AAR RESEARCH REPORT

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RESULTS OF LABORATORY QUASI-STATIC JACKING TESTS ON THREE VEHICLES

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13. Abstract

Laboratory quasi-static jacking tests were performed on three vehicles at the Transportation Technology Center, Pueblo, Colorado. Results indicate vehicle wheel unloading that occurred during the tests varied with cross level difference, car body torsional stiffness, truck spacing, and vehicle weight. Transportation Technology Center, Inc., a subsidiary of the Association of American Railroads, conducted the tests in conjunction with the Volpe National Transportation Systems Center (VNTSC).

Tests results show that unloaded vehicles with torsionally stiff bodies are more likely to experience a high percentage of wheel unloading on twisted track.

This working paper is a supplement to Federal Railroad Administration report "Effect of Track Twist on Vehicle Dynamic Performance" (to be published).

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EXECUTIVE SUMMARY

Results of laboratory quasi-static jacking tests indicate that vehicle wheel unloading during test varied with the cross level difference, car body torsional stiffness, truck spacing, and vehicle weight. The tests were conduced by Transportation Technology Center, Inc. (TTCI), a subsidiary of the Association of American Railroads (AAR), in conjunction with the Volpe National Transportation Systems Center (VNTSC).

Track twist is defined as a variation in cross level between two points along the track. Excessive twist can cause truck center plate unloading and wheel unloading. This condition may lead to a wheel climb derailment if a sufficient lateral force is present. The laboratory quasi-static jacking test exposes a vehicle to simulated track twist by jacking two of the vehicle's wheels up to 4 inches at one corner of the test vehicle while keeping the remaining wheels in the original plane.

Three vehicles were tested in an empty load condition: a 100-ton covered hopper with truck spacing of 40 feet 8 inches, a 70-ton tank car with truck spacing of 29 feet 9 inches, and a 100-ton center beam flatcar with truck spacing of 59 feet 10 inches. Test results are summarized below.

Unloaded vehicles with torsionally stiff bodies are more likely to experience a higher percentage of wheel unloading on twisted track than vehicles with more flexible bodies. Of the three tested vehicles, the covered hopper and the tank car showed more torsional stiffness than the flatcar. For the covered hopper, wheel unloading increased from 25 percent to 57 percent in the cross level difference range of 2.25 inches to 2.6 inches. Wheel unloading for the tank car increased sharply from 13 percent to 68 percent in the cross level difference range of 2 inches to 2.5 inches. Above 2.6 inches, the wheel load remained constant on both vehicles. The flatcar experienced a wheel unloading of 28 percent at the 2.6-inch cross level difference and increased linearly to 56 percent at the 4-inch cross level difference.

The full separation of the center plate from the car body was detected at the maximum unloading end of the covered hopper and the tank car above the 2.6-inch cross level difference. Beyond that level, the vertical load was supported only by the side bearing at that end of the vehicle.

Based on the jacking test results, to ensure significant wheel unloding the cross level perturbation installed for the track test was determined to be 2.25 inches for the covered hopper and the tank cars, and 3 inches for the flatcar.

This working paper (Report No. WP-172) complements the Federal Railway Administration report "Effect of Track Twist on Vehicle Dynamic Performance" (to be published).

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1.0 INTRODUCTION

The effect of track twist on vehicle performance has been investigated by the Association of American Railroads' (AAR) Transportation Technology Center (now known as Transportation Technology Center, Inc., a subsidiary of the AAR). Tests were performed in conjunction with the Volpe National Transportation Systems Center (VNTSC).[1] The laboratory quasi-static jacking tests discussed in this report were performed at the Federal Railroad Administration's (FRA) Transportation Technology Center, Pueblo, Colorado prior to the track test to measure wheel load redistribution of a vehicle as it experienced a cross level difference. Results were used to determine the cross level perturbation amplitudes to be installed in the track tests. The amplitudes were chosen such that each vehicle showed maximum sensitivity of wheel unloading to small changes in cross-level.

This working paper (WP-172) is a supplement to FRA report "Effect of Track Twist on Vehicle Dynamic Performance" (to be published).

1.1 BACKGROUND

Track twist is defined as the change in cross level between two points along the track. Its existence of causes the wheels of a vehicle not to remain in the same plane. Track twist occurs by design within transition curves or spirals as superelevation is introduced. Twist also occurs as a defect in the track geometry. A redistribution of vertical wheel loading takes place when a vehicle travels over a change in cross level. Exhibit 1 illustrates the reaction of the car body and truck bolster to a sudden change in cross level. The vertical load is shared by the edge of the center plates and the side bearings as the car body contacts the side bearings at two diagonal corners.

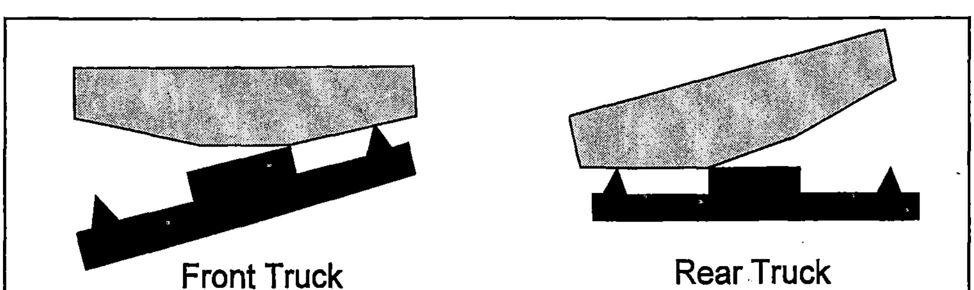


Exhibit 1. Reaction of Vehicle to Track Twist

In an extreme twist condition, all the load may be transferred to the side bearing, in which case the center plate becomes unloaded and the wheels at one side of the truck experience a high percentage load reduction. This condition may lead to a wheel climb derailment if a sufficient lateral force is present.

An investigation conducted by VNTSC illustrated the relationship between vertical load redistribution and cross level difference (Exhibit 2).[2] Between the cross level of point B and point C, the vertical load is shared by the center plate and side bearing. Above point C, the vertical load is carried only by the side bearing. No further load transition is performed above the level at point C as the side bearing can only support a vertical load. Test results discussed in later sections of this report prove that the definition of each zone shown in Exhibit 2 is the proper description for the end of the vehicle where the center plate fully unloading occurs.

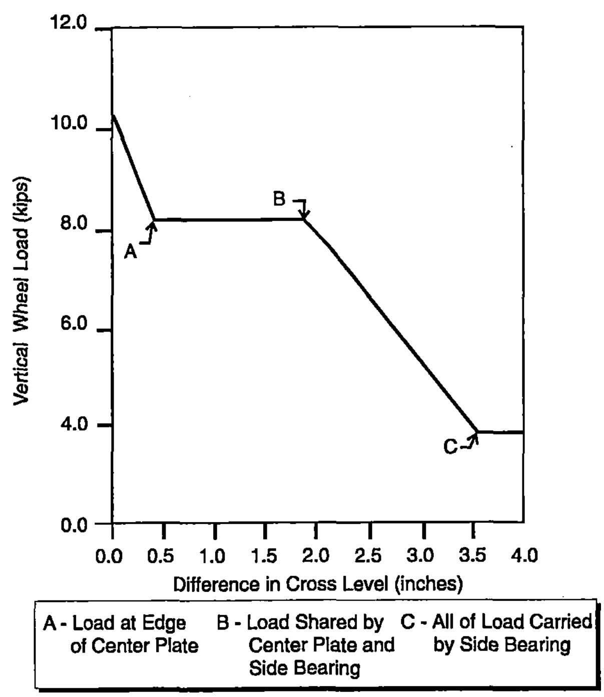


Exhibit 2. Relation of Wheel load and Cross Level Difference

The laboratory quasi-static jacking test simulated a vehicle being exposed to track twist by jacking up two wheels at one corner of the test vehicle and maintaining wheels at the rest of the three corners in the original plane.

1.2 OBJECTIVE

The objective of the quasi-static jacking test was twofold: to obtain the wheel unloading response of the test vehicles to cross level difference and to determine perturbation amplitude to be installed in the track tests.

2.0 TEST VEHICLE DESCRIPTION AND MEASUREMENTS

2.1 TEST TRUCK DESCRIPTION

The trucks selected for test were two 100-ton ride control constant column-damped trucks with 36-inch wheels, and two 70-ton Barber-S2 variable column-damped trucks with 33-inch wheels. Both 100-ton trucks were equipped with nine D-5 outer springs and five D-5 inner springs. Both 70-ton trucks were equipped with five D-3 outer springs, five D-3 inner springs, and two B-421 control coils. The suspension vertical stiffness and damping values for each truck are listed in Exhibit 3.

Exhibit 3. Vertical Characterization Results

Parameter	Truck	Value
Vertical Spring Stiffness without Snubbers, left	100 - B	25.7 kips/inch
Vertical Spring Stiffness without Snubbers, right	100 - B	26.4 kips/inch
Vertical Spring Damping with Snubbers, left	100 - B	5.7 kips
Vertical Spring Damping with Snubbers, right	100 - B	5.8 kips
Vertical Spring Stiffness without Snubbers, left	100 - A	25.6 kips/inch
Vertical Spring Stiffness without Snubbers, right	100 - A	25.4 kips/inch
Vertical Spring Damping with Snubbers, left	100 - A	5.5 kips
Vertical Spring Damping with Snubbers, right	100 - A	6.9 kips
Vertical Spring Stiffness without Snubbers, left	70 - B	31.0 kips/inch
Vertical Spring Stiffness without Snubbers, right	70 - B	30.0 kips/inch
Vertical Spring Damping with Snubbers, left	70 - B	5.5 kips
Vertical Spring Damping with Snubbers, right	70 - B	5.5 kips
Vertical Spring Stiffness without Snubbers, left	70 - A	31.0 kips/inch
Vertical Spring Stiffness without Snubbers, right	70 - A	30.0 kips/inch
Vertical Spring Damping with Snubbers, left	70 - A	5.5 kips
Vertical Spring Damping with Snubbers, right	70 - A	5.0 kips

Notice that the "damping" values here were the bandwidth of the hysteresis plots of force-displacement. The damping values were determined at 40 kips vertical load per spring group for the variable column-damped trucks.

2.2 TEST VEHICLE DESCRIPTION

The three vehicles selected included a 100-ton center beam flatcar, a 100-ton covered hopper car, and a 70-ton tank car. This selection, described in Exhibit 4, represents a range of vehicle types with varying truck center spacings and empty weight.

Exhibit 4. Description of Test Vehicles

Description	Truck Center Spacing	Empty Weight (pounds)
Center beam flatcar	59' 10"	64,000
Covered hopper	40' 6"	61,800
Tank car	29' 9"	56,400

2.3 TEST MEASUREMENTS

The measurements recorded in the jacking test, as shown in Exhibit 5, were wheel vertical and lateral force measured by the instrumented rail segments, vertical displacement of truck suspension, displacement of car body relative to the ground, and variation of side bearing clearances.

Positive measurements were assigned to upward motion for all string pots and the Linear Variable Differential Transformers (LVDT), while negative measurements were assigned to downward motion

The center plates at each end of the car were also inspected at the maximum jacking height to determine if any center pin binding had occurred. Car body twist was determined by measurements at two ends of the car body relative to the ground. Distances between these two measured points along the vehicle were 40 feet 8 inches, 35 feet, and 59 feet 8 inches for the covered hopper, tank car, and flatcar; respectively.

Exhibit 5. Jacking Test Measurements

Channel	Name	Location and Description	Transducer Type
0	FLV1	Left Vertical Rail Force, Axle 1, B-end	Instrumented Rail
1	FLV2	Left Vertical Rail Force, Axle 2, B-end	Instrumented Rail
2	FRV1	Right Vertical Rail Force, Axle 1, B-end	Instrumented Rail
3	FRV2	Right Vertical Rail Force, Axle 2, B-end	Instrumented Rail
4	FLV3	Left Vertical Rail Force, Axle 3, A-end	Instrumented Rail
5	FLV4	Left Vertical Rail Force, Axle 4, A-end	Instrumented Rail
6	FRV3	Right Vertical Rail Force, Axle 3, A-end	Instrumented Rail
7	FRV4	Right Vertical Rail Force, Axle 4, A-end	Instrumented Rail
8	FLL1	Left Lateral Rail Force, Axle 1, B-end	Instrumented Rail
9	FLL2	Left Lateral Rail Force, Axle 2, B-end	Instrumented Rail
10	FRL1	Right Lateral Rail Force, Axle 1, B-end	Instrumented Rail
11	FRL2	Right Lateral Rail Force, Axle 2, B-end	Instrumented Rail
12	FLL3	Left Lateral Rail Force, Axle 3, A-end	Instrumented Rail
13	FLL4	Left Lateral Rail Force, Axle 4, A-end	Instrumented Rail
14	FRL3	Right Lateral Rail Force, Axle 3, A-end	Instrumented Rail
15	FRL4	Right Lateral Rail Force, Axle 4, A-end	Instrumented Rail
16	DSP1	Left Vertical Spring Displacement, B-end	String Pot
17	DSP2	Right Vertical Spring Displacement, B-end	String Pot
18	DSP3	Left Vertical Spring Displacement, A-end	String Pot
19	DSP4	Right Vertical Spring Displacement, A-end	String Pot
21	DCB1	Left Vertical Car body/Bolster Displacement, B-end	LVDT
22	DCB2	Right Vertical Car body/Bolster Displacement, B-end	LVDT
23	DCB3	Left Vertical Car body/Bolster Displacement, A-end	LVDT
24	DCB4	Right Vertical Car body/Bolster Displacement, A-end	LVDT
25	DAZ1	Lead Axle Jacking Height	String Pot
26	DAZ2	Trail Axle Jacking Height	String Pot
27	DJP1	Left Vertical Jack Pad/Ground Displacement, B-end	String Pot
28	DJP2	Right Vertical Jack Pad/Ground Displacement, B-end	String Pot
29	DJP3	Left Vertical Jack Pad/Ground Displacement, A-end	String Pot
30	DJP4	Right Vertical Jack Pad/Ground Displacement, A-end	String Pot

2.4 TEST SETUP

Initially, all wheels of the test vehicle were leveled in a plane and positioned on the instrumented rail. The vehicles were tested empty and the side bearing clearances were set at .25 inch before the jacking tests began.

2.5 TEST PROCEDURE

During the jacking test, two hydraulic cylinders of the same size were operated simultaneously to slowly jack up two wheels on one corner of the vehicle (at the positions of wheel bearing) to 4 inches above their initial level plane. The vehicle was then slowly lowered to the original position. Eight tests were performed — two in each corner of the test vehicle. Results showed the similar responses between corners for the three vehicles; thus, subsequent discussions in this report refer to the situation in which the B-end-left of the vehicle was jacked.

3.0 RESULTS OF JACKING TESTS

The primary measurements during the jacking test were wheel unloading, center plate separation, and car body torsional displacement.

3.1 WHEEL LOADING AND UNLOADING

Vertical load redistribution while one corner of the vehicle was being jacked up caused wheel loading and unloading. Wheel load increased in the diagonal corner opposite to the jacking corner and decreased in the other two corners. The load redistribution was dependent upon cross level differences between the two trucks, the car body type, and the car body weight.

The maximum wheel unloading evaluated as percent of static load for three test vehicles is summarized in Exhibit 6. This presents the unloading situation at A-end-left, when B-end-left was jacked (Exhibit 7). For the covered hopper, the cross level difference ranged between 2.25 inches and 2.6 inches and wheel unloading sharply increased from 25 percent to 57 percent. For the tank car, cross level differences ranged from 2 inches to 2.5 inches while the wheel unloading increased sharply from 13 percent to 68 percent. Wheel load remained constant above 2.6 inches for both vehicles. Based on the unloading mechanism discussed in Section 1.1, both the covered hopper and tank car at the A-end experienced center plate full unloading. The total vertical load at the A-end was carried solely by one side bearing above a certain level jacking height. The initiation of center plate full unloading was also shown by the measurements of side bearing clearance.

The wheel unloading increased somewhat linearly with the cross level difference for the flatcar, although a ratio change could be recognized at 2.4 inches. About 57 percent wheel unloading was recorded at a cross level difference of 4 inches. Compared to the covered hopper and the tank car, the wheel unloading was only about 28 percent at 2.6-inch cross level difference.

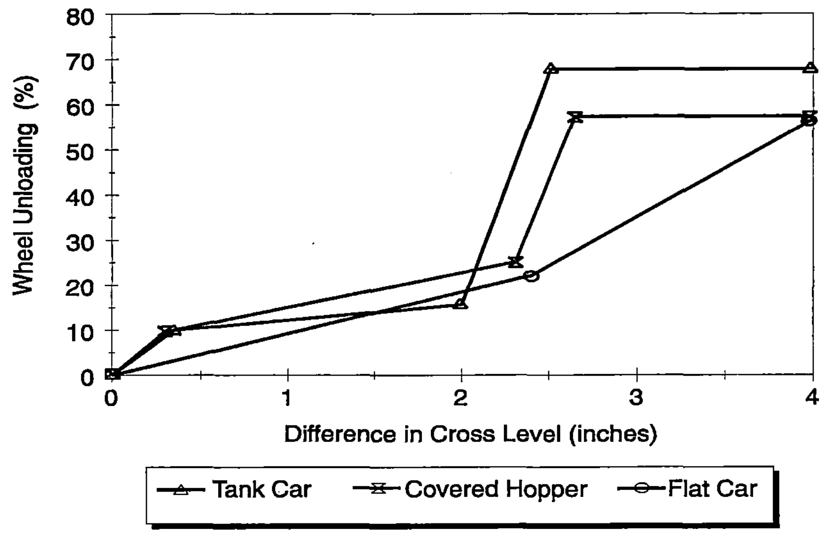


Exhibit 6. Relationship between Static Wheel Unloading and Cross Level Difference

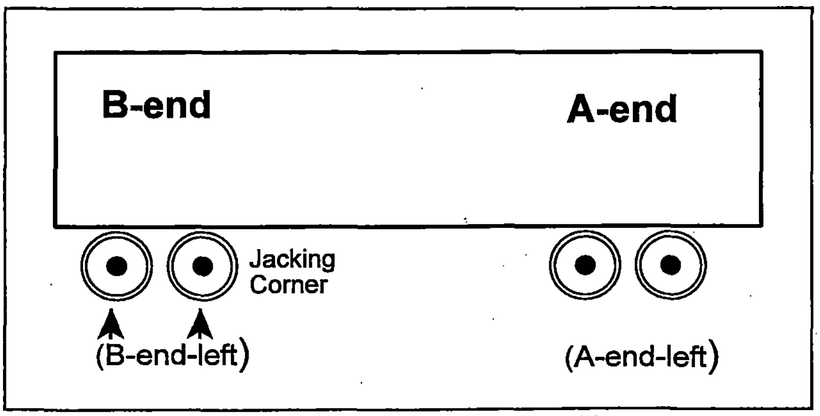


Exhibit 7. Illustration of Jacking Tests

The percentage of wheel unloading at B-end-right was lower than that at A-end-left. Exhibit 8 shows the comparison. Taking the covered hopper as an example, wheel unloading maintained the constant of 33 percent above 2.6 inch cross level difference at B-end-right (see Appendix A) compared to 57 percent at A-end-left. Apparently, above that cross level difference, the load transformation approached a steady state at both ends of the vehicle; however, the center plate full unloading obviously did not occur in the B-end truck as shown by the side bearing clearance measurements discussed in the next section.

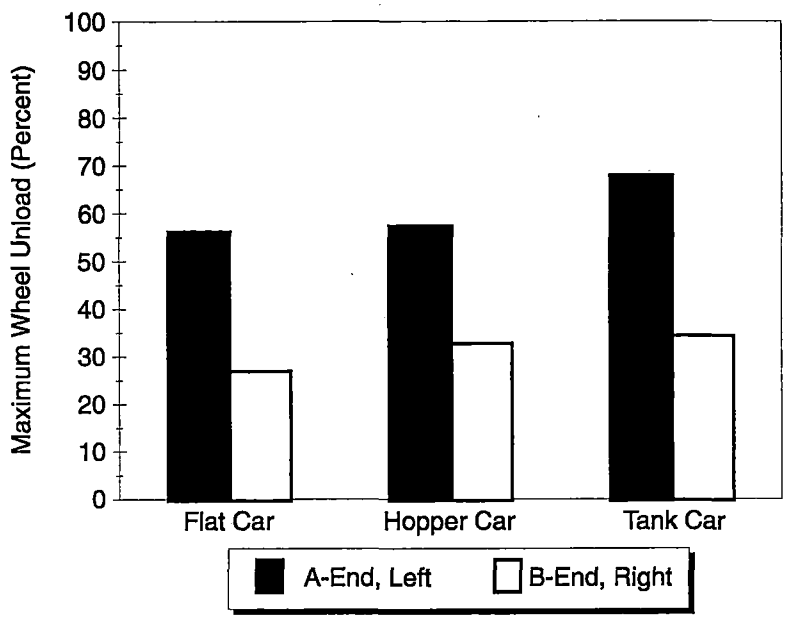


Exhibit 8. Comparison of Maximum Wheel Unloading

3.2 CENTER PLATE UNLOADING

Center plate full unloading was determined by measurements taken at the side bearings. The geometric relation of side bearing and center plate is illustrated in Exhibit 9. The car body rotation center was assumed at the edge of the center plate. The geometric criterion of center plate separation can be defined by Equation 1,

$$H > c_2 + c_1 \frac{D + d}{D - d} \tag{1}$$

where:

H is the side bearing to car body distance,

c_1 and c_2 are the initial settings of side bearing clearance,

D is the distance between the center of two side bearings, and

d is the dimension of the center plate.

If the initial setting of side bearing clearances is the same before the vehicle is exposed to the cross level difference, then $c_1 = c_2 = c$, and Equation 1 can be written as:

$$H > \frac{2cD}{D - d} \tag{2}$$

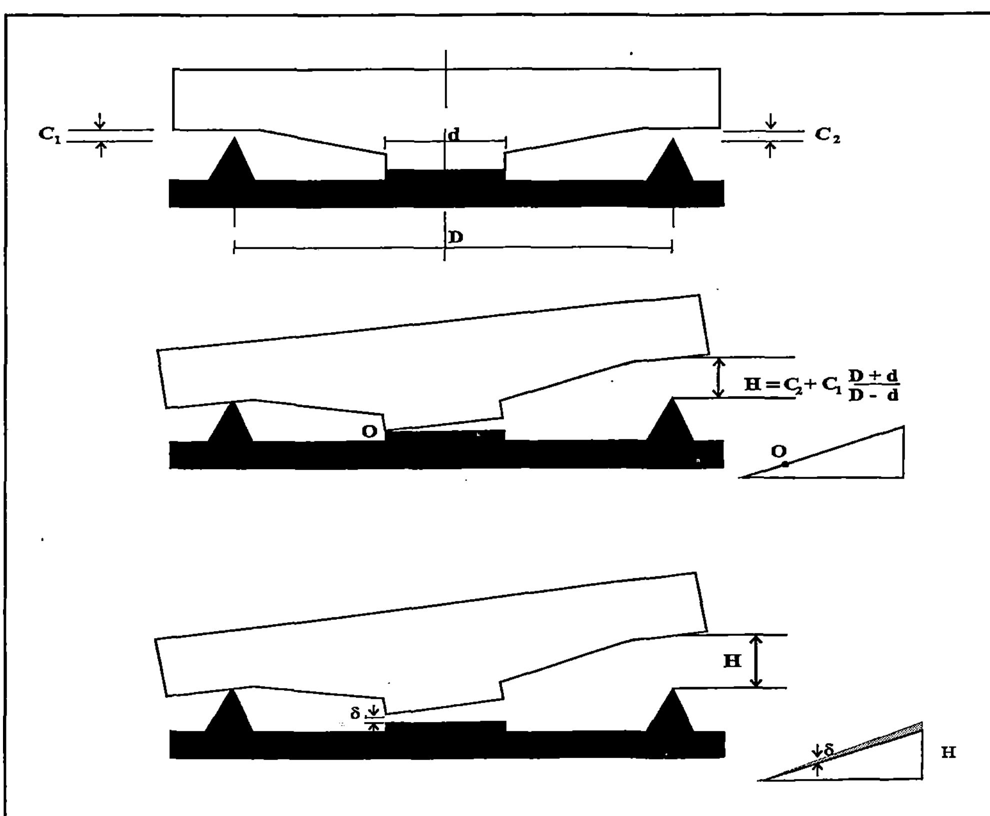


Exhibit 9. Center Plate Separation.

Since the relative motion was measured between the side bearing and the car body, the geometric criterion of center plate separation was not affected by the displacement of truck suspensions. The dimensions and the initial side bearing clearances for three vehicles during the static jacking tests are listed in Exhibit 10.

Using the parameters in Exhibit 10, the geometric criteria of center plate separation for the three test vehicles can be computed using Equation 2 as follows:

$$\begin{aligned} &H_{HC} > 0.68 \text{ inch} && \text{covered hopper} \\ &H_{TC} > 0.67 \text{ inch} && \text{tank car} \\ &H_{FC} > 0.71 \text{ inch} && \text{center beam flat car} \end{aligned} \tag{3}$$

Exhibit 10. Dimensions and Initial Side Bearing Clearances

	Center Beam Flat Car	Covered Hopper Car	Tank Car
D (inch)	50	50	52
d (inch)	15	13	13
c_1 (inch)	0.25	0.25	0.25
c_2 (inch)	0.25	0.25	0.25

** A 1/32-inch tolerance was given for the initial setting of side bearing.*

Exhibit 11 shows the side bearing separation at the maximum unloading corner for the three test vehicles. Notice that the initial clearance was 0.25 inch. At about 2.5 inches cross level difference, the side bearing clearances of the covered hopper and the tank car reached the threshold value of 0.7 inch. This corresponds to the situation presented by

$$H = c_2 + c_1*(D+d)/(D-d),$$

which is the second position of Exhibit 9. The side bearing clearances further increased, to 1.9 inch for the covered hopper car and 1.6 inch for the tank car, at the 4-inch cross level difference. Based on the criteria in Equation 3, center plate full unloading occurred above a 2.5 inch cross level difference. For the flatcar, only a 0.69-inch side bearing clearance was reached at the 4-inch cross level difference. Although it was very close to the threshold value, complete center plate separation did not occur for the flatcar as shown by the continued reduction of vertical forces in Exhibit 6.

Notably, a large percentage of vertical force was transferred from the center plate to the side bearing before the center plate fully separated; hence, the criteria would indicate the completion of the force transfer. It should also be noted that the above criteria are based on a two-dimensional analysis. The rotation center of the center plate is on its center line in the lateral direction. The validity of the two-dimensional assumption has been shown in the track test.[1]

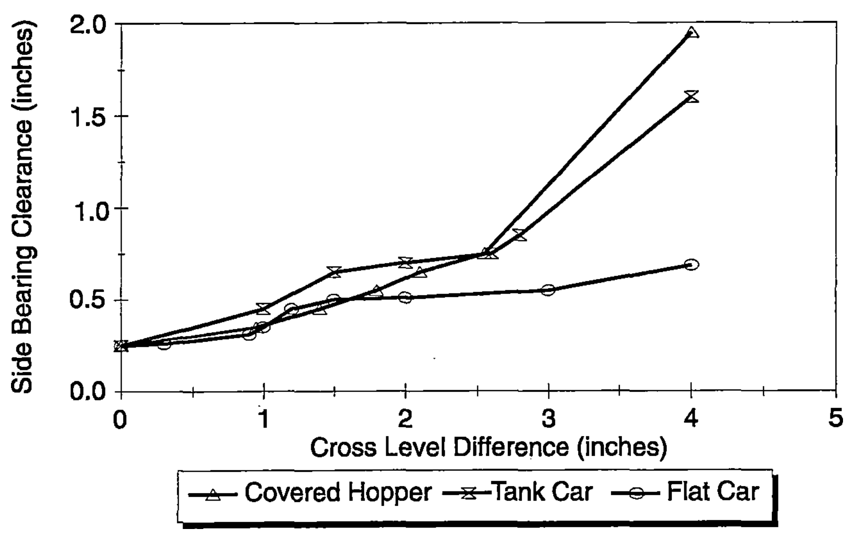


Exhibit 11. Relative Displacement between Car Body and Side Bearing

Once the threshold value was reached, the lack of further increase in side bearing clearance at B-end-right proved that the center plate full separation did not occur at the B-end truck (see Appendix B).

3.3 CAR BODY TORSIONAL DISPLACEMENT

When the corner B-end-left is lifted a distance D_z, the corner A-end-left would be raised the same amount if the car body was rigid. However, in this case, the car body was not rigid. The actual movement of corner A-end-left was less than that at corner B-end-left. The amount of the car body movement was a function of the car body torsional flexibility.

As shown in Exhibit 12, when B-end-left was jacked up 4 inches, the car body at A-end-left was up 1 inch for the flatcar, 2.5 inches for the tank car, and 2.65 inches for the covered hopper car. Although car body torsional stiffness was not quantitatively defined, a qualitative comparison can still be made based on the measurements of the car body movement. Results indicate that the flatcar has higher car body torsional flexibility than the covered hopper car and the tank car.

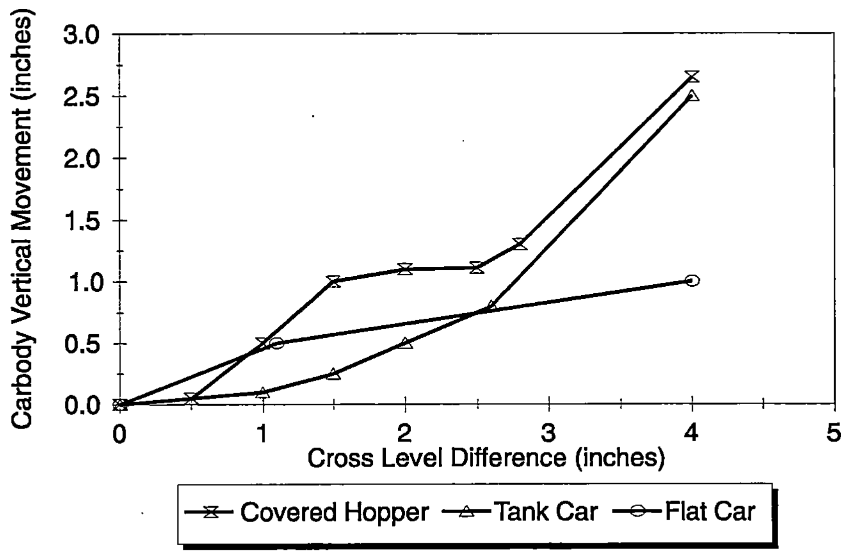


Exhibit 12. Torsional Displacement of Car Body

3.4 <u>WHEEL LATERAL FORCE AND SPRING NESTS DISPLACEMENT</u>

All lateral forces measured at the unloading corners were less than 0.5 kip. The suspension spring nest compressed at the loading corners and extended at the unloading corners. However, the amount of displacement was minimal, as all three vehicles were tested under the empty condition (see Appendix D).

4.0 CONCLUSIONS

Unloaded vehicles with torsionally stiff bodies are more likely to experience a high percentage of wheel unloading on twisted track. Of the three tested vehicles, the covered hopper and the tank car showed more torsional stiffness than the flatcar. For the covered hopper, in the cross level difference ranging from 2.25 inches to 2.6 inches, the wheel unloading increased from 25 percent to 57 percent. For the tank car, in the cross level difference range of 2.0 to 2.5 inches, the wheel unloading sharply increased from 13 percent to 68 percent. Above 2.6 inches, the wheel load remained constant for both vehicles. The flatcar experienced a wheel unloading of 28 percent at a 2.6-inch cross level difference and linearly reached to 56 percent at 4-inch cross level difference.

Wheel unloading occurred in a non-symmetric diagonal pattern. The maximum unloading was recorded on the same side as the jacking corner but at the other end of the vehicle.

The center plate full unloading was detected at the maximum unloading end of the covered hopper and the tank car when the wheel load remained constant above the 2.6-inch cross level. Above that level, the vertical load was only supported by the side bearing at that end of the vehicle. The center plate full separation criterion, which was formed as a function of the geometric dimension of the truck and the pre-set side bearing clearances, agreed with the measurement results.

Based on the jacking test results, the cross level perturbations installed for the track test were determined as 2.25 inches for the covered hopper and the tank car, and 3 inches for the flatcar. This ensured that each vehicle showed maximum sensitivity of wheel unloading to small changes in crosslevel.

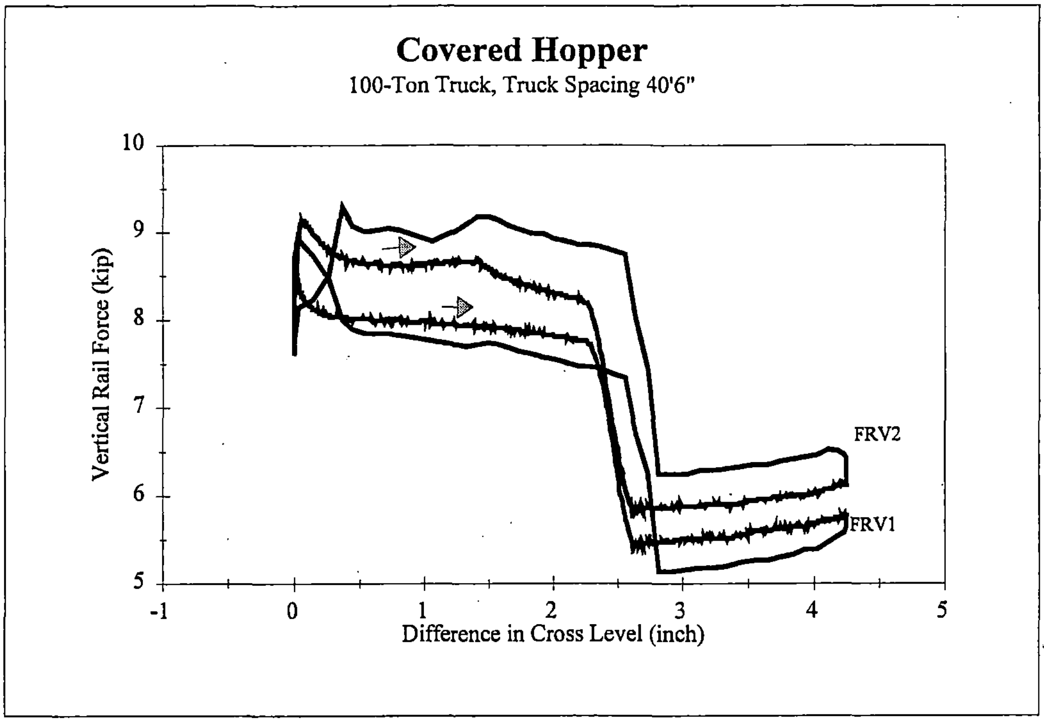
References

1. H. Wu, D. Read. "Effect of Track Twist on Vehicle Dynamic Performance," DOT/FRA/ORD, to be published.

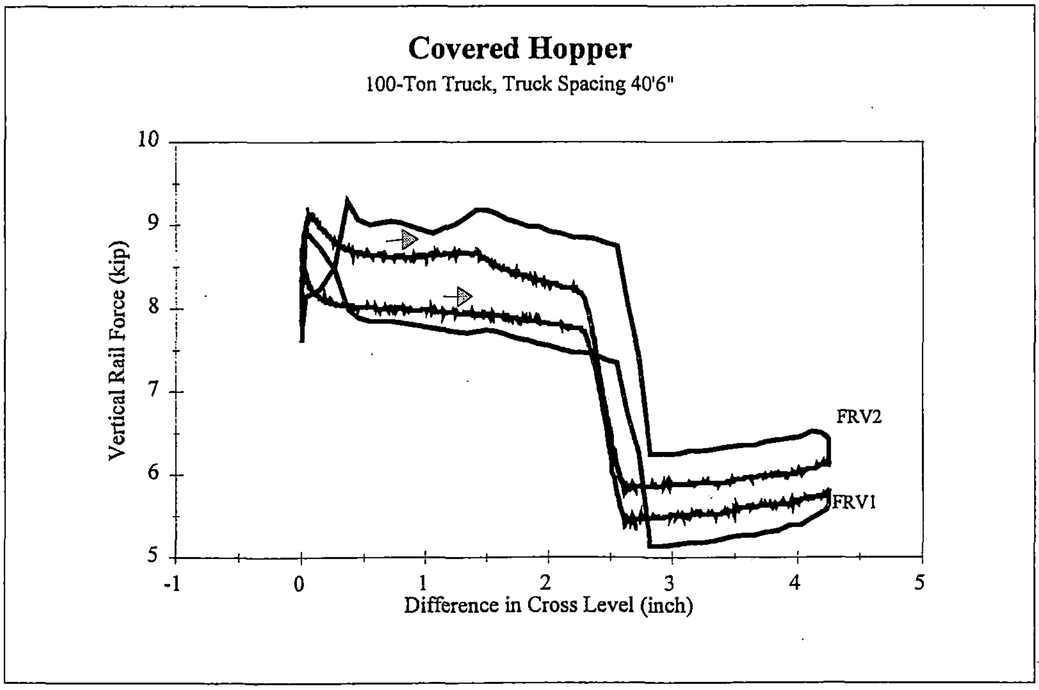
2. D. Tyrell, H. Weinstock, R. Greif. "Wheel Unloading of Rail Vehicles Due to Track Twist," DOT-FRA-ORD-85/14, February 1986.

APPENDIX A:
WHEEL UNLOADING AND LOADING

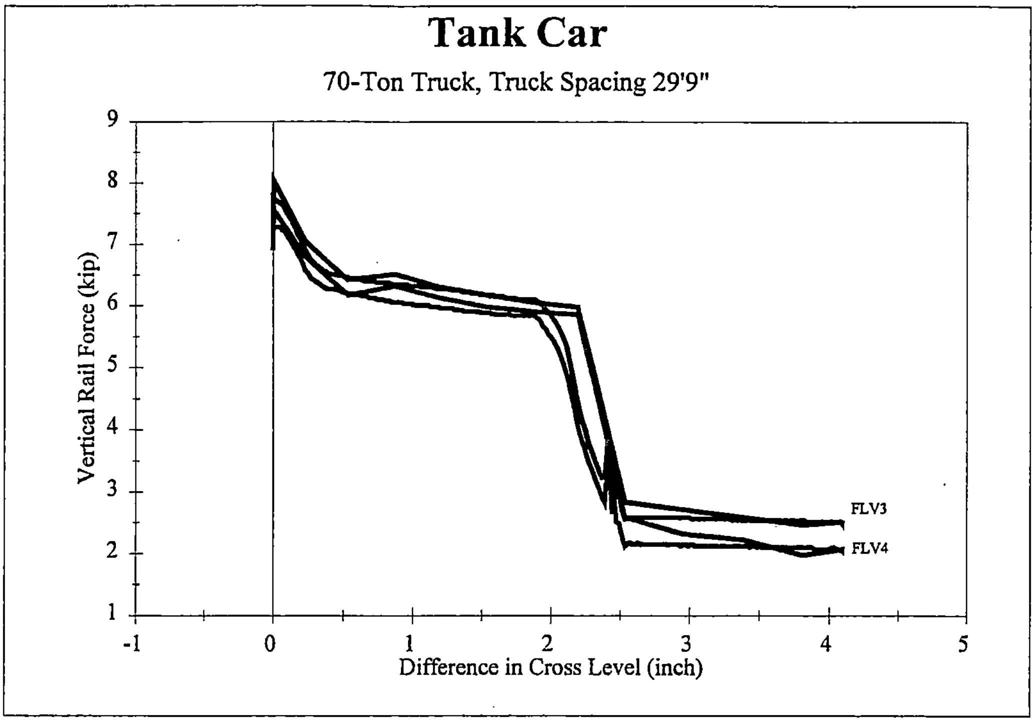
- •A1. Wheel Unloading at A-end Left. B-end Left Was Jacked Up, Covered Hopper
- •A2. Wheel Unloading at B-end Right. B-end Left Was Jacked Up, Covered Hopper
- •A3. Wheel Unloading at A-end Left. B-end Left Was Jacked Up, Tank Car
- •A4. Wheel Unloading at B-end Right. B End-left Was Jacked Up, Tank Car
- •A5. Wheel Unloading at A-end Left. B-end Left Was Jacked Up, Center Beam Flatcar
- •A6. Wheel Unloading at B-end Right. B-end Left Was Jacked Up, Center Beam Flatcar
- •A7. Wheel Loading at A-end Right. B-end Left Was Jacked Up, Covered Hopper
- •A8. Wheel Loading at A-end Right. B-end Left Was Jacked Up, Tank Car
- •A9. Wheel Loading at A-end Right. B-end Left Was Jacked Up, Center Beam Flatcar



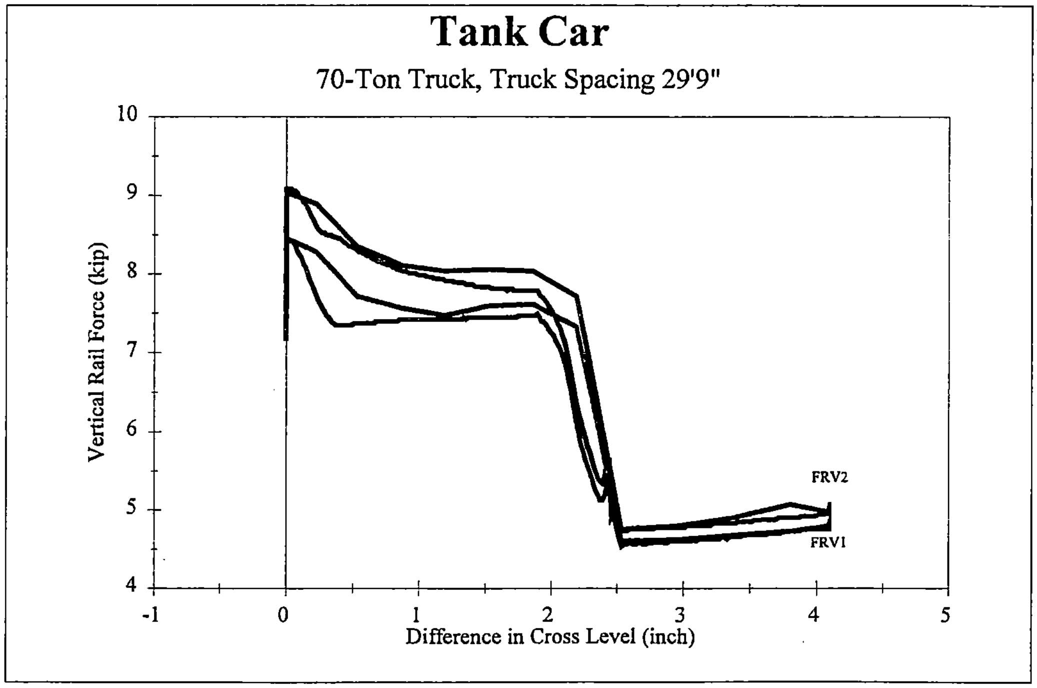
A1. Wheel Unloading at A-end-left. B-end-left was Jacked Up



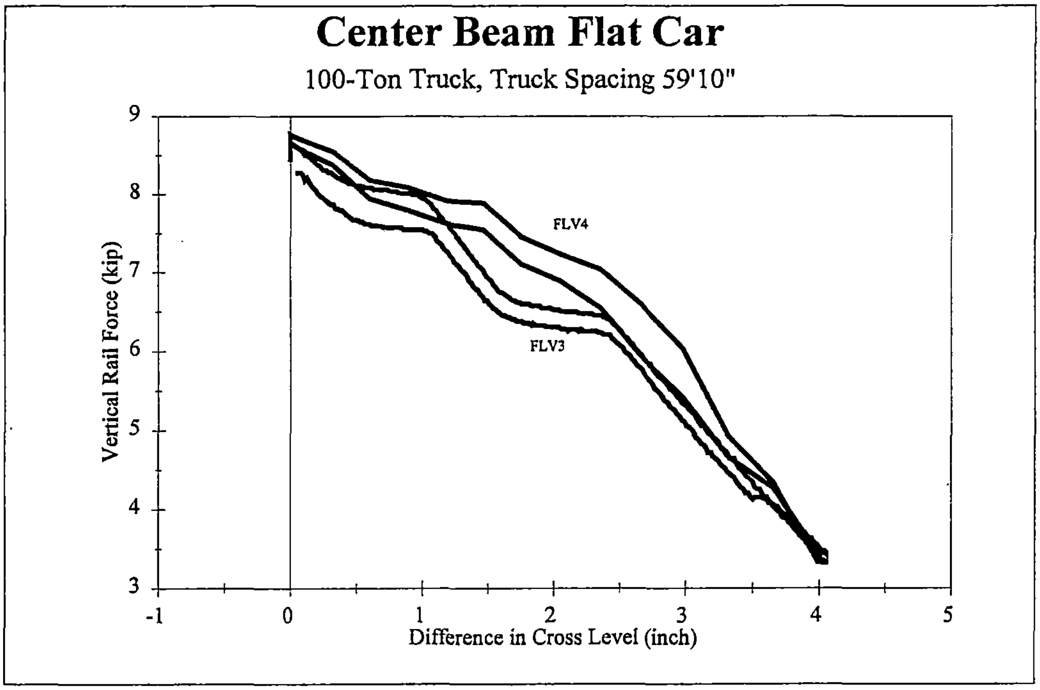
A2. Wheel Unloading at B-end-right. B-end-left was Jacked Up.



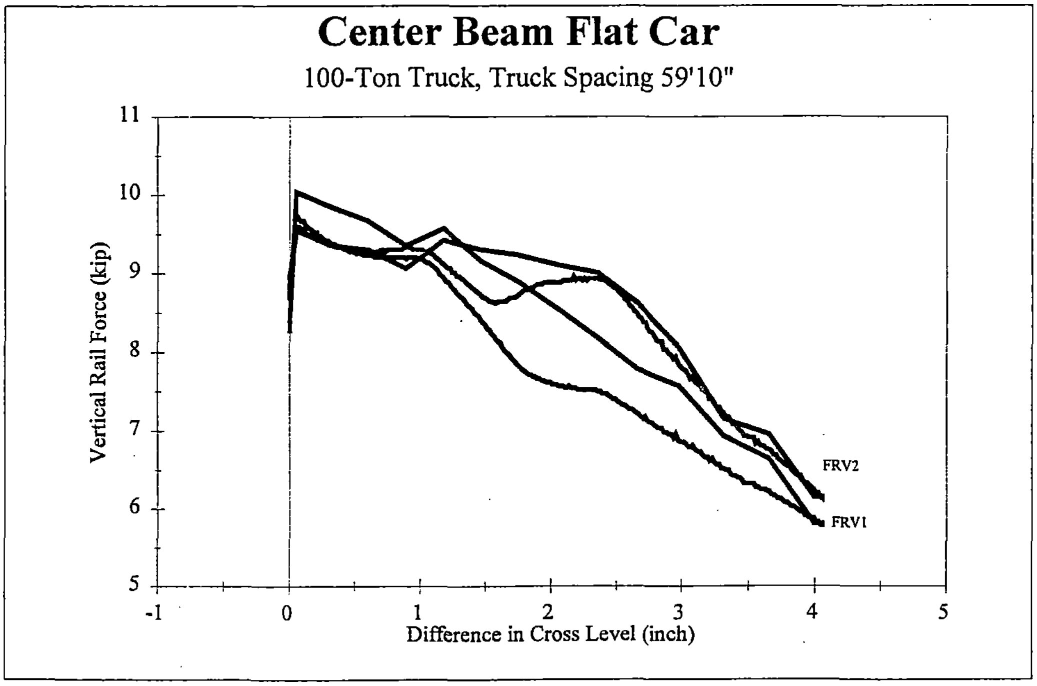
A3. Wheel Unloading at A-end-right. B-end-left was Jacked Up.



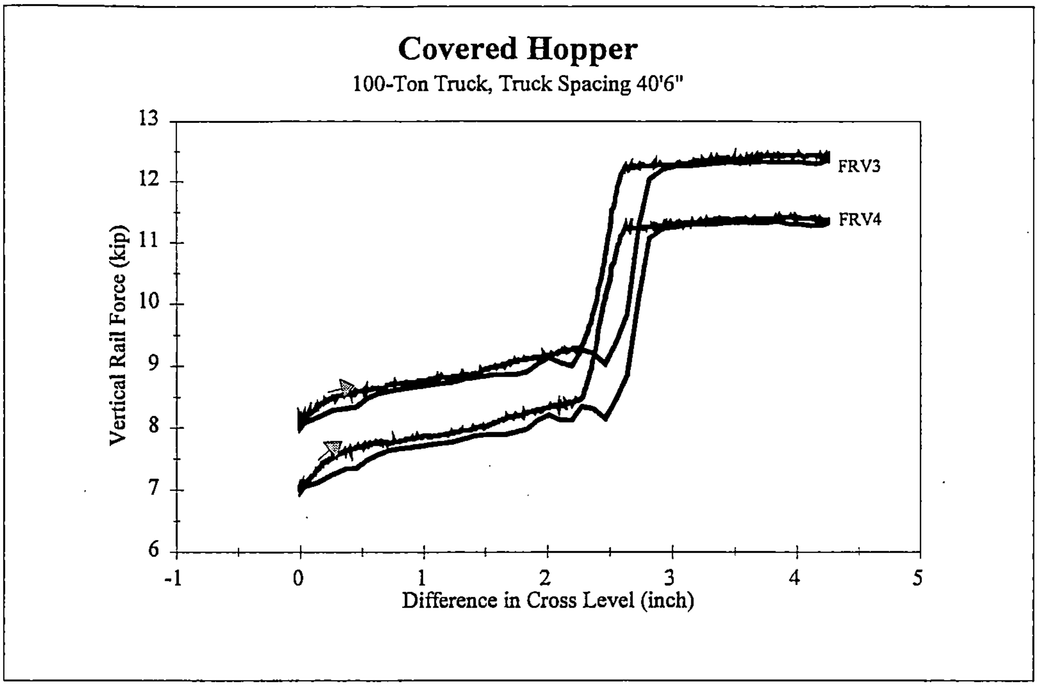
A4. Wheel Unloading at B-end-right. B-end-left was Jacked Up



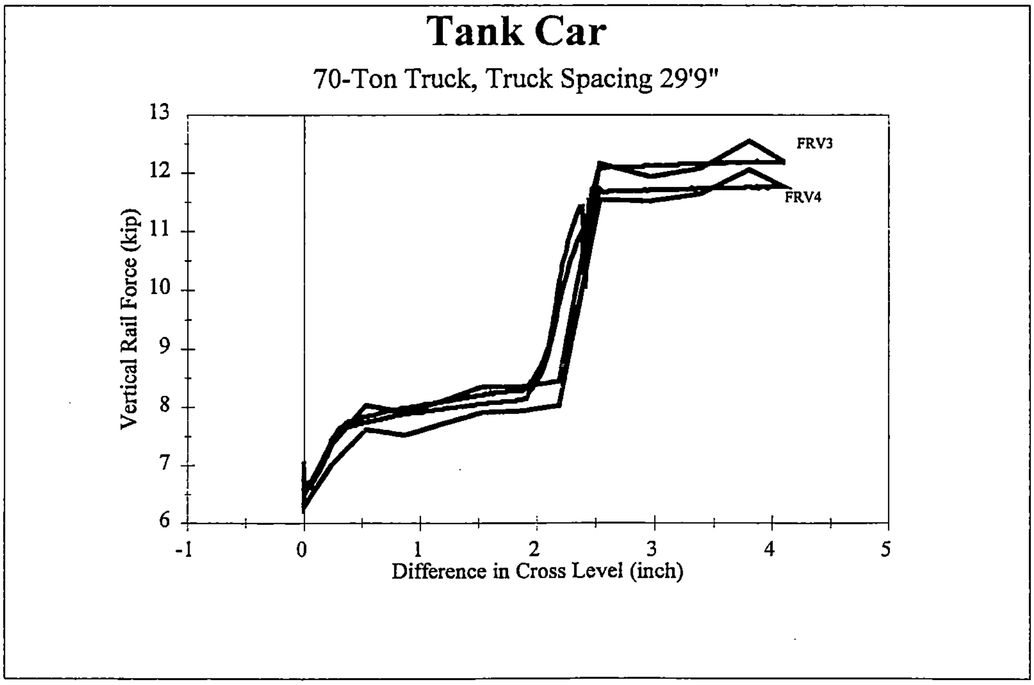
A5. Wheel Unloading at A-end-left. B-end-left was Jacked Up



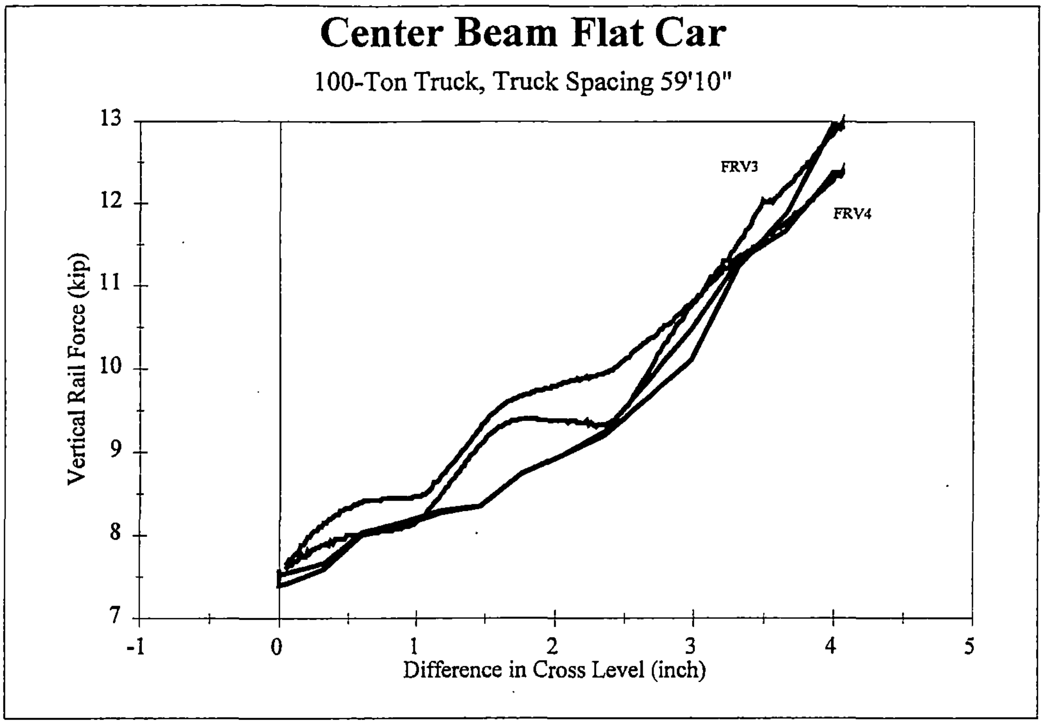
A6. Wheel Unloading at B-end-right. B-end-left was Jacked Up.



A7. Wheel loading at A-end-right. B-end-left was Jacked Up



A8. Wheel loading at A-end-right. B-end-left was Jacked Up

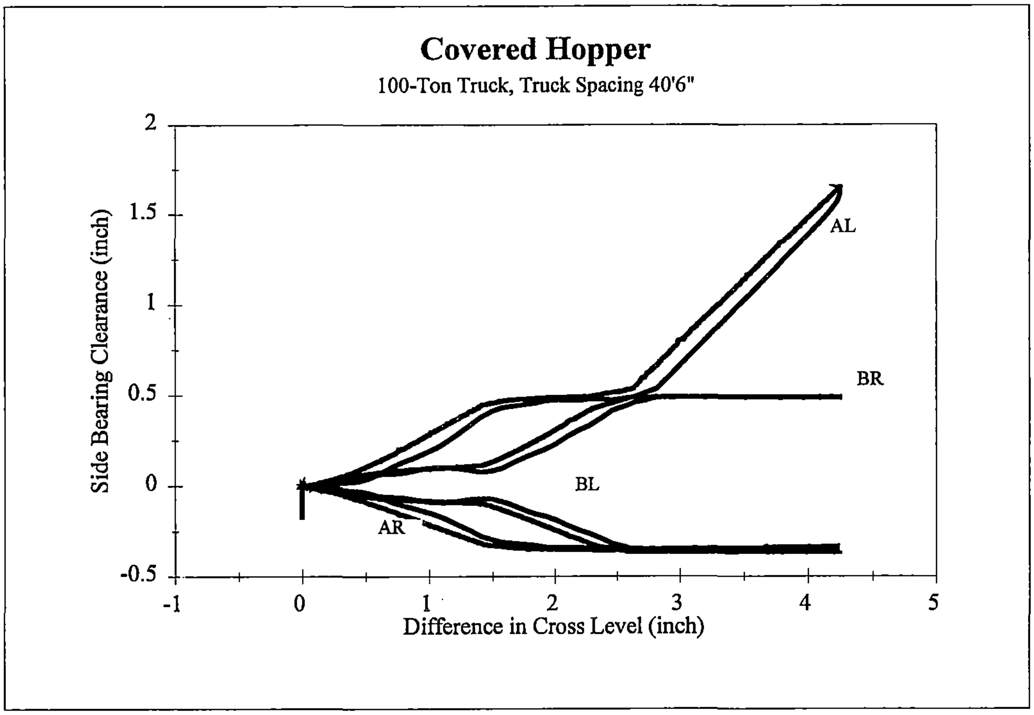


A9. Wheel loading at A-end-right. B-end-left was Jacked Up

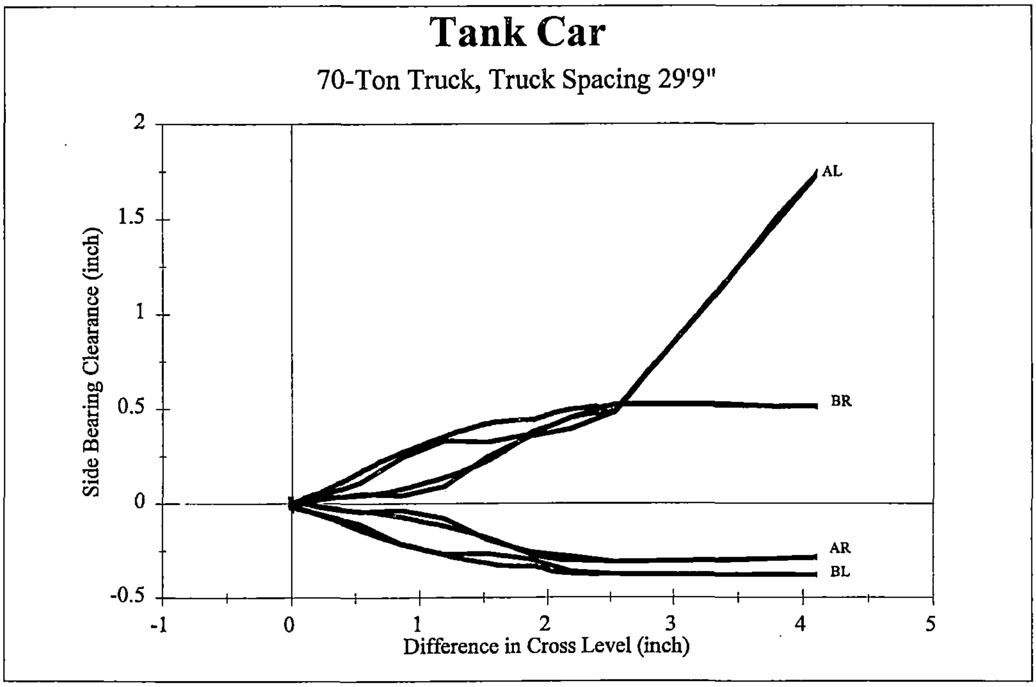
APPENDIX B:

VARIATION OF SIDE BEARING CLEARANCES

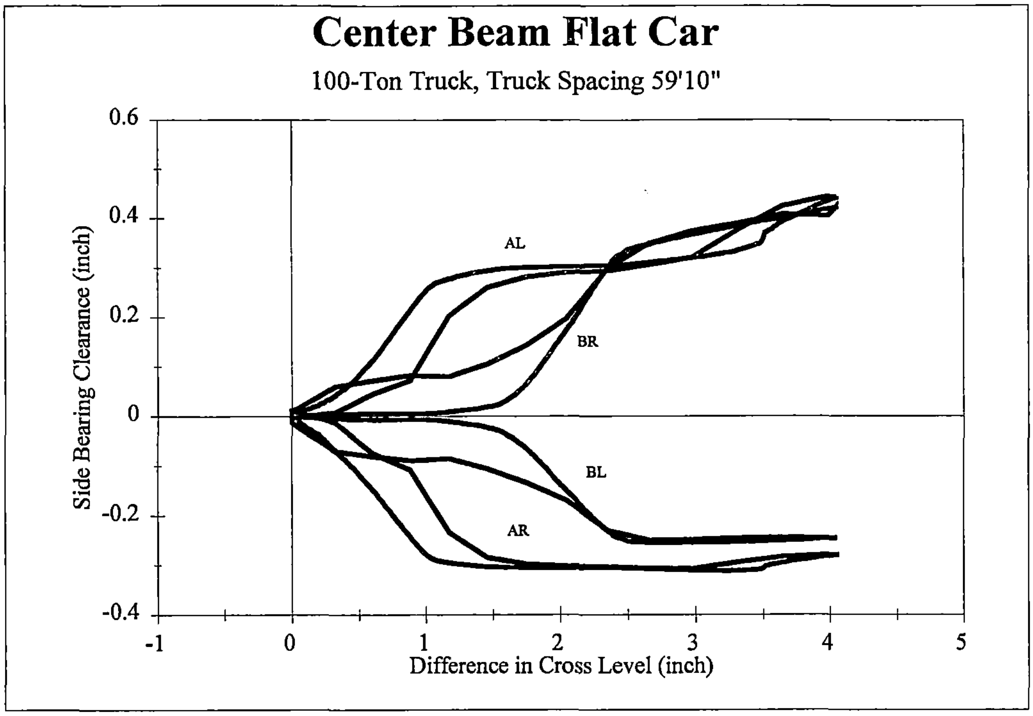
- •B1. Variation of Side Bearing Clearances: B-end Left Was Jacked Up, Covered Hopper
- •B2. Variation of Side Bearing Clearances: B-end Left was Jacked Up, Tank Car
- •B3. Variation of Side Bearing Clearances: B-end Left was Jacked Up, Center Beam Flatcar



B1. Variation of Side Bearing Clearance. B-end-left was Jacked Up
(Side Bearing Learances were Set in 0.25 Inch Before the Test)



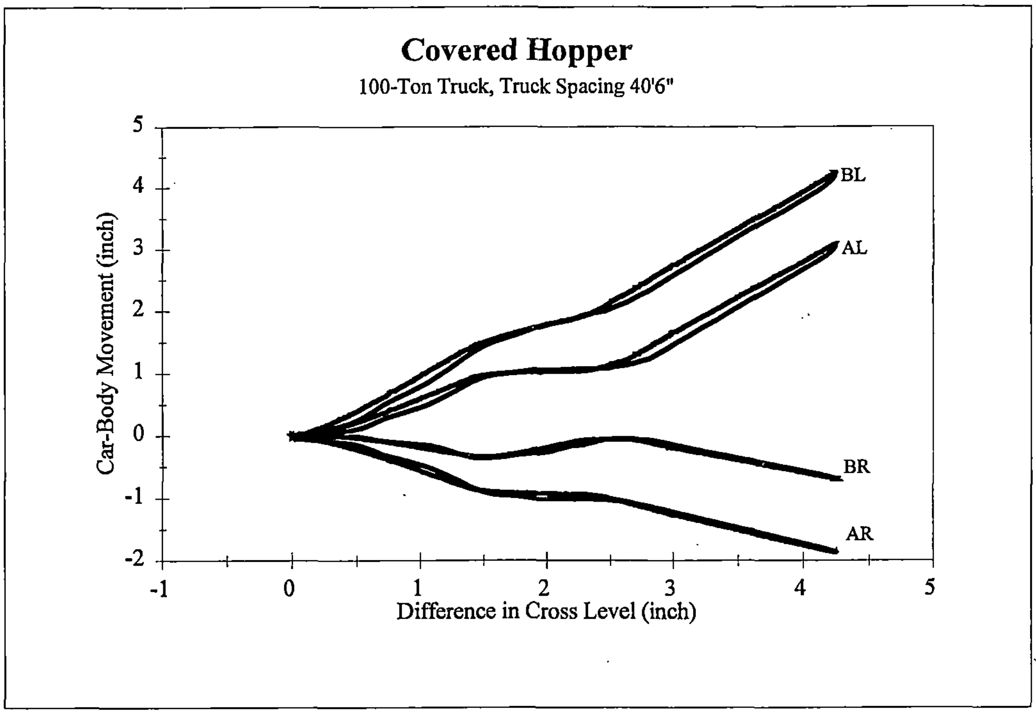
B2. Variation of Side Bearing Clearance. B-end-left was Jacked Up
(Side Bearing Learances were Set in 0.25 Inch Before the Test)



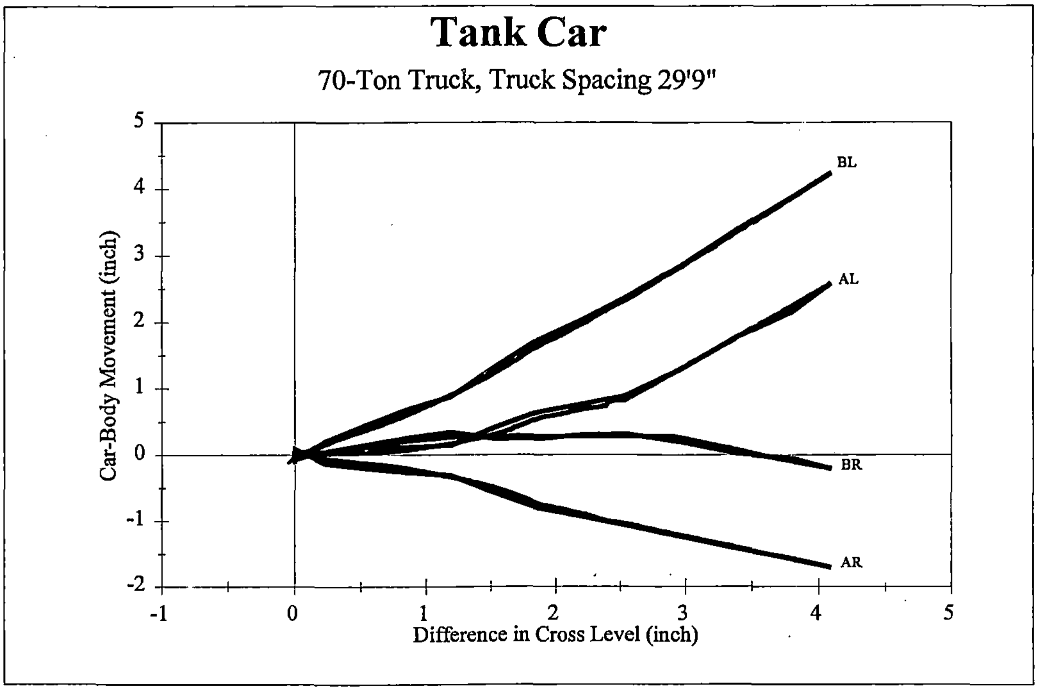
B3. Variation of Side Bearing Clearance. B-end-left was Jacked Up.
(Side Bearing Learances were Set in 0.25 Inch Before the Test)

APPENDIX C:
CAR BODY MOVEMENT RELATIVE TO THE GROUND

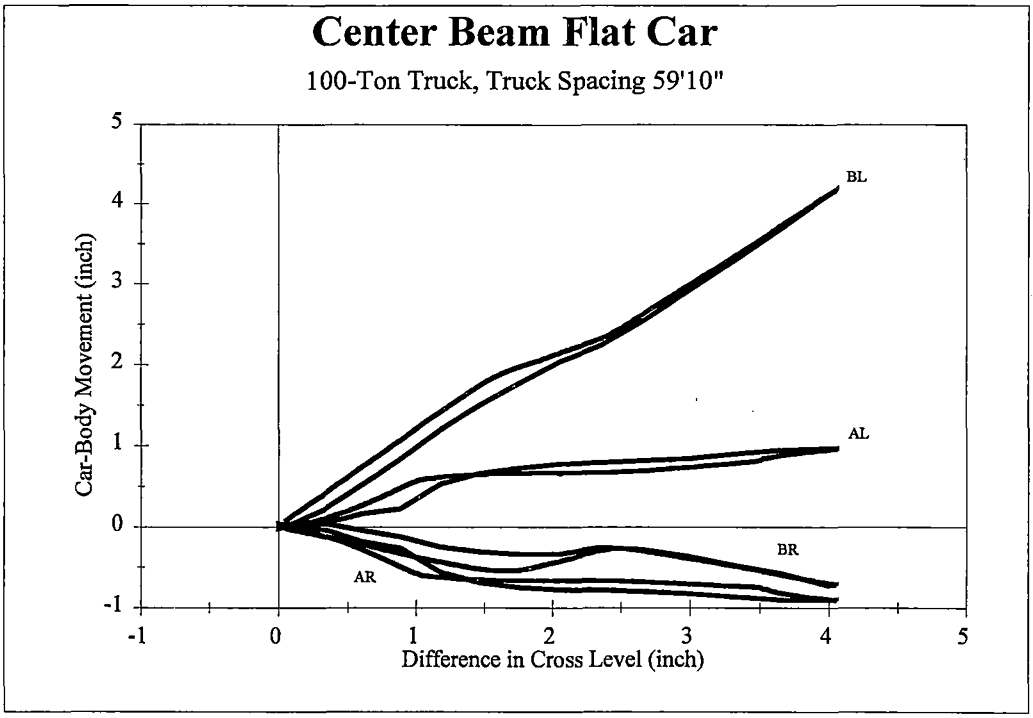
- C1. Car Body Movement Relative to the Ground: B-end Left was Jacked Up, Covered Hopper
- C2. Car Body Movement Relative to the Ground: B-end Left was Jacked Up, Tank Car
- C3. Car Body Movement Relative to the Ground: B-end Left was Jacked Up, Center Beam Flatcar



C1. Car-Body Movement Relative to the Ground. B-end-left was Jacked Up



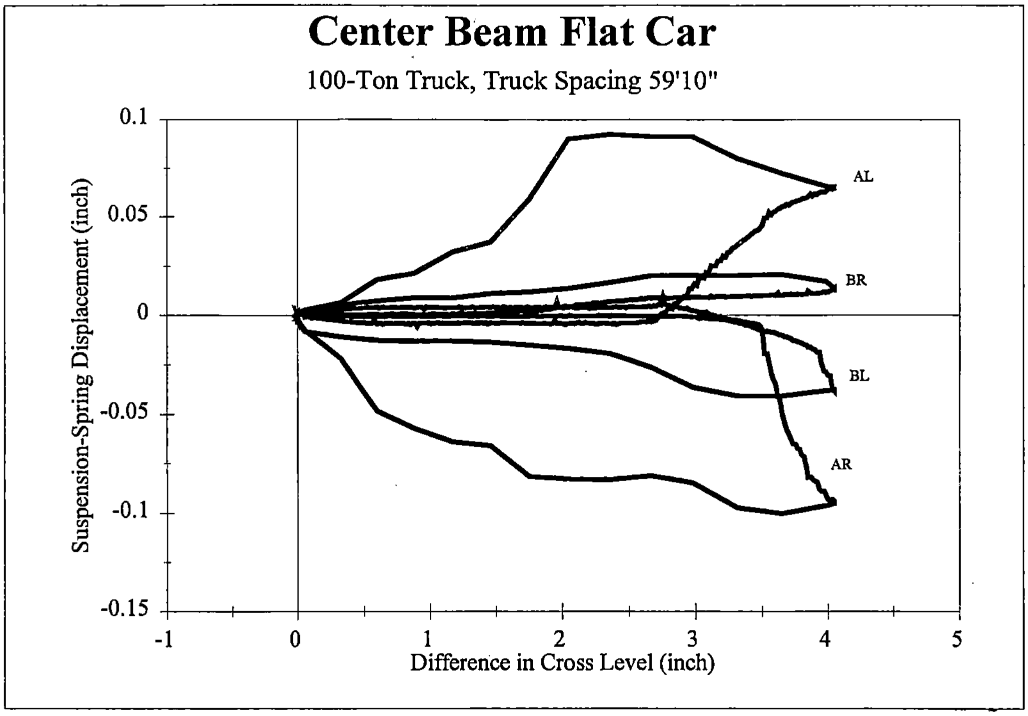
C2. Car-Body Movement Relative to the Ground. B-end-left was Jacked Up



C3. Car-Body Movement Relative to the Ground. B-end-left was Jacked Up

APPENDIX D:
DISPLACEMENT OF SUSPENSION SPRINGS

- •D1. Displacement of Suspension Springs: B-end Left was Jacked Up, Covered Hopper
- •D2. Displacement of Suspension Springs: B-end Left was Jacked Up, Tank Car
- •D3. Displacement of Suspension Springs: B-end Left was Jacked Up, Center Beam Flatcar



D3. Displacement of Suspension Spring. B-end-left was Jacked Up
(Ride Control Constant Damped Truck)

Results of Laboratory Quasi-Static Jacking Tests on Three Vehicles, AAR Research Report, 1998
Association of American Railroads, Transportation Technology Center, Huimin Wu

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