle shall not exceed 1.3, at any speed at or below 70 mph. A record of the lateral and vertical loads, measured on the truck with the largest truck side L/V, shall be submitted as required test data.

11.6.5. ALIGNMENT, GAGE AND CROSS-LEVEL VARIATION IN CURVES (DYNAMIC CURVING)

This requirement is designed to ensure the satisfactory negotiation of the car over jointed track with a combination of misalignments at the outer rail joints and crosslevel due to low joints on staggered rails at low speed. The analyses and tests are required to show that the resulting forces between the wheel and rail show an adequate margin of safety from any tendency for the car forces to cause the wheel to climb the rail or to move the track or rail or to give unwanted interference, either between subsystems of the car, or between the car components and track.

11.6.5.1. PREDICTIONS AND ANALYSES

A review shall be made of the previous tests and analyses for the natural frequencies and response of the car body, fully loaded, in the yaw and roll modes.

No analysis is presently available, which can predict the results accurately for this test, for all possible designs. It is therefore necessary to provide additional safety features in the running of the test program to prevent unexpected derailments or unnecessary damage.*

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*Analyses suitable for predictions of new car performance in this test are under development and will be added later.

11.6.5.2. TEST PROCEDURE AND CONDITIONS

The test car shall be operated between two cars that are loaded to provide them with a low center of gravity. If suitable, an instrumentation car may be used as one of these cars.

Tests shall be carried out on dry rail, in a curve of between 10 and 15 degrees with a balance speed of between 15 and 25 mph, with the test car empty and fully loaded.

The wheels of the test car shall have less than 5000 miles wear on the new profiles specified for production, except that those on instrumented wheelsets shall have modified Heumann profiles. The rail profiles shall have a width at the top of the head not less than 95 percent of the original value when new.

The track shall consist of staggered rails, 39 feet long, on good ties and ballast, shimmed to provide a cross level of 0.5 inch, low at each joint, over the test zone length of 200 feet, as shown in Figure 11.4.

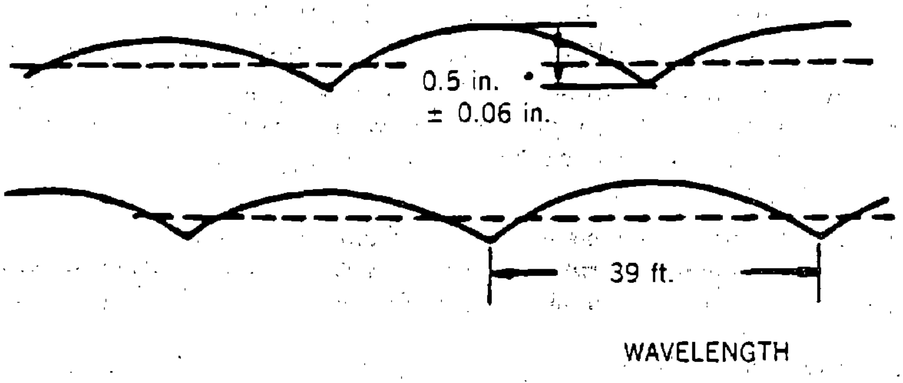

Figure 11.4.

CROSS LEVEL FOR DYNAMIC CURVING TESTS

Combined gage and alignment variation shall be provided in the test zone by shimming the outer rail in the form of an outward cusp, giving a maximum gage of 57.5 inches at each outer rail joint and a minimum gage of 56.5 inches at each inner rail joint, the inner rail being within class 5 standards for alignment in curves, as given in Figure 11.5.

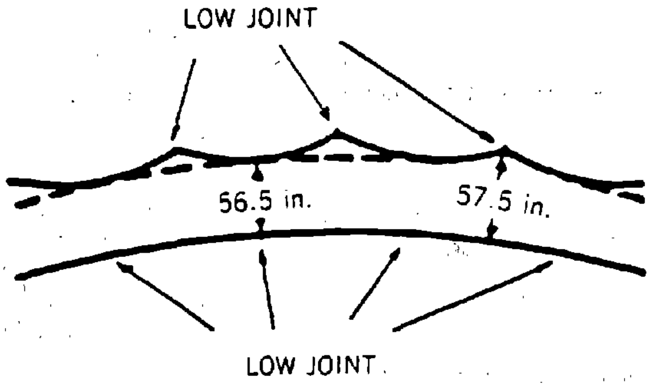

Figure 11.5.

GAGE AND ALIGNMENT VARIATION IN DYNAMIC CURVING

It is recommended that a guard rail be used to prevent unpredicted derailment; however, it must not be in contact with the wheel during normal test running. The test shall be carried out at constant speeds up to 3 inches of overbalance, increasing in 2 mph steps from well below any predicted lower center roll resonance until it is passed. The resonance may be approached from a speed above that predicted to give a lower center roll resonance.

The test shall be stopped if an unsafe condition is encountered or if the maximum unbalance is reached. It shall be regarded as unsafe if a wheel lifts, the instantaneous sum of the absolute L/V values of the individual wheels on any axle exceeds 1.3, or car body roll exceeds 6 degrees, peak-to-peak.

11.6.5.3. INSTRUMENTATION AND CRITERIA

The leading axle on both trucks on an end unit or car, or each axle on an end unit or car with single-axle trucks, shall be equipped with instrumented wheelsets. The car body roll angle shall also be measured at one end of the lead unit. The lateral and vertical wheel forces and the roll angle shall be measured continuously through the test zone. Measured force components having frequencies above 15 hertz are to be filtered out.

The maximum roll angle shall not exceed 6 degrees, peak-to-peak, the vertical wheel load shall not be less than 10 percent of its static value, the individual wheel L/V shall be less than 0.8, and the instantaneous sum of the absolute wheel L/Vs on any axle shall be less than 1.3, at any test speed.

A record of both wheel loads measured on the axle with the lowest measured vertical load and largest measured lateral load, and the roll angles measured, taken at the resonant speeds for each car load, shall be submitted as required test data.

11.7. COUPLED CARS AND UNITS

11.7.1. GENERAL

The tests described in this section will be designed to establish the track-worthiness of the car under conditions associated with the realistic operation of cars within a train. This may include severe transient forces due to coupling with adjacent cars. These forces may have a significant effect on the stability of cars and may lead to derailment. The investigations will be designed to demonstrate that the car design provides an adequate margin of safety from structural damage and from any tendency to derail.

11.7.2. VERTICALLY CURVED TRACK *

* This section to be added at a later date

11.7.3. HORIZONTALLY CURVED TRACK +

+ Investigations are currently underway which will allow the addition of this section in the near future.

APPENDIX A
VEHICLE CHARACTERIZATION
Adopted 1987

1.0. GENERAL

The characteristic properties of the car body and its suspension, required for analysis of its track-worthiness, must be supported by test results providing evidence of their validity. Forces and motions between suspension components and the body modal frequencies of the car, as assembled, can vary significantly from the values calculated or specified in the design, and may be important to the safe performance of the vehicle.

1.1. TEST CAR

It is important that characterizations be carried out on the particular car in the same condition that it is to be track tested so that accurate predictions of its performance can be made. For cars with more than one type of suspension, at least one of each type should be tested.

The tests apply to all new car suspensions, including trucks retrofitted with devices such as inter-axle connections, sideframe cross-bracing and additional suspension elements, which have not been tested previously.

Tests for horizontal characteristics of the suspension of trucks with at least two axles, may be carried out with the truck separated from the body. In this case static vertical loads must be applied to simulate those due to the body or bodies and the rotational and lateral characteristics between the truck and body must be measured separately.

Where connections exist between the truck and body that may affect the truck characteristics, such as with a truck steered through links to the body, and for all cars with single axle trucks, the suspension characteristics must be tested while connected to the body.

Where the truck is at the junction of two articulated bodies, both must be simulated or used in the suspension characterization tests specified.

1.2. TEST LOADS

Modal tests, and tests for the horizontal and vertical suspension characteristics are required with vertical loads equivalent to the car in the loaded condition required for the analyses in which the results will be used. This includes tests to measure the alignment of the axles to each other and to other elements in the system.

1.3. GENERAL PROCEDURE

In tests for the suspension characteristics, the recommended procedure is to load the suspension and to measure the load and displacement, or velocity, across the particular suspension element, in the required direction. These should be recorded up to the required maximum and down to the required minimum identified.

The loads may be applied, either through automatic cycling at an appropriate frequency or through manual increase and decrease of load through at least two complete cycles. If manual loading is used, delays and intermediate load reversals between measurements should be avoided. For the determination of stiffness and frictional energy dissipation, the frequency of cycling must be between 0.2 and 0.5 hertz.

Graphs of load versus displacement or velocity are desirable for the determination of the required stiffness or damping.

2.0. TESTS WITH THE WHEELS RESTRAINED

2.1. GENERAL

In the tests described in this section, the wheels are rigidly attached to the rails or supporting structure and the frame is moved relative to them.

The methods described are not suitable for trucks having steering links, which couple the lateral or roll motion of the body or truck frame to the yaw motion of the axles. In such a case, provision must be made for unrestrained longitudinal movement of the wheels, discussed in section 3. The steering links may be disconnected to measure the characteristics of suspension elements in the unsteered condition.

All tests require that the actuators and restraining links, other than those at the wheels, have the equivalent of ball joints at both ends to allow for motion perpendicular to their axis.

2.2. VERTICAL SUSPENSION STIFFNESS

For this test, equal measured vertical loads are applied across the spring groups in the range from zero to 1.5 times the static load, if possible, and at least to the static load of the fully loaded car. Vertical actuators are attached to each side of the body or the structure simulating it. The load may also be applied by adding dead load or a combination of both dead and actuator loads.

Vertical deflections are required across all significant spring elements under load. It is important to report any differences in the measurements taken between each axle and frame or sideframe.

2.3. TOTAL ROLL STIFFNESS

A roll test is required if the roll characteristic between the body and axle includes movement at or forces due to elements other than the vertical suspension, such as clearances at sidebearings, or anti-roll bars.

For the roll test, two vertical actuators are required as in the vertical test, but with the loads in the actuators in opposite directions. The range of roll moments, in inch-pounds, applied to the truck should be between plus and minus 30 times its static load, in pounds, or until the wheels lift. The roll angle across all suspension elements may be measured directly or deduced from displacements.

2.4. TOTAL LATERAL STIFFNESS

The lateral stiffness characteristic may be found by attaching an actuator to apply loads laterally to the body or bodies, which should be positioned as if on tangent track. If the lateral motion of the truck frame is coupled to its yaw through a steering mechanism, it should be disconnected to prevent the yaw resistance of the frame from affecting the measurement of lateral stiffnesses.

The minimum and maximum lateral loads applied per truck should be minus and plus one fifth of the static load carried. Measurements are required of the lateral displacements across all suspension elements.

2.5. INTER-AXLE TWIST AND EQUALIZATION

This test is carried out with only one axle fixed to the track. One wheel of the other axle in the car or truck is jacked up to a height of 3 inches, and the vertical load and displacement are measured. The stiffness between the axles in twist is the ratio of the load to the displacement multiplied by the square of the gage. It is a measure of the truck equalization.

3.0. TESTS WITH UNRESTRAINED WHEELS

3.1. GENERAL

These tests involve movements in the suspension system and axles relative to other elements of the system or to other axles, without restraint between the wheel and rail, but with the normal static vertical load.

The shear resistance between the rail and the wheel must be eliminated by the provision of a device having very low resistance, such as an air bearing, under each axle.

3.2. AXLE ALIGNMENT

Both radial and lateral misalignments may be deduced from measurements of the yaw angle of each axle from a common datum. The radial misalignment between axles is half the difference in their yaw angles, taken in the same sense, and the lateral misalignment is their mean yaw angle.

In the case of trucks which have significant clearance between the axle and frame, it may be necessary to establish the axle in the center of the clearance for the purpose of identifying the mean axle misalignments.

3.3. LONGITUDINAL STIFFNESS

A longitudinal load must be applied to the axle, equivalent to a single load at its center, and cycled between tension and compression up to half the static load on the axle.

The load may be applied directly between axles, or between the test axle and ground through an appropriate structure, with the body or truck frame restrained. The load may also be applied directly between the axle and frame, or in the case of a car with single axle trucks, between the axle and the body.

The longitudinal deflection across each spring element must be measured and the results plotted.

Where the load is applied directly between the axles of a truck or car, this measurement may be combined with the inter-axle shear test in section 3.4., or the inter-axle bending stiffness test in section 3.5.

3.4. AXLE LATERAL AND INTER-AXLE SHEAR STIFFNESS

The inter-axle shear stiffness may be found by shearing the axles, or moving them in opposite directions along their axes, and measuring the shear or lateral deflection between them. The shear force on each axle must be at least one tenth of the static vertical axle load.

This test may be combined with the inter-axle longitudinal test of section 3.3., where the required load can be achieved.

In the case of direct inter-axle loading, the locations of the applied force and restraint are such that they are equal and opposite, diagonally across the truck or car.

The actuator and restraint each provide two components of force on the axle to which they are attached. One component lies along the direction of the track and provides tension and compression, as in section 3.3., for the longitudinal stiffness. The other component lies along the axle and applies the required shear force bewteen axles. This component may be applied separately with a suitable arrangement of actuators and restraints.

Measurements are made of the lateral misalignment of the axles during the load cycle. The shear stiffness is the ratio of shear force to the lateral misalignment.

For single axle trucks, a test similar to that described above may be used to determine the lateral stiffness, with force applied laterally between ground and the axle with the body restrained, or with the truck frame restrained in the case of trucks having more than one axle. For trucks which also provide steering through coupling axle lateral motion to its yaw angle, this test may be preferred over the lateral test of section 2.4. for finding the lateral stiffness, since the axles are free to yaw.

3.5. AXLE YAW AND INTER-AXLE BENDING STIFFNESS

The inter-axle bending stiffness may be found by yawing the axles in the opposite directions and measuring the yaw angle between them. The yaw moment applied, in inch-pounds, must be at least equal to the axle load in pounds.

This test may be combined with the inter-axle longitudinal test of section 3.3. If this is done, the test is carried out by applying an effective force on the axle a known distance laterally from the truck centerline.

In the case of direct inter-axle loading the restraint must be applied to the axle, at the other end of the car or truck, on the same side as the applied force. The applied and restraining forces each provide a longitudinal force and a yaw moment on the axle to which they are attached. The force provides the tension and compression as in section 3.3. for the longitudinal stiffness and the moment is applied between the truck axles in yaw. This moment may be applied independently of the longitudinal force.

Measurements are made of the resulting radial mis-alignment of the axles during the load cycle. The bending stiffness is the ratio of applied bending moment to the radial misalignment.

A similar test of the axle yaw stiffness may be arranged with forces applied in yaw between a single axle and ground, with the body restrained, or with the truck frame restrained in the case of trucks having more than one axle.

3.6. YAW MOMENT BETWEEN THE SUSPENSION AND BODY

The required yaw stiffness and breakout torque between the car body and truck must be measured by applying a yaw moment, using actuators in equal and opposite directions at diagonally opposite corners of the truck to rotate the truck in yaw. The car body must be restrained.

The applied yaw moment must be increased until gross rotation is observed, representing the breakout torque, or to the limit recommended for the yaw of the secondary suspension.

The angle in yaw between the car body and truck bolster or frame must be measured.

4.0. RIGID AND FLEXIBLE BODY MODAL CHARACTERISTICS

4.1. GENERAL

Tests are required to identify the rigid and flexible body modal frequencies and damping. The rigid body modal frequencies may be compared to predictions using estimated or measured body masses, and inertias and the suspension parameters measured according to the requirements of sections 2. and 3. Tests and estimates should be made with the car in the empty and fully loaded state.

4.2. TEST CAR BODY

For cars consisting of more than one coupled unit, tests for body modes are required on one of each of the unit bodies having a different structural design. Dead loads may be added to give the required additional loading to any shared suspensions.

Where coupling exists between the modes of adjacent bodies, such as in roll or torsion, this may be examined in a dynamic analysis, validated for the case of tests without coupling.

The frequency and modal damping are only required for the flexible body modes which are predicted to have a natural frequency below 12 hertz.

4.3. GENERAL PROCEDURE

Transient or continuous excitation may be applied, using one or more actuators or dropping the car in a manner to suit the required mode of excitation.

The modal frequency and damping are required for an amplitude typical of the car running on class 2 track.

In the case of the rigid body modes, the actuators must be located at the rail level or the level of the truck frame with the body free to oscillate on its suspension. In the case of the flexible body modes, the excitation may be applied directly to the body.

The frequency in hertz may be determined from the wavelength in the transient test, or from the peak response, or from the 90 degree phase shift between the response and excitation where continuous excitation is used.

The percentage modal damping may be determined using the logarithmic decrement in transient tests or the bandwidth of the response from a range of frequencies.

4.4. RIGID BODY MODES

The rigid body modes for the car are:

Body bounce
Body pitch
Body yaw and sway
Lower center roll
Upper center roll

In the case where the normal load on the body is not centered between the suspensions, the body bounce mode may be coupled to the body pitch. The required measurement of bounce and pitch may be achieved by two vertical measurements at the ends of the car. Their weighted sum provides bounce and their weighted difference pitch. The weighting is dependent on their position relative to the center of mass.

Yaw and sway are deduced from lateral measurements made at each end of the body, a known distance from its mass center, similarly to the determination of pitch.

Measurement of the upper and lower center roll modes are determined from lateral displacements taken at two heights, or by a single lateral displacement and a roll angle measurement.

4.5. FLEXIBLE BODY MODES

The flexible body modes for the car are:

Torsion
Vertical bending
Lateral bending

Determination of the frequency and damping in the torsion mode requires excitation and measurement of roll at one end of the car.

The excitation is similar to that for roll but resonance occurs at a higher frequency. The response between the ends of the car is out of phase for modes number 1,3, and in phase for modes number 2,4, although it is unlikely that modes above 2 will be significant.

Vertical or lateral bending modes are measured as a response to the vertical or lateral excitation at one end or both ends of the car. The first bending mode has a maximum amplitude at or near the car center. The second bending mode has a node or point of minimum response at the center.

5.0. PARAMETER ESTIMATION*

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* Tests are presently being conducted to examine this method.

APPENDIX B

SPECIFICATION FOR INSTRUMENTED WHEELSETS FOR CHAPTER XI (M-1001) TESTING

Adopted 1989

1.0. INTRODUCTION

Instrumented wheelsets to be used in acceptance testing of new and untried cars under Chapter XI of AAR Standard M-1001 must meet the requirements of this specification. Load measuring wheelsets are a critical transducer for a wide range of the Chapter XI vehicle dynamics tests. Calibrated wheelsets will be required to accurately measure lateral and vertical wheel/rail forces, as well as wheel lateral to vertical force (L/V) ratios. A verification of wheelset accuracy is performed through a three-step process consisting of calibration, analysis, and field procedures.

2.0. INSTRUMENTED WHEELSET SPECIFICATIONS

To be accepted for Chapter XI testing, a load measuring wheelset design must meet the following specifications:

2.1.

Vertical wheel load measurements must be within +/− 5 percent of the actual vertical load. This accuracy is to be maintained for loads ranging from 0 to 200 percent of the static wheel load. The minimum signal resolution is to be no less than 0.5 percent of the static wheel load.

2.2.

Lateral wheel load measurements must be within +/− 10 percent of the actual lateral load. This accuracy is to be maintained for loads ranging from 0 to 100 percent of the static (vertical) wheel load. The minimum signal resolution is to be no less than 0.5 percent of the static (vertical) wheel load.

2.3.

Maintain the above stated accuracy requirements, at all times, for:

2.3.1.

All potential load cases (longitudinal loads of up to 60 percent of the static (vertical) wheel load, lateral loads of up to 100 percent of the static (vertical) wheel load, and vertical loads of up to 200 percent of the static wheel load).

2.3.2.

All potential wheel/rail contact conditions including full flange contact, outside tread contact, two-point contact, and flange contact at high wheelset angles of attack.

2.3.3.

An operating speed (for dynamic wheelset output) of from 5 to 80 mph.

2.3.4.

Signals from 0 to 30 Hertz.

2.3.5.

Over a recommended operating ambient temperature range of 0 to 110 degrees Fahrenheit. Any restrictions in the operating temperature range are to be noted.

2.4.

Wheelset reprofiling or recalibration requirements due to profile wear are to be documented. Temperature compensation arrangements and operating limitations due to ambient temperature swings are to be detailed as well. The wheelsets are to be equipped with the modified Heumann profile shown in Figure 8.1 of Chapter VIII of AAR Standard M-1001.

3.0. VERIFICATION

Wheelset accuracy is to be substantiated through calibration, analysis, and testing. A minimum number of required wheelset static tests to calibrate and verify wheelset output are described. Since dynamic calibration of load measuring wheelsets has proven difficult, further verification of wheelset accuracy relies on required static and dynamic analyses. A limited set of simple experimental procedures are then prescribed to confirm proper wheelset function under field conditions.

3.1. STATIC CALIBRATION

Static tests to determine the wheelset calibration factors are required of all instrumented wheelsets. Documentation in support of the calibration tests is to include a complete description of the calibration stand and the calibration procedure. Calibration for vertical and lateral loads is to include testing for a minimum of six wheel rotational positions (0, 60, 120, 180, 240, and 300 degrees). Calibration for vertical loads is to include testing for a minimum of three contact point lateral positions (on tape line and one inch), respectively, to the flange and wheel face of the tape line. Each calibration sequence is to be repeated at least once to verify measurement repeatability.

The static calibration tests are as follows:

3.1.1.

Using an appropriate loading scheme, vertical loads ranging from 0 to 200 percent of the static wheel load are to be applied with a minimum of 5 equally spaced inputs (0, 50, 100, 150, and 200 percent of the static wheel load). Strain gauge output for both vertical and lateral force circuits is to be recorded.

3.1.2.

Using an appropriate loading scheme, lateral wheel loads are to be applied at the wheel tread ranging from −100 to 100 percent of the static wheel load with a minimum of 10 equally spaced inputs (+/− 20, 40, 60, 80, and 100 percent). A vertical force equivalent to the static wheel load is to be applied simultaneously. Both vertical and lateral force strain gauge outputs are to be recorded.

The static calibration report is to include raw measurement values and the derived calibration factors. The calibration report must also include a table comparing the applied forces and, given the calibration factors obtained during the testing, the measured forces. It is assumed here that the calibration factors will represent average values independent, for example, of wheelset rotational position.

3.2. ANALYSIS

The following theoretical analyses are required to verify theoretical wheelset accuracy for load combinations that cannot satisfactorily be applied using a conventional static loading frame. It is assumed that finite element or similar calculations will have been performed beforehand to obtain the theoretical wheelset calibration factors. Any variations in wheelset output or accuracy due to rotational position are to be described.

Static finite element or similar calculations to verify theoretical wheelset accuracy for the following scenarios:

3.2.1.

Single point contact at one inch toward the wheel face from the wheel tape line for a vertical load of 50 and 200 percent of the static wheel load in combination with a lateral load of −25 and 25 percent of the static wheel load (giving a total of four load combinations).

3.2.2.

Single point contact on the flange (defined as being at a point giving a rolling radius one-half inch greater than that obtained at the tape line) for a vertical load of 100 and 150 percent of the static wheel load in combination with a lateral load of 25, 50, and 75 percent of the static wheel load (giving a total of six load combinations).

3.2.3.

Single point contact at the wheel tape line for a vertical load equal to the static wheel load in combination with a longitudinal load of −50, −25, 25, and 50 percent of the static wheel load and a lateral load of 10 percent of the static wheel load (for a total of four load combinations). Note that a negative longitudinal load is defined here as a load directed in the sense of the wheel rotation.

3.2.4.

Single point contact at the flange for a vertical load of 75 percent of the static wheel load in combination with a longitudinal load of −50, −25, 25, and 50 percent of the static wheel load and a lateral load of 50 percent of the static wheel load (for a total of four load combinations).

3.2.5.

Two-point contact with the first point of contact at one-half inch toward the wheel face from the wheel tape line and the second point of contact at the flange and displaced −0.5, 0, and 0.5 inches longitudinally from the mid-plane axis of the wheelset. The loading at the tread contact is to be a vertical load of 50 percent of the static wheel load in combination with a longitudinal load of −25 percent and a lateral load of −10 percent of the static wheel load. The loading at the flange contact is to be a vertical load of 75 percent of the static wheel load in combination with a longitudinal load of 50 percent and a lateral load of 50 percent of the static wheel load (for a total of three calculation cases).

3.2.6.

Single point contact at the tape line for a wheel with a radius one-quarter inch less than nominal and a vertical load equal to the static wheel load in combination with a lateral load of 10 percent of the static wheel load.

3.2.7.

Single point contact at the flange for a wheel with a radius one-quarter inch less than nominal and a vertical load equal to 75 percent of the static wheel load in combination with a lateral load of 50 percent of the static wheel load.

Results for the twenty-three static calculation cases described above are to be given as the percent deviation of the predicted lateral and vertical force values from the applied values.

A single dynamic finite element or similar calculation to verify theoretical wheelset accuracy under dynamic conditions:

3.2.8.

This calculation is to verify that no wheelset vibration modes are present with natural frequencies below 30 Hertz. If such modes exist, a dynamic calculation is to be performed for the following wheelset input: single point contact at the wheel tape line for a vertical load equal to the static wheel load in combination with a time varying longitudinal load with an amplitude of 25 percent and a lateral load with an amplitude of 10 percent of the static wheel load. The mean longitudinal and lateral force are both to be zero. The calculation is to consider an input frequency ranging from 0 to 30 Hertz where the lateral and longitudinal force signals are 90 degrees out of phase. The boundary condition to be used for both this calculation and the wheelset natural frequency calculation is to fix the wheelset in the longitudinal, lateral, vertical, and rotational sense at the bearing centerline (axle top dead center).

The results of the dynamic calculation are to be given as the mean value and amplitude of the predicted lateral and vertical forces as functions of the wheelset rotational position.

3.3. TEST PROCEDURES

The following experimental analyses are required:

3.3.1.

A zero speed jacking test to set the wheelset zero followed by a slow speed roll (at ten, twenty, and thirty miles per hour) along tangent track to verify that wheel vertical load signals are within +/− 5 percent of the calibrated scale axle load for constant speed operation on level tangent track. Wheelset signals will be evaluated on the basis of mean values for a randomly chosen output segment having a minimum duration of ten seconds.

3.3.2.

A steady-state curving test to confirm that net truck or car lateral loads are within +/− 10 percent of the theoretical value for constant speed operation on constant radius track at speeds corresponding to +3, 0, and −3 inches cant deficiency. Both curvature and superelevation of the track need to be constant and accurate. Wheelset accuracy is to be verified on a sharp curve (7 degrees curvature and above) for curving with hard flange contact. Wheelset signals will be evaluated on the basis of mean values for a randomly chosen output segment having a minimum duration of ten seconds.

3.3.3.

As an alternative to this test a zero speed jacking test is suggested using equal and opposing lateral loads applied (via a hydraulic jack) to the wheel backs. Measured lateral loads are to be within +/− 5 percent of the applied value for loads ranging from 0 to 50 percent of the static (vertical) wheel load.

3.3.4.

A steady-state curving test to again confirm that total truck vertical loads are within +/− 5 percent of the theoretical value for constant speed operation on constant curvature track (for the test curve described above). Wheelset signals will be evaluated on the basis of mean values for a randomly chosen output segment having a minimum duration of ten seconds.

The test procedures prescribed above are also to be repeated and recorded at the start of each Chapter XI test series. A record of such results is to be kept for each Chapter XI certified wheelset. A minimum of the vertical load accuracy test is to be performed at the start of each daily test session.

4.0. RECORDS

4.1.

The theoretical analyses described are necessary only once for each wheelset design. The static calibration and field procedures must be performed for each wheelset produced to an accepted specification.

4.2.

An instrumented wheelset which has met these requirements will be so certified by the designated AAR representative.

4.3.

The designated AAR observer for Chapter XI testing will verify that the instrumented wheelsets to be used have been accepted for testing and the test procedures described in Section 3.3 above are completed satisfactorily.

APPENDIX B

TEST PLAN FOR STATIC TESTING
OF BRAKE SYSTEMS
ON INDIVIDUAL CARS AND LOCOMOTIVES

PEACEKEEPER RAIL GARRISON
TEST PLAN FOR STATIC TESTING OF BRAKE SYSTEMS ON INDIVIDUAL CARS AND LOCOMOTIVES
PROCEDURE

1.0 DESCRIPTION

This procedure outlines the sequence of tests to provide reasonable assurance that the train brake system will perform as intended, providing satisfactory slowdown, stopping ability and able to hold the train stationary on level or expected track gradients. These tests include static (vehicle standing) tests of the air brake system to ensure compliance with existing AAR and FRA rules and regulations. Other tests are conducted other than those that are strictly in accordance with AAR and FRA rules to ensure the brake system on each car will be compatible and perform as uniformly as possible when coupled together.

1.1 INDEX

2.8 Tests On Second ABDW Control Valve (If Equipped)
3.0 Net Shoe Force Tests With Calibrated Brake Shoes
4.0 Hand Brake Net Shoe Force Tests
5.0 Tests Of Locomotive Brake System
5.1 Basic Braking Ratio Of Locomotive
5.2 Net Shoe Force Tests
5.3 Air Brake System Tests
5.4 Main Reservoir Pressure And Leakage
5.5 Brake Pipe Leakage Test
5.6 Brake Cylinder Equalization Or Independent Application And Release Pipe Leakage
5.7 Pressure Maintaining Capacity Test
5.8 Calibration Test For Brake Pipe Flowmeter
5.9 Equalizing Reservoir (ER) Leakage
5.10 Service Brake Application And Release
5.11 Emergency Application
5.12 Penalty Brake Application
5.13 Suppression Of Penalty Application

1.2 EQUIPMENT LIST

a.	1ea.	Standard AAR Single Car Test Device for Freight
b.	as needed	FS-5 Plugged Dummy Hose Coupling With Double #80 Choke
c.	as needed	LS-5 Plugged Dummy Coupling
d.	2ea.	0-160 psi or 0-200 psi 3-1/2" Dia. Air Brake Test Air Gauges
e.	1ea.	1/8" Wire Braided armored Hoses 18" Long
f.	1ea.	Filling piece 1/16-3/32"
g.	2 sets	Four Strain Gaged "JIM SHOES"
h.	as needed	Batteries
i.	1ea.	Portable Bellofram Adjustable Control Air Valve
j.	1ea	Hose 1/8" or 1/4" of Ample Size
k.	2ea.	3 Lb. Blacksmith Hammers
l.		All Safety Equipment As Required By TTC

1.3 FIGURE LIST

1.4 TABLE LIST

None

1.5 REFERENCE LIST

PRKG 2100....	Truck Inspection Procedure
PKRG 3100....	Instrument Installation Procedure
M1001........	Manual of Standards and Recommended Practices, Section C, Part II, Volume I, Chapter XI
	TTC Operation Rules for the Transportation Test Center, Pueblo, Colorado, AAR, November 1, 1989.
	Peacekeeper Rail Garrison Test Implementation Plan, (for appropriate test car), Chapter XI Testing
	TTC Safety Rule Book
	AAR Single Car Test Code (IP No. 5039-4 Sup. 1)
	Canadian Pacific Instructions and Methods

1.7 ATTACHMENT LIST

None

NOTE

All personnel involved in the performance of this procedure or observing the test(s) will comply with the TTC Safety Rule Book.

2.0 CAR AIR AND HANDBRAKE SYSTEM

2.1 Material and Equipment Requirements

TASK NUMBER	PROCEDURE	QA INITIAL
2.1.1	<u>IN DATE</u> Standard AAR Single Car Test Device for Freight, complete with FS-5 FS-5 hose coupling with double #80 choke.	
2.1.1.1	LS-5 dummy coupling, plugged, to insert at brake pipe hose at end car brake pipe hose coupling.	
2.1.2	Two 0-160 psi or 0-200 psi 3-1/2" dia. Air Brake Test air gauges each attached to a 1/8" wire braided armored hoses approximately 18" long with a very thin filling piece (1/16" - 3/32") to insert between brake cylinder pipe or reservoir pipe flange fitting and flange fitting mounting bracket, in order to read pressure in these pipes, see Figure 2.1.	

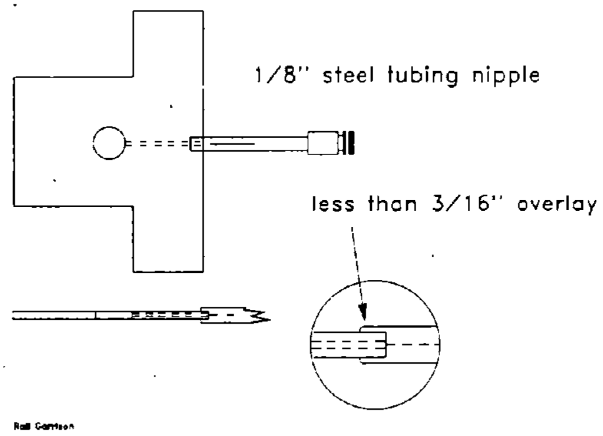

Figure 2.1 Weld Setup

2.1.3 One, preferably two, sets of four strain gaged "JIM SHOE". They are the type of calibrated brake shoes for measuring actual brake shoe force during various applications of the brakes. These sets should be complete with electronic direct readout of brake shoe force.

2.1.4 New batteries to be installed with spares available.

2.1.5 Portable Bellofram adjustable control air valve with suitable air supply.

2.1.6 Delivery hoses (1/8" or 1/4" size) of ample length to vary and control brake cylinder pressure during calibrated shoe force tests.

2.1.7 One, preferably two, 3-lb. Blacksmith's hammers to perform rapping during calibrated brake shoe tests.

2.1.8 Currently effective copy of AAR Single Car Test Code booklet, IP No. 5039-4 Sup. 1. This is AAR STANDARD S-486.

2.2 Single Car Test On Cars

TASK NUMBER	PROCEDURE	QA INITIAL
2.2.1	Install Test air gage filling piece and hose in brake cylinder pipe associated with each ABDW control valve.	
2.2.2	If car has two ABDW control valves, one on each span bolster controlling only the brake cylinders on the two four wheel trucks. Separate brake cylinders on the two four wheel trucks and separate brake pipe length into two sections, if possible, when testing for control valve performance.	

2.2.3 Measure the effective brake pipe length on the control valve being tested or use the complete run of brake pipe through car, measuring and recording the total length including end hose.

2.2.4 Cut out and drain the other ABDW control valve, its auxiliary and emergency reservoirs.

2.2.5 Follow applicable tests in AAR Single Car Test Code, IP No. 5039-4 Sup. 1, Test 3.1.

2.2.6 Attach single car tester to the brake pipe end hose on the car on which the control valve being tested is located.

2.2.7 Install plugged FS-5 dummy coupling at rear end or opposite end of brake pipe hose after determining that air is flowing freely from "rear end" with single car tester in #1 or release position (AAR Single Car Test Code, IP No. 5039-4 Sup. 1), Test 3.1.3.

2.2.8 Cut out the operative ABDW control valve, completely drain its reservoirs and proceed with Test 3.2 to determine brake pipe leakage.

2.2.9 If car does not pass this test, inspect complete length of brake pipe and hoses using soap suds or acceptable leak detector fluid. Correct leakage found.

2.2.10 If there are no detectable or significant leaks in the brake pipe, angle cocks or hoses. Pull reservoir release rod and hold it open to see if there is any air pressure in reservoirs. Do this for the first control valve and then for the other control valve. If there is pressure now it indicates a leaking 1" branch pipe cut out cock.

2.2.10.1 Change out 1" branch pipe cut out cock and dirt collector assembly as required with a new one or one known to be in good condition.

2.2.10.2 Repeat Test 3.2 to ensure BP leakage is satisfactory.

2.2.11 If car is equipped with an A-1 Reduction Relay Valve or an Emergency Brake Pipe Vent perform AAR Single Car Test Code, IP No. 5039-4 Sup. 1, Test 3.3.

2.3 Hand Brake Inspection

TASK NUMBER	PROCEDURE	QA INITIAL
2.3.1	Chock wheels so car will not roll.	
2.3.2	Determine that shoes connected to handbrake release have effective force on them.	
2.3.3	Release handbrake.	
2.3.4	Check that the chain is "loose" but still is in line with sheave wheels and not jam or foul when reapplied.	

2.4 System Leakage Test

TASK NUMBER	PROCEDURE	QA INITIAL
2.4.1	Cut in ABDW control valve on end nearest single car tester and allow to charge.	
2.4.2	Leave other ABDW control valve cut out with its reservoirs drained.	

2.4.3	Perform AAR Single Car Test Code, IP No. 5039-4 Sup. 1, Test 3.5.	
2.4.4	When test is satisfactory proceed with remainder of applicable tests on ABDW control valve at this end of car.	

2.5 Piston Travel And Rigging

TASK NUMBER	PROCEDURE	QA INITIAL
2.5.1	Perform AAR Single Car Test Code, IP No. 5039-4 Sup. 1, Test 3.6.	
2.5.2	When making this test make service BP reduction carefully, noting the brake pipe pressure at which service brake cylinder pressure (BCP) reaches its maximum. Record these values.	
2.5.3	Brake cylinder pressure must be between 48 and 52 psi with reduction made accurately, set and fully charged 70 psi in system.	
2.5.4	Check piston travel on all brake cylinders controlled by this ABDW valve.	
2.5.5	If brake cylinder pressure is outside the 48 to 52 psi range try resetting piston travel to bring BCP within this range.	

2.6 Minimum Application And Brake Cylinder Leakage And Slow Release

TASK NUMBER	PROCEDURE	QA INITIAL
2.6.1	Perform AAR Single Car Test Code, IP No. 5039-4 Sup. 1, Tests 3.7 and 3.8 in accordance with the effective BP length on the car.	

2.6.2 Following successful passing of Test 3.7 and 3.8 recharge the equipment.

2.6.3 Make approximately 10 psi BP reduction by reducing the setting of the reducing valve on the single car test device.

2.6.4 Note brake cylinder and brake pipe pressure and monitor this for 10 minuets. Pipe pressure should remain steady.

2.6.5 Increase in BCP over appx. 2 psi and particularly if it is a steady rise, which may mean there is brake pipe pressure leaking into brake cylinder, probably past quick service limiting valve "O" rings in the service portion.

2.6.6 If brake pipe pressure leaking occurs, the service portion will have to be changed out and a new or COT'D portion applied.

2.6.8 If there is brake pressure leaking recharge equipment and repeat Tests 3.5, 3.6, 3.7 and 3.8.

2.7 Service Stability, Emergency, Release After Emergency ABDW Application And Manual Release Valve Tests

TASK NUMBER	PROCEDURE	QA INITIAL
2.7.1	Perform The following Test(s): Service Stability, Emergency, Release After Emergency ABDW Application and Manual Release Valve as per AAR Single Car Test Code, IP No. 5039-4 Sup. 1. 1.	
2.7.2	Record the emergency equalization pressure and the piston travel at each brake cylinder.	

2.8 Tests On Second ABDW Control Valve (If Equipped)

TASK NUMBER	PROCEDURE	QA INITIAL
2.8.1	On car equipped with a second ABDW valve and second set of brake cylinders cut out the first control valve previously tested and drain its reservoirs completely.	
2.8.2	Cut in the second ABDW on the span bolster at other end of car.	

NOTE

It will not be necessary to preform the BP leakage test or auxiliary brake pipe reduction device tests if the complete BP was previously tested.

TASK NUMBER	PROCEDURE	QA INITIAL
2.8.3	Repeat Sections 2.4 - 2.7.	

3.0 NET SHOE FORCE TESTS WITH CALIBRATED BRAKE SHOES

TASK NUMBER	PROCEDURE	QA INITIAL
3.0.1	Arrange to introduce pressure into brake cylinder pipe independently from the ABDW control valve(s).	
3.0.2	A thin piece of shim stock should be used to blank off the brake cylinder pipe (#3 port) at the AB pipe bracket.	
3.0.2	The bellofram adjustable reducing valve should be connected to the single car tester supply line and the delivery hose into the tee under the test air gage hose assembly. The supply pressure should be 90 to 100 psi.	

3.0.3 Remove brake shoes and install a "JIM SHOE" in each brake head key bridge.

3.0.4 Follow "JIM SHOES" instruction for zeroing and calibrating the circuits of the electronic readout device.

3.0.5 Make actual ("net") shoe force readings at the following pressures, set with the Bellofram adjustable reducing valve:

- 10 psi, 20 psi, 30 psi and 40 psi actual service equalization pressure from 70 psi, 80 psi and 80 psi.

NOTE

Do not back off or reduce pressure if actual
turns out a psi or too different from that desired.
Use the pressure attained such as 22 or 43 psi and make
all force reading at this particular pressure.

3.0.6 Make a full set of pressure and force readings with the rigging at each truck rapped with the 3-lb blacksmith's hammer.

3.0.7 Hit each pin or clevis joint on each side of brake beam not more than three times.

3.0.8 Following this release of BCP, reapply to the specific service equalization pressure previously determined and make accrual force readings without rapping the rigging.

3.0.9 Calculate the efficiency of the rigging on each truck and the Net Braking Ratio (NBR) of the service equalization pressure at 50 psi.

NOTE

These overall values @ 50 psi on the total gross weight of the car should not be over 10% and must not be less than 6.5%. At empty weight of the car the NBR must not exceed 30% @ 50 psi.

4.0 HAND BRAKE NET SHOE FORCE TESTS

TASK NUMBER	PROCEDURE	QA INITIAL
4.0.1	Install suitable load cell or Strain Sert pin, preferably in the vertical chain coming down out of the geared hand brake or the closest horizontal chain.	
4.0.2	Install Strain Sert pins at the delivery end pin of each TMB hand brake lever (Ellcon National) or the hand brake clevis connection to the BC push rod Thrall TMB.	
4.0.3	Apply geared hand brake to its specified vertical chain force or slightly above if exact force cannot be obtained.	
4.0.4	Make net shoe force reading on each "JIM SHOE": 1. Without rapping rigging. 2. With rapping reading.	
4.0.5	If force is above specified vertical chain force release and reapply to a force somewhat less and repeat Steps 4.0.3 - 4.0.4	
4.0.6	Handbrake net braking ratio must be a minimum of 11% of the gross rail load of the complete vehicle. Preferably the empty weight net braking ratio should not be more than 50% of the empty weight on the handbrake trucks.	

5.0 TESTS OF LOCOMOTIVE BRAKE SYSTEM

5.1 Basic Braking Ratio Of Locomotive

TASK NUMBER	PROCEDURE	QA INITIAL
5.1.1	Determine the leverage ratio associated with each brake cylinder.	
5.1.2	Determine the size of each brake cylinder.	
5.1.3	Check lever lengths and compare with locomotive builder recommendations/specifications.	
5.1.4	The above Step 5.1.2 may require removing and measuring one truck side set of levers. Then hopefully comparative outside measuring points can be found so that the others can be checked.	
5.1.5	The condition of the pins and bushings should be carefully inspected on the locations where parts are removed.	
5.1.6	Worn or broken pins and bushings should be replaced in the truck frame, levers and brake head assemblies.	
5.1.7	Apply independent brake making sure that all shoes are line up with and contact the normal tread of each wheel.	
5.1.8	If a shoe overhangs the outside rim of a wheel, release brake and push rigging laterally to determine if pins and bushings are worn. Remedy the situation.	

CAUTION

Overhanging shoes are a Federal defect.

5.1.9 With the weight of locomotive known, either light, with fuel or with supplies ready to run, calculate the gross braking ratio of the locomotive @ 50 psi.

5.1.10 If locomotive is equipped with a J-1.6-16 brake cylinder relay, calculate gross braking ratio at 80 psi BCP and for independent brake at 50 psi Independent and Release Pipe pressure.

NOTE

Normally these should be in the range of 26-28% @ 80 psi with AAR high friction composition shoes.

5.2 Net Shoe Force Tests

TASK NUMBER	PROCEDURE	QA INITIAL
5.2.1	With rigging installed and operable with independent brake valve, remove brake shoes and install calibrated "JIM SHOES" at the location controlled by each brake cylinder on the truck.	
5.2.2	Make actual or net shoe force reading each 10 psi up to 80 psi with rigging rapped.	
5.2.3	Make unrapped tests at 30, 50 and 80 psi.	
5.2.4	Calculate rigging efficiency and determine net braking ratios.	

5.2.5	On front truck or that equipped with handbrake, arrange to install Strain Sert pin or load cell preferably in vertical chain and apply handbrake to manufactures specified force.	
5.2.6	Make "JIM SHOE" reading of actual shoe force at each shoe operated by the handbrake mechanism. DO NOT rap the rigging.	
5.2.7	Calculate net braking ratio.	

5.3 Air Brake System Tests

TASK NUMBER	PROCEDURE	QA INITIAL
5.3.1	Ensure that all cab air gages are checked and meet master air gauge within + or - psi.	

5.4 Main Reservoir Pressures And Leakage

TASK NUMBER	PROCEDURE	QA INITIAL
5.4.1	Partially open main reservoir (MR) drain cock in 2nd main reservoir and note the pressure where the Compressor Control Switch (CCS) causes the air compressor to "cut-in" and start pumping. This should be between 125 and 130 psi. Note the pressure where the CCS causes the air compressor to "cut out" and stop pumping at between 135 and 145 psi.	
5.4.2	Install LS-5 plugged dummy coupling at front and rear MR hose couplings.	
5.4.3	Open MR cut out cocks (usually reachable through end steps).	

5.4.4	Close MR drain cock tightly and deactivate automatic drain valves.	
5.4.5	Close MR cut out cock leading to brake equipment, generally downstream from air filter.	
5.4.6	When compressor next cuts out, stop the diesel engine.	
5.4.7	Measure the amount of MR pressure drop for three minutes. Maximum allowed pressure drop is 9 psi or 3 psi per minute average. If greater than this locate source (s) of leakage and eliminate.	
5.4.8	Restart engine and repeat Steps 5.4.2 - 5.4.7.	
5.4.9	Close MR cut out cocks at front and rear.	
5.4.10	Remove LS-5 Dummy Couplings.	
5.4.11	Restart engine and continue with tests.	

5.5 Brake Pipe Leakage Test

TASK NUMBER	PROCEDURE	QA INITIAL
5.5.1	Install FS-5 dummy couplings in front and rear BP end hose coupling.	
5.5.2	Open angle cocks or 1-1/4" cut out cocks (reachable through end steps).	

5.5.3 Check and set 26-C automatic brake valve (ABV) BP regulating valves if necessary to 90 psi as read on BP cab air gauge.

5.5.4 Allow time for BP pressure to readjust and close the cut out cock in branch pipe leading to 26-F control valve (under floor).

5.5.5 Cut out 26-C ABV.

5.5.6 Wait a few minutes and then check BP pressure drop for 3 minutes.

NOTE

BP leakage rate must not exceed 3 psi in one minute.
If leakage exceeds this rate, locate source(s) and repair.
Repeat Steps 5.5.1 - 5.5.6.

5.5.7 "Cut In" 26-C ABV and open branch pipe cut out cock leading to 26-F control valve.

5.5.8 Close angle cocks or 1-1/4" BP cut out cocks and remove LS-5 dummy couplings from front and rear BP end hoses.

5.6 Brake Cylinder Equalization Or Independent Application And Release Pipe Leakage

TASK NUMBER	**PROCEDURE**	**QA INITIAL**
5.6.1	Install HS-2 plugged Dummy couplings, one with test air gauge to front and rear BC air hose couplings and then open 1/2" BC line cut out cocks at front and rear.	
5.6.2	Apply Independent Brake Valve (IND) to maximum.	

5.6.3	Adjust pressure to read 80 psi on cab air gauge, if necessary, allowing time for pressure to adjust. BC test air gauge should read appx. 50 psi.	
5.6.4	Close the "double ported MU cut out cock" or place MU-2A valve in Trail position.	
5.6.5	Check leakage for three minutes, rate should not exceed 5 psi per minute.	
5.6.6	Close end BC cut out cocks, remove dummy couplings, open double ported cut out cock or place MU valve in Lead position.	

5.7 Pressure Maintaining Capacity Test

TASK NUMBER	PROCEDURE	QA INITIAL
5.7.1	Install special pressure maintaining dummy coupling on coupling of rear BP hose.	
5.7.2	Open adjacent angle cock or 1-1/4" cut out cock under front steps.	

NOTE

In cab it may be necessary to increase engine speed to hold 90 psi BP setting on cab air gauge against flow out of the 3/16" orifice. 90 psi must be maintained against the orifice.

5.7.3	Close 1-1/4" BP cut out cock and remove test dummy coupling.	

5.8 Calibration Test For Brake Pipe Flowmeter

TASK NUMBER	PROCEDURE	QA INITIAL
5.8.1	If locomotive is so equipped, follow instructions of the manufacturer of the flowmeter to properly calibrate or check calibration of the particular flowmeter. See Canadian Pacific Instructions and Method for the WABCO B-1 Flowmeter and the WABCO.	

5.9 Equalizing Reservoir (ER) Leakage

TASK NUMBER	PROCEDURE	QA INITIAL
5.9.1	Make Approximately a 10 psi ER and BP reduction with 26-C ABV, then place BV cut off valve in "OUT" position.	
5.9.2	ER pressure should show no leakage for a period of one minute.	
5.9.3	Correct any leakage found and repeat Steps 5.9.1 - 5.9.2.	

5.10 Service Brake Application And Release

TASK NUMBER	PROCEDURE	QA INITIAL
5.10.1	Move 26-C ABV handle to minimum reduction position.	

NOTE

The equalizing reservoir and brake pipe should respond and drop appx. 6 to 8 psi. Also brake cylinder pressure should respond.

5.10.2 Depress IND handle and BC pressure must exhaust to atmosphere.

5.10.3 Release and recharge.

5.10.4 Move 26-C ABV into service zone making approximately a 10 psi reduction, note brake responds.

5.10.5 Increase BP reduction in two or three appx. 2 psi steps and note brake cylinder pressure increases.

5.10.6 Move to the right hand end of the service quadrant, note ER and BP reduction increases to appx. 24-26 psi.

NOTE

Brake cylinder pressure should have increased to the setting of the service limiting valve in the 26-F control valve which should nominally be 60 psi maximum.

5.10.7 Move to the next notch or Suppression Position and then partly into the overreduction quadrant noting the ER and BP pressure reduce further from the 24-26 psi in effect in suppression position and that there is no increase in BC pressure.

5.10.8 Move the automatic brake valve handle to the left past suppression and into the service quadrant to about the position of a 10 psi reduction. Note the ER and BC pressure do not increase and BC pressure holds steady.

5.10.9 Move the ABV handle further left to release position. Note that the ER and BP pressures rise to 90 psi and BC pressure exhausts completely.

5.10.10 Release and recharge.

5.11 Emergency Application

TASK NUMBER	PROCEDURE	QA INITIAL
5.11.1	From engineman's brake valves. With system fully charged, quickly move 26-C ABV handle to far right of Emergency Position. Note that "PC" light illuminates, BP pressure quickly reduces to zero and that ER pressure steadily reduces to zero.	
5.11.1.1	BC pressure should quickly rise to appx. 75 psi. Record BC pressure.	
5.11.1.2	Power and dynamic brake are nullified.	
5.11.1.4	Release and recharge brake system.	
5.11.2	From other side of cab emergency brake valve. With system fully charged and 26-C ABV in release position, quickly open the 1-1/4" Emergency Brake Valve.	
5.11.2.1	Check that BP quickly drops to zero, 26-C ABV is cut off from suppling BP pressure and PC light illuminates after 26-C ABV is moved to emergency position.	
5.11.2.2	Timed sanding may operate if locomotive is equipped. This indicates that the A-1 charging cut off pilot valve is operating; timed sanding may also operate, if locomotive is so equipped. Power and dynamic brake are nullified.	
5.11.3	From train brake pipe emergency. With system fully charged and 25 ABV in release position, quickly open the rear end angle or BP cut out cock. Note that BP quickly reduces to zero, BC pressure quickly builds up to normal emergency BC pressure and PC light illuminates.	

5.12 Penalty Brake Application

TASK NUMBER	PROCEDURE	QA INITIAL
5.12.1	With system fully charged and 26-ABV in release position, lift or release foot pressure from the foot pedal.	
5.12.2	After 4 to 6 seconds and warning signal, note that penalty application results and produces appx. 24-26 psi BP reduction and brake cylinder pressure builds up to appx. 60 psi.	
5.12.3	Place 26-C ABV handle in suppression position and wait appx. 1 minute.	
2.12.4	Move ABV handle to release position and note that penalty application is reduced to zero. This indicates proper operation of the P-2-A brake application valve.	

5.13 Suppression Of Penalty Application

TASK NUMBER	PROCEDURE	QA INITIAL
5.13.1	Apply independent to about 10 psi BCP, release foot pedal and note alarm sounds, quickly increase pressure to above 25 psi, note alarm silences and no penalty application results.	

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