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Wheel Rail Forces Measured Under Severe Track Geometry Alignment Variations

Office of Safety
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Washington, DC 20590

1984 Vehicle Track Interaction Tests

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Research and Special Programs Administration
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16. Abstract

This report describes a series of vehicle track interaction tests conducted from October 1984 to December 1984, under the Federal Railroad Administration (FRA) Improved Track Safety Research Program, at the Department of Transportation, Transportation Test Center (TTC) at Pueblo, Colorado.

The test results provide a base of measured data on a broad range of track geometry irregularity amplitudes and wavelengths, over a range of operating speeds for three types of freight cars, in loaded and empty conditions, with two types of wheel profiles. The types of rail cars tested included 100-ton open hopper cars, 70-Ton Flatcars and 100-Ton Tank Cars. The rail cars were tested over specially constructed track test sections which had sinusoidal alignment perturbations with 39 foot, 50 foot, 75 foot and 90 foot wavelengths. The amplitudes of the perturbations were selected, using the results of analytical simulation studies to provide approximately equal dynamic severity at the critical operating speed for the most critical train consist for that section.

The cars were tested in both loaded and unloaded conditions and with AAR new wheel 1/20 profiles and with a Heumann worn wheel profile. The results of the tests are presented as plots of peak wheel rail force as a function of speed for each of the cars and test sections.

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PREFACE

This report describes a series of vehicle track interaction tests conducted from October 1984 to December 1984 under the Federal Railroad Administration (FRA), Improved Track Safety Research Program. This program is being conducted by the Transportation Systems Center (TSC) under the direction of the Office of Rail Safety Research of the FRA. The tests were conducted at the Department of Transportation, Transportation Test Center (TTC), at Pueblo, Colorado operated by the Association of American Railroads (AAR).

The information from these tests is being applied to the definition of acceptable limits for track geometry variations and for validation of analysis tools for predicting rail car dynamic performance.

The rail cars used in these tests were borrowed from the FAST Program consist provided by the railroad industry. The special track sections used in these tests were constructed by the AAR. Personnel from AAR/TTC and the FRA Instrumentation Contractor, ENSCO, Inc. participated in the instrumentation of the cars and in the conduct of the tests. TSC was responsible for the definition of the test requirements and test direction. Michael Coltman and Raymond Ehrenbeck of TSC acted as test directors during the conduct of the tests.

ENSCO was responsible for the operation of the two locomotive instrumented wheelsets (fabricated by ASEA), the two 70-ton freight car instrumented wheelsets (fabricated by ENSCO), the location detectors, and the FRA T-6 track geometry measurement vehicle. AAR was responsible for the operation of the Heumann profile freight car instrumented wheels (fabricated by IITRI), carbody transducers such as roll gyros, displacement transducers, and video cameras, and the operation of the FRA T-7 instrumentation car. Carbody accelerometers were provided to AAR from the FRA equipment inventory maintained by ENSCO in Colorado Springs, Colorado.

METRIC / ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

$[(x - 32)(5/9)]$ °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

$[(9/5)y + 32]$ °C = x °F

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES	0	1	2	3	4	5	6	7	8	9	10

CENTIMETERS 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 | 25.40

QUICK FAHRENHEIT-CELCIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and/or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10 286.

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EXECUTIVE SUMMARY

This report describes a series of vehicle track interaction tests conducted from October 1984 to December 1984 under the Federal Railroad Administration (FRA) Improved Track Safety Research Program. This program is being conducted by Transportation Systems Center (TSC) under the direction of the Office of Rail Safety Research of the FRA. The Tests were conducted at the Department of Transportation, Transportation Test Center (TTC) at Pueblo, Colorado operated by the Association of American Railroads (AAR).

In cooperation with the railroad industry, the Federal Railroad Administration (FRA) has been sponsoring research to develop analysis tools and experimental data to quantify the behavior of railroad vehicles operating on track with known track geometry irregularities. This information is being applied to the development of performance based specifications for acceptable track geometry variations and the required strength of railroad track and components. The results are also being applied to the development of techniques and criteria to evaluate the safety of new types of railroad equipment.

In order to extrapolate the results of controlled track tests to a broader range of track conditions and to evaluate new vehicle designs, computer simulation programs have been developed. The computer program SIMCAR developed under the FRA Improved Track structures Research Program is currently being used at Transportation Systems Center (TSC) to define limits on the acceptable range of track geometry variations to permit safe dynamic performance of the current rail car fleet. The Association of American Railroads (AAR) is currently developing the NUCARS program for simulating the performance of vehicles which incorporate new and untried design features.

Tests conducted to develop and evaluate the SIMCAR program include low speed tests (up to 30 mph) at Starr, Ohio, on Chessie System Track in June 1981 and at Bennington, New Hampshire, on the Boston and Maine track in September of 1982. These tests were limited in speed and in amplitude of track irregularity by the rail restraint capacity of the relatively weak track selected for the measurements. The tests were also limited to measurements on a partially loaded 100 ton hopper car.

The tests described in this report were intended to provide a base of measured data on a broader range of track geometry irregularity amplitudes and wavelengths, over a wider range of operating speeds for three types of freight cars, in loaded and empty conditions, with two types of wheel profiles. The types of rail cars tested included 100-ton open hopper cars, 70-ton Flatcars and 100-ton tank cars. The rail cars were tested over specially constructed track test sections which had sinusoidal alignment perturbations with 39 foot, 50 foot, 75 foot and 90 foot wavelengths. The amplitudes of the perturbations were selected, using the results of analytical simulation studies conducted with the "SIMCAR" computer program described in Reference 1, to provide approximately equal dynamic severity at the critical operating speed for the most critical train consist for that section.

Three test sections were constructed for the alignment perturbation tests. Section 2 was the low speed test section with a maximum expected test speed of 30 mph. Section 3 represented an intermediate test section for speeds up to 60 mph. Section 4 was intended for speeds up to the maximum speed attainable by the locomotive. The cars were tested in both loaded and unloaded conditions and with AAR new wheel 1/20 profiles and with a Heumann worn wheel profile. Because of limitations in available instrumented wheelsets, 70 ton instrumented wheel sets were used for the AAR profile tests on the 100 ton cars. These wheelsets were installed in 100 ton trucks using special bearing adapters.

Test Section 1 was constructed to simulate extreme track twist conditions for validation of unloading calculations made to define allowable twist specifications. The results of the tests conducted on Section 1 are described in Reference 2.

This report concentrates on the results obtained from the alignment perturbation tests. Section 2 provides a description of the test consist and test instrumentation. Section 3 describes the test zones and details of the track construction and geometry stability during the tests. Section 4 provides the procedures and chronology of the conduct of the test. The results of the wheel rail force measurements are presented in Section 5. The wheel rail forces measured in the tests are compared with those computed using the "SIMCAR" program and with earlier data obtained at Bennington, New Hampshire in Section 6.

SUMMARY OF TEST RESULTS

GENERAL OBSERVATIONS

The range of Speeds covered in these tests was limited by the capabilities of the GP-9 locomotive used in the test consist. The locomotive generated wheel rail forces and L/V ratios under these test conditions that approached the safe limits prescribed for the tests. Studies directed towards defining maximum loads on track structures should include consideration of locomotive dynamic behavior as well as freight car behavior.

The interpretation of the data was confused by the low speed filters applied to the signals from the instrumented AAR profile freight car wheelsets and sensitivities of the signals to the lateral position of the wheelset. The data from these wheelsets at low speed differed strongly from expected results, however, a review of the instrumentation indicated no clear reason for the differences. Future testing should include a more detailed calibration of the wheelsets and design to minimize the sensitivities to position of the wheel rail contact under large variation conditions.

The use of Heumann profiles on conventional truck designs did not result in a reduction of wheel rail forces in traversing large alignment irregularities. For unloaded cars, the Heumann wheel profile produced significantly larger L/V ratios than the AAR profile. More conclusive data is needed to establish the relative safety of different wheel profiles for conventional truck designs.

Changes in amplitude of sinusoidal alignment perturbations result in very significant changes in the peak force vs speed characteristic of rail cars. Extrapolations of test results must therefore be made with extreme caution. Tests and analyses to establish safe limits must be conducted at the extreme limits.

For the alignment variations tested, the ride vibration levels generated in the locomotive and instrumentation car were a much more severe limitation on maximum test speed than the likelihood of derailment of the freight cars tested. In the specification of allowable alignment deviations it would be desirable to include control of ride vibration experienced by train operating personnel as a criterion.

The wheel rail forces generated by the freight cars with worn wheel profiles were consistent with predictions made using the SIMCAR program. It is therefore concluded that SIMCAR is a reasonable valid tool for estimating wheel rail forces generated by alignment variations over speeds up to 50 mph. Further testing will be required to establish a sufficient data base for analysis tools capable of predicting rail car response at higher speed. Further testing will also be required to quantify the effects of wheel profile variations.

MAXIMUM LATERAL FORCES

The largest wheel rail forces measured during the tests were produced by the locomotive in segment 4.4 (75 foot wavelength - 3.25 inch peak to peak) at a speed of 50 mph with a peak measured lateral force of about 42 kips. For the freight cars, the largest lateral wheel rail load was produced by the tank car with a peak lateral force of about 24 kips as measured in segment 2.3 (50 foot wavelength - 3.5 inch peak to peak) at a speed of 20 mph.

MAXIMUM L/V RATIOS

For the locomotive, the maximum L/V ratio measured was 0.9 in segment 4.4 at a speed of 50 mph. For the freight cars tested, the largest L/V ratio measured was for the unloaded tank car with the AAR profile wheels. For the unloaded tank car with the AAR wheel profile an L/V ratio of 1.3 was measured at 36 mph in segment 4.3 (50 ft wavelength- 1.25 inch peak to peak).

For the freight cars in the lower speed sections, the largest L/V ratios were experienced by the unloaded flatcar with Heumann profile wheels. For the 39 foot wavelength sections, L/V ratios in excess of 0.8 are measured for the Heumann wheel profile at all speed ranges. In the 50 foot wavelength low speed and intermediate speed sections, L/V ratios of 0.9 are measured for the Heumann profile. For the 75 foot wavelength, in the low speed and intermediate speed sections, and in the 90 foot intermediate speed section, the Heumann profile L/V ratios were about 1.0.

INFLUENCE OF WHEEL PROFILE

With the exception of the 39 foot wavelength sections and the unexpected results produced by the AAR profile wheelsets at low speed, the lateral forces measured by the Heuman profile wheels and by the AAR profiled wheels were generally of comparable magnitudes. In the 39 foot sections, the AAR profile wheels (including the locomotive) produced much smaller lateral forces than the Heumann profile wheel. It is believed that this results from a smaller effective flange clearance for the Heumann wheel than for the AAR profile wheel.

The behavior of the L/V ratios generated by the two wheel profiles appears to be strongly influenced by the car weight. For the loaded hopper car and the loaded tank car, the L/V ratios (with the exception of the intermediate and high speed 39 foot sections) measured for the AAR profile wheel were comparable or larger than those measured for the Heumann profile. For the loaded flat car, the L/V ratios for the AAR wheel profile were comparable or larger than those for the Heumann profile at the 75 and 90 foot wavelengths. However, at the 39 foot and 50 foot wavelengths, the Heumann profile wheel generated larger L/V ratios than the AAR profile wheel for the loaded flatcar.

For the unloaded flatcar, the L/V ratios generated by the Heumann wheel profile are much larger than those generated by the AAR wheel profile. The L/V ratios generated by the Heumann wheel profile on the unloaded hopper cars also tended to be larger or comparable to those generated by the AAR wheel profile. For the empty tank car, the L/V ratios generated by the two wheel profiles are similar and small except for the behavior observed in the 50 foot wavelength section at speeds of 35 and 36 mph where the AAR wheel profile generates L/V ratios of 1.1 and 1.3 while the Heumann profile L/V ratio remains at about 0.3.

INFLUENCE OF CAR WEIGHT

The magnitude of the peak lateral forces measured in the tests tended to be proportional to the weight of the car on the rail. Lightly loaded cars developed significantly higher wheel L/V ratios than fully loaded cars.

INFLUENCE OF WAVELENGTH AND SPEED

The peak lateral forces generated by the locomotive were relatively insensitive to speed, for speeds less than 35 mph, for the 39 foot, 75 foot and 90 foot wavelengths. At the 3.5 inch peak to peak 50 foot wavelength, the locomotive forces increased with speed from about 20 kips at 4 mph to about 30 kips at 28 mph. However, at the 1.75 inch peak to peak 50 foot wavelength, there was almost no sensitivity to speed up to 30 mph, with the peak force remaining uniform at a level of about 19 kips. This result would indicate that the shape of the peak force-speed characteristic is dependent on the amplitude of the perturbation.

Above 35 mph, the peak locomotive wheel forces were relatively insensitive to speed for wavelengths of 39 and 50 feet. However, above 35 mph the wheel rail forces generated by the locomotive in the 75 foot wavelength section increase very rapidly with speed. For the 34 foot truck center spacing of the locomotive, the 75 foot wavelength produces a locomotive yaw mode input. The peak locomotive wheel forces in the 90 foot section also increase with speed above 35 mph, but not as rapidly as in the 75 foot section.

The freight cars tested with the Heuman wheelsets did not show as strong a sensitivity of peak lateral wheel forces to speed variations as the locomotive. In the low speed test sections, independent of wavelength, the peak lateral wheel rail forces measured for the Heumann profile were relatively independent of speed for speeds less than 25 mph. In the intermediate speed sections, the largest speed sensitivities were observed at wavelengths of 50 and 75 feet. The amplitude of the perturbation had a significant affect on the shape of the peak lateral force speed characteristics at a given wavelength.

1. INTRODUCTION

In cooperation with the railroad industry, the Federal Railroad Administration (FRA) has been sponsoring research to develop analysis tools and experimental data to quantify the behavior of railroad vehicles operating on track with known track geometry irregularities. This information is being applied to the development of performance based specifications for acceptable track geometry variations and the required strength of railroad track and components. The results are also being applied to the development of techniques and criteria to evaluate the safety of new types of railroad equipment.

Until recently, efforts to quantify the wheel rail forces that exist in rail vehicle operation over track having irregular track geometry were limited by a lack of adequate measurement instrumentation and analysis tools. A further difficulty exists in the high degree of variability of the wheel rail forces with small variations in test conditions (e.g. wet or dry track) or in wheel and rail profiles. The development of accurate and reliable instrumented wheelsets for wheel rail force measurement in the 1970's and 1980's combined with the availability of track for research testing at the Department of Transportation, Transportation Test Center at Pueblo, Colorado, operated by the Association of American Railroads (AAR), has improved the feasibility of conducting controlled track tests.

In order to extrapolate the results of controlled track tests to a broader range of track conditions and to evaluate new vehicle designs, computer simulation programs have been developed. The computer program SIMCAR, developed under the FRA Improved Track Structures Research Program, is currently being used at the Transportation Systems Center (TSC) to define limits on the acceptable range of track geometry variations to permit safe dynamic performance of the current rail car fleet. The Association of American Railroads (AAR) is currently developing the NUCARS program for simulating the performance of vehicles which incorporate new and untried design features.

Tests conducted to develop and evaluate the SIMCAR program include low speed tests (up to 30 mph) at Starr, Ohio on the Chessie System track in June 1981 and at Bennington, New Hampshire on the Boston and Maine track in September of 1982. These tests were limited in speed and in amplitude of track irregularity by the rail restraint capacity of the relatively weak track selected for the measurements. The tests were also limited to measurements on a partially loaded 100 ton hopper car. The tests described in this report were intended to provide a base of measured data on a broader range of track geometry irregularity amplitudes and wavelengths, over a wider range of operating speeds for three types of freight cars, in loaded and empty conditions, with two types of wheel profiles.

A series of tests were conducted at the Transportation Test Center in Pueblo, Colorado, from October to December 1984 to provide data on the dynamic behavior of typical railroad cars operating over severe track geometry alignment variations. The types of rail cars tested included 100-ton open hopper cars, 70-ton flatcars, and 100-ton tank cars. The rail cars were tested over specially constructed track test segments which had sinusoidal alignment perturbations with 39 foot, 50 foot, 75 foot, and 90 foot wavelengths. The amplitudes of the perturbations were selected, using the results of analytical simulation studies conducted with the "SIMCAR" computer program described in Reference 1, to provide approximately equal dynamic severity at the critical operating speed for the most critical train consist for that zone.

Three test zones were constructed for the alignment perturbation tests. Zone 2 was the low speed test section with a maximum expected test speed of 30 mph. Zone 3 represented an intermediate test section for speeds up to 60 mph. Zone 4 was intended for speeds up to the maximum speed attainable by the locomotive. The cars were tested in both loaded and unloaded conditions, with AAR new wheel 1/20 profile, and with a Heumann worn wheel profile. Because of limitations in available instrumented wheelsets, 70 ton instrumented wheelsets were used for the AAR profile tests on the 100 ton cars. These wheelsets were installed in 100 ton trucks using special bearing adapters.

Test zone 1 was constructed to simulate extreme track twist conditions for validation of unloading calculations made to define allowable twist specifications. The results of the tests conducted on zone 1 are described in Reference 2.

This report concentrates on the results obtained from the alignment perturbation tests. Section 2 provides a description of the test consist and test instrumentation. Section 3 describes the test zones and details of the track construction and geometry stability during the tests. Section 4 provides the procedures and chronology of the conduct of the test. The results of the wheel rail force measurements are presented in Section 5. The wheel rail forces measured in the tests are compared with those computed using the "SIMCAR" program and with earlier data obtained at Bennington, New Hampshire in Section 6.

2. TEST DESCRIPTION

2.1 TEST ZONES

The 1984 Vehicle Track Interaction test was conducted over six separate test zones installed at the Transportation Test Center in Pueblo, Colorado as listed below and shown in Figure 2-1.

a. Segment 1.1 - Pueblo Depot Access Track, Stations 3106 + 00 to 3109 + 10.

b. Segment 2.2-2.5 - Precision Test Track, Stations 21 + 00 to 37 + 50.

c. Segment 2.6 - Pueblo Depot Access Track, Stations 3057 + 00 to 3065 + 00.

d. Segment 3.2-3.5 - Precision Test Track, Stations 1659 + 65 to 1687 + 00.

e. Segment 3.6 - Precision Test Track, Stations 1712 + 00 to 1719 + 50.

f. Segment 4.2-4.5 - Railroad Test Track, Stations 350 + 00 to 377 + 35.

Within each test zone, subsections called segments were installed based on specified types and amplitudes of track perturbations. Fourteen of the segments contained either three or five cycles of crosslevel and/or alignment perturbations of various amplitudes, and one segment contained a warp perturbation. Specifications for these perturbations are shown in Table 2-1. All track was specified to have a track gage of 56.625 inches within plus or minus 0.125 inches.

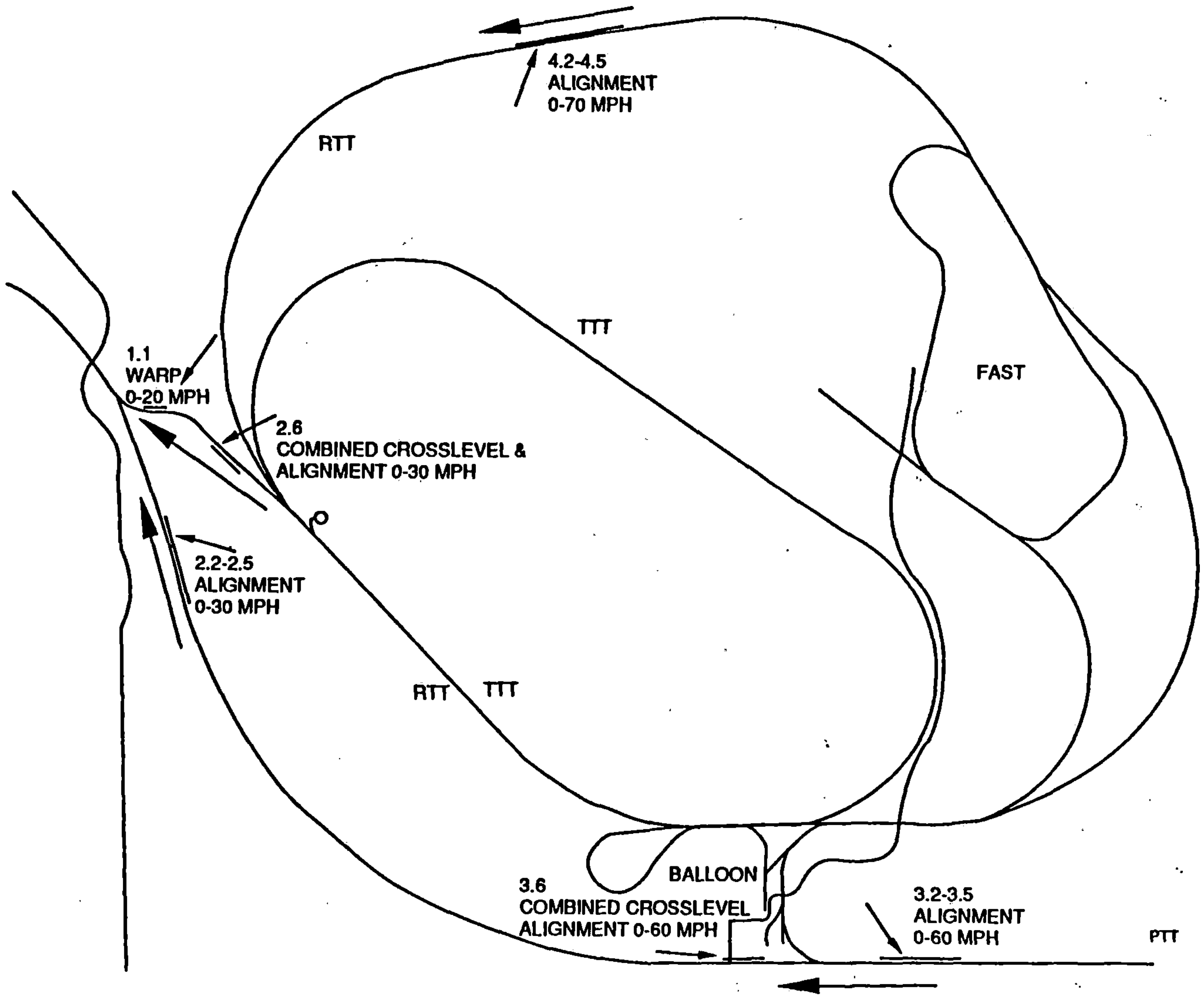


FIGURE 2-1 TEST ZONES

TABLE 2-1. SPECIFIED TRACK PERTURBATIONS

Segment Number	Speed Range (mph)	Type	Wavelength (ft)	Amplitude (in)	Number Of Cycles
1.1	0-20	Warp	-	6" Vertical 0" Lateral	-
2.2	0-30	Alignment	39'	2.25"	3
2.3	0-30	Alignment	50'	3.5"	3
2.4	0-30	Alignment	75'	5.0"	3
2.5	0-30	Alignment	90'	8.0"	3
2.6	0-30	Alignment Crosslevel	50'	3.5" Lateral 2" Vertical	5
3.2	0-60	Alignment	39'	1.5"	5
3.3	0-60	Alignment	50'	1.75"	5
3.4	0-60	Alignment	75'	4.25"	5
3.5	0-60	Alignment	90'	6.0"	5
3.6	0-60	Alignment Crosslevel	50'	1.75" Lateral 1.0" Vertical	5
4.2	0-Max.	Alignment	39'	1.0"	5
4.3	0-Max.	Alignment	50'	1.25"	5
4.4	0-Max.	Alignment	75'	3.25"	5
4.5	0-Max.	Alignment	90'	4.5"	5

** Speed ranges were, in most cases, restricted to less than those shown for this test due to severe effects from traversing the relatively large perturbations used*

The track alignment wavelengths of 39, 50, 75, and 90 feet were selected to provide a representative spectrum of the wavelengths expected in typical track. The amplitudes were selected based upon simulation studies of the loaded and unloaded hopper cars and the empty flatcar. Safety criteria used in the simulation studies included wheel climb (represented by the lateral excursion of the wheel beyond the point of initial flange contact point), net truck lateral force (representing any tendency towards panel shift), minimum wheel force (representing wheel lift tendency), and peak wheel lateral to vertical force ratios.

The amplitudes selected for each of the alignment perturbations, with the exception of segment 2.5, were the largest amplitudes that all of the cars could be expected to traverse without wheel climb or excessive truck lateral force. At the low speed range of 0 to 30 mph, the simulation results indicated that amplitudes larger than the 8 inch peak to peak could be tolerated for the 90 foot wavelength. However, an 8 inch peak to peak amplitude is significantly more severe than that which would be found in United States track at that wavelength. Track segments 3.2 to 3.5 were intended for testing from 30 to 60 mph. The track segments 4.2 to 4.5 were intended for testing up to 100 mph, however the maximum speed available from the locomotive used in these tests was 70 mph.

The arrangement of the track perturbations specified for these tests is shown in Figures 2-2 to 2-7. The direction of the tests was from the shortest to the longest wavelength. All of the track alignment perturbation sections contained irregularities that are more severe than could be expected in typical operations at the speed range specified for the tests.

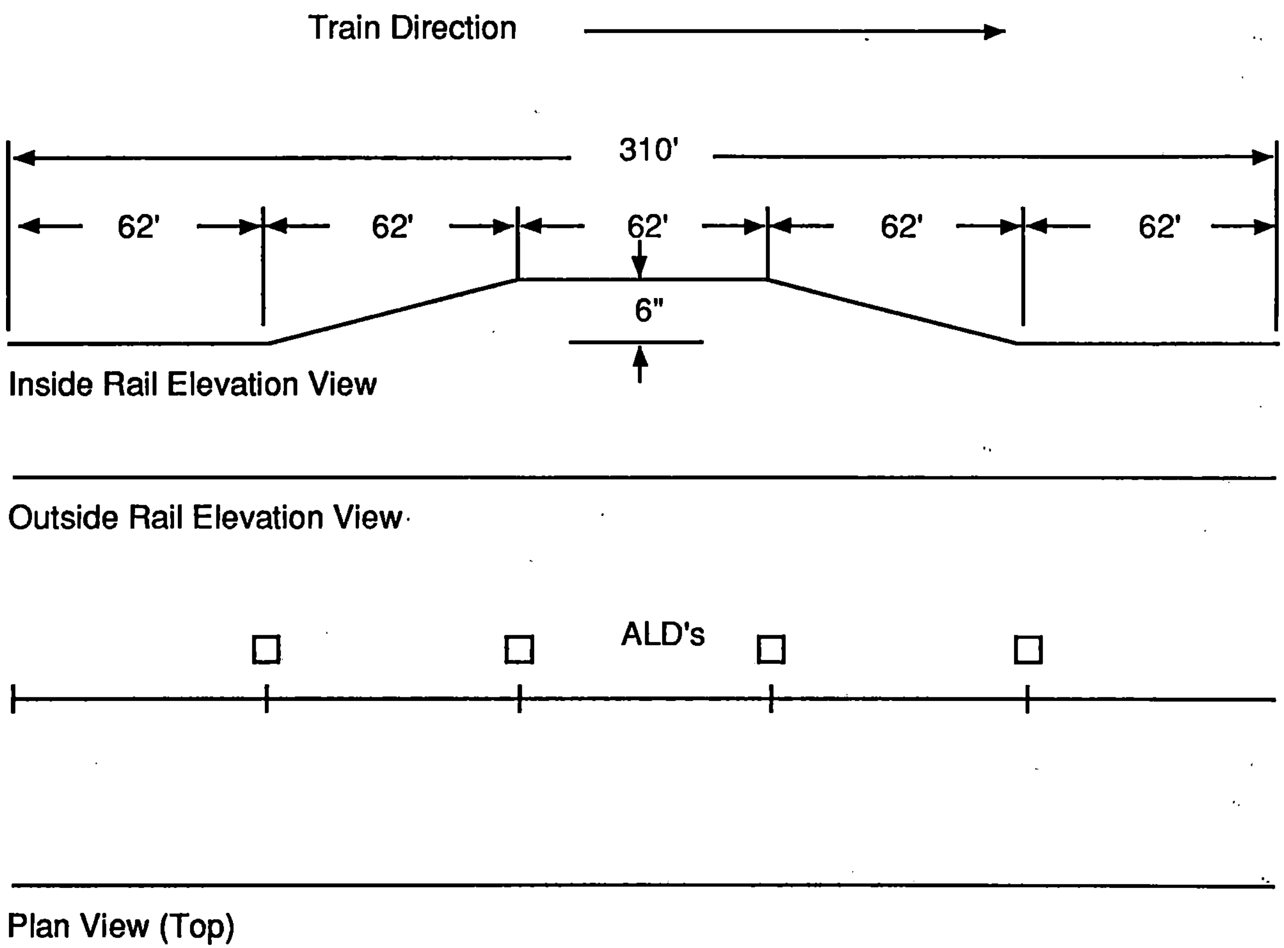
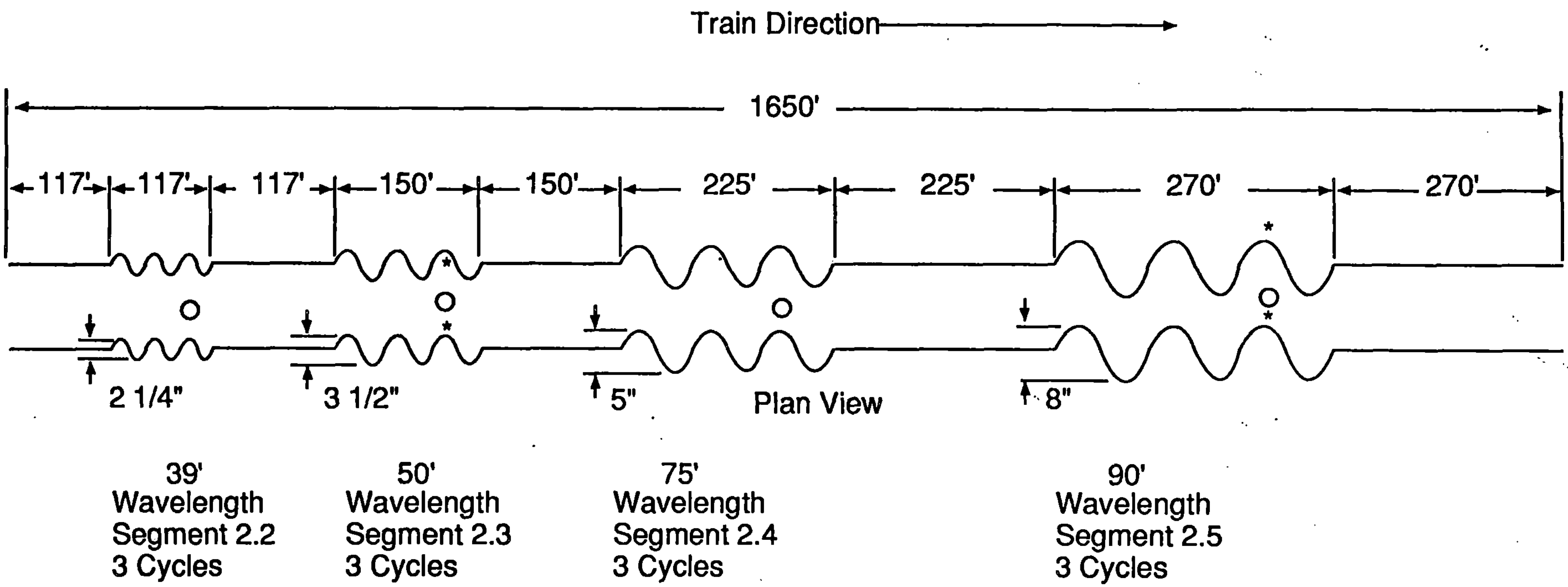
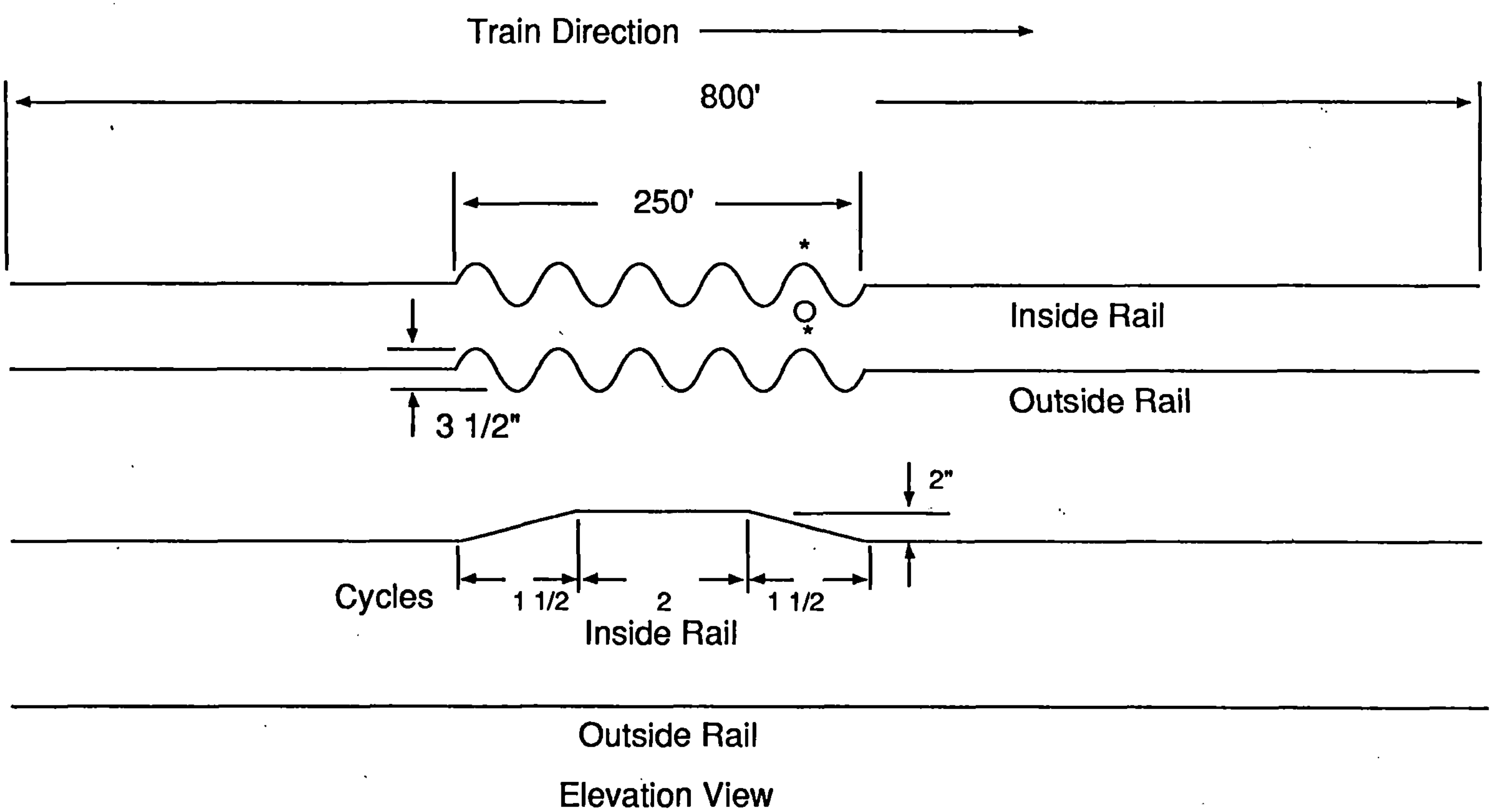


FIGURE 2-2 WARP, TEST SECTION SEGMENT 1.1



Slow Speed Test Section 0-30 MPH
Tangent Track 56.5" Gage
NOTE: * - Lateral Rail Deflection Sites
* - Frictional Rail Force Sites
O - Lateral Rail Deflections Sites (Dynamic)

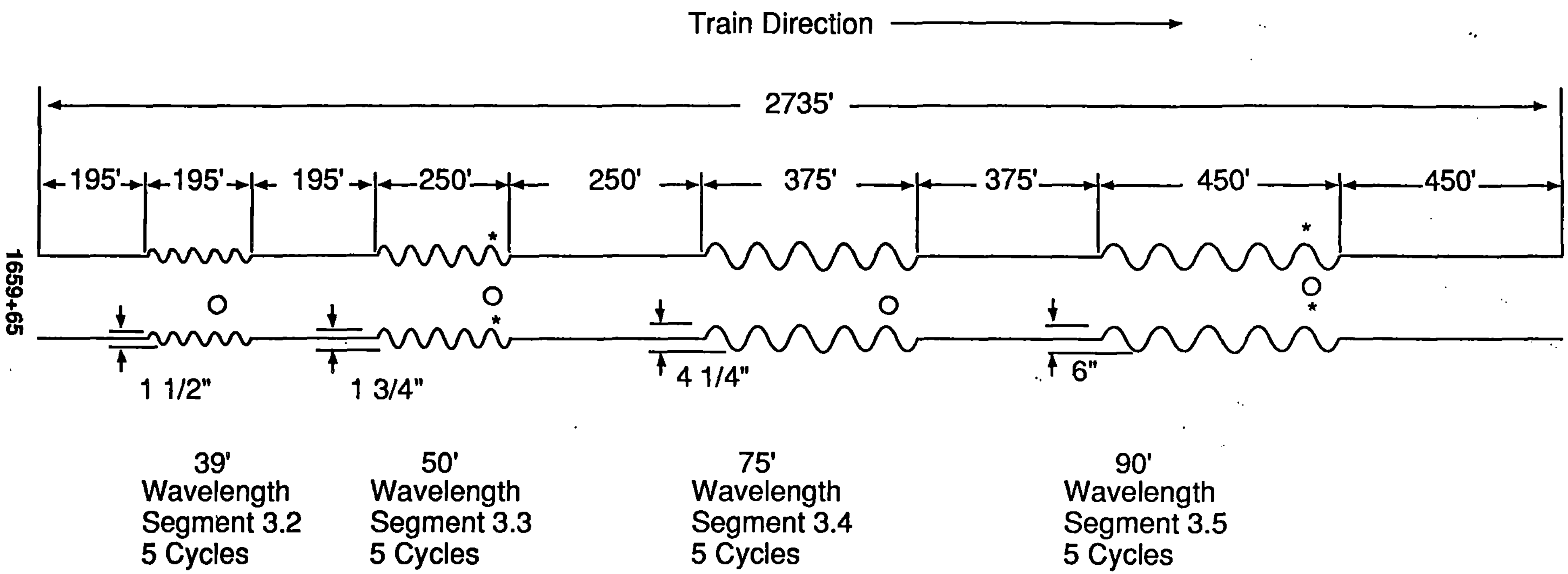
FIGURE 2-3 ALIGNMENT, TEST SECTION SEGMENTS 2.2-2.5 - PRECISION TEST TRACK ACCESS



50'
Wavelength
Segment 2.6
5 Cycles
Slow Speed Test Section 0-30 MPH
Tangent Track 56.5" Gage

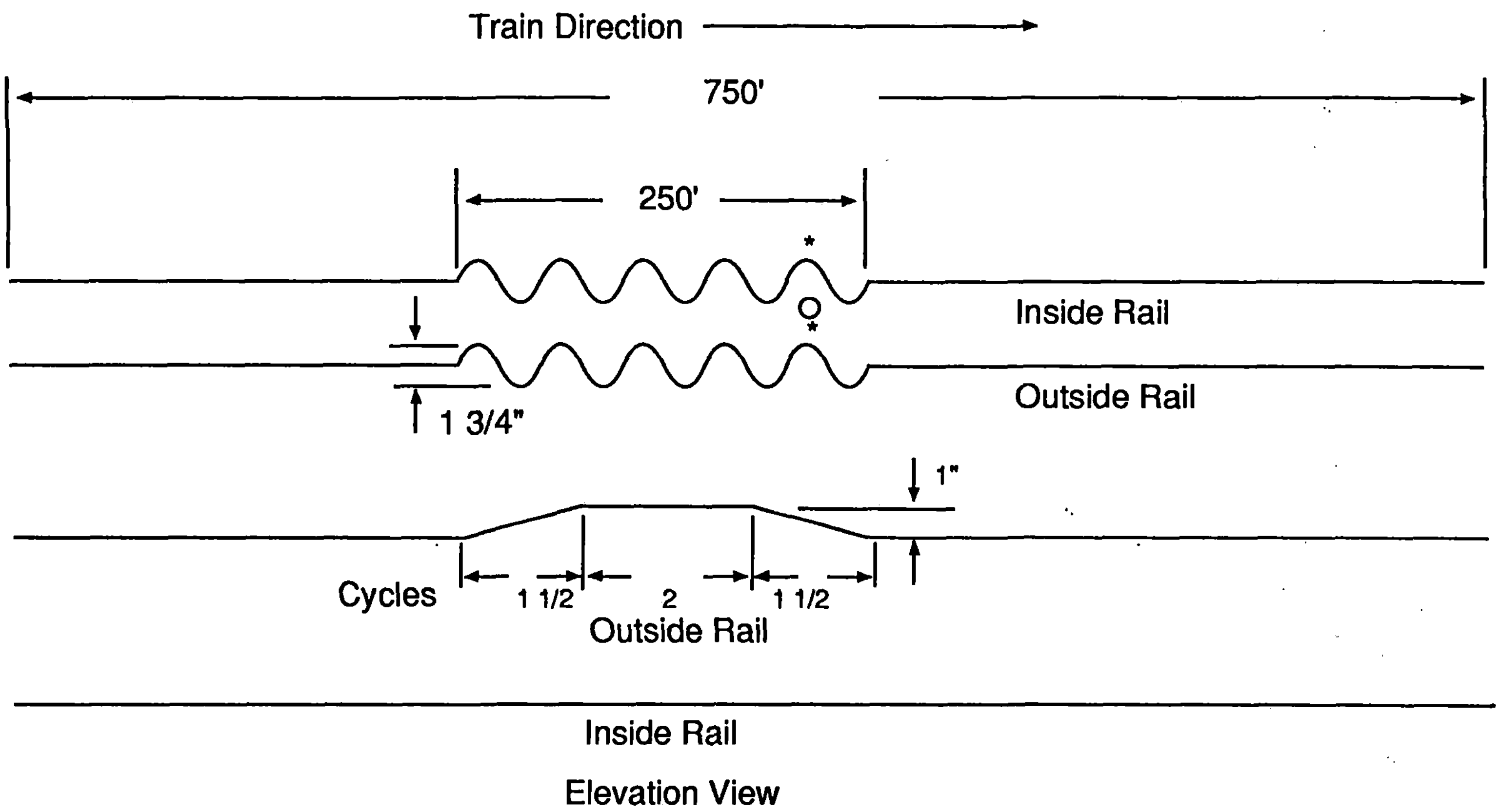
NOTE: * - Lateral Rail Deflection Sites
* - Frictional Rail Force Sites
O - Lateral Rail Deflection Sites (Dynamic)

FIGURE 2-4 COMBINED ALIGNMENT AND CROSS-LEVEL, TEST SECTION SEGMENT 2.6



Medium Speed Test Section 0-60 MPH
Tangent Track 56.5" Gage
NOTE: * - Lateral Rail Deflection Sites
* - Frictional Rail Force Sites
O - Lateral Rail Deflection Sites (Dynamic)

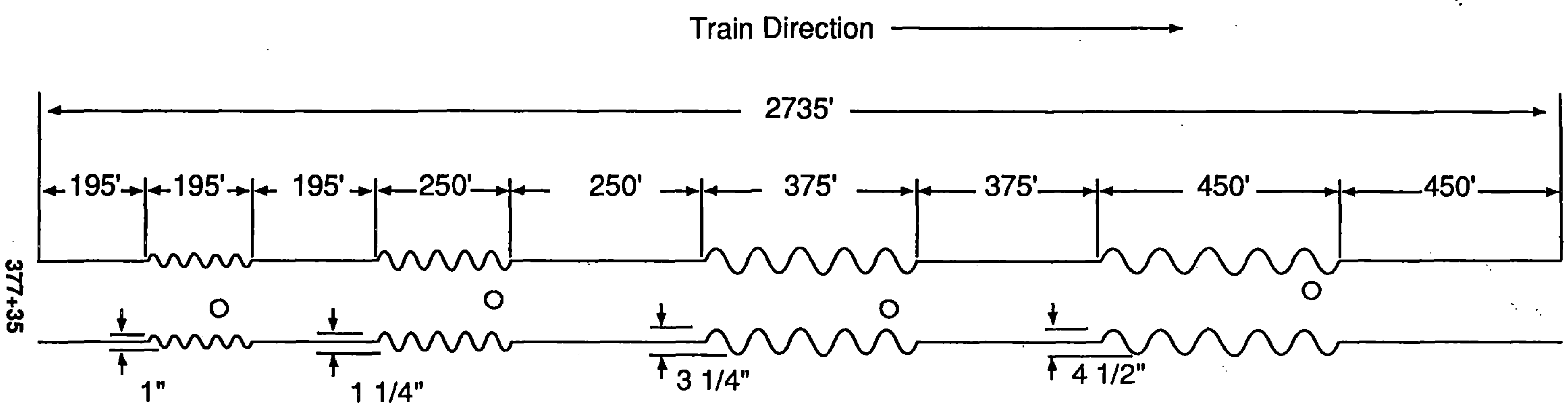
FIGURE 2-5 ALIGNMENT, TEST SECTION SEGMENTS 3.2-3.5 - PTT



50'
Wavelength
Segment 3.6
5 Cycles
Slow Speed Test Section 0-60 MPH
Tangent Track 56.5" Gage

NOTE: * - Lateral Rail Deflection Sites
* - Frictional Rail Force Sites
O - Lateral Rail Deflection Sites (Dynamic)

FIGURE 2-6 COMBINED ALIGNMENT AND CROSS-LEVEL, TEST SECTION SEGMENT 3.6 - PTT



39' Wavelength Segment 4.2 5 Cycles	50' Wavelength Segment 4.3 5 Cycles	75' Wavelength Segment 4.4 5 Cycles	90' Wavelength Segment 4.5 5 Cycles

High Speed Test Section 0-70 MPH
Tangent Track 56.5" Gage
NOTE:O - Lateral Rail Deflection Sites (Dynamic)

FIGURE 2-7 ALIGNMENT, TEST SECTION SEGMENTS 4.2-4.5 - RTT

Figure 2-8 shows the lateral acceleration (as a function of speed) that would be experienced by the trucks of the test consist if they followed the track alignment perfectly. Dynamic amplifications of these accelerations result from the suspension characteristics of the cars and locomotive at speeds that correspond to those that are near the car or locomotive natural frequency at that wavelength.

For the locomotive and the instrumentation car (T-7), dynamic amplifications (by a factor greater than 2) of the accelerations given in Figure 2-8 could be expected during the tests. At the speed corresponding to the car natural frequency, dynamic amplifications of between 3 and 5 are not unlikely. For frequencies less than 2 Hz, the International Standards Organization (ISO) specifies a limit of 0.2 g rms, or about 0.3 g peak acceleration as a fatigue limit for an exposure of 1 minute. The maximum test speeds were not achieved due to the severity of the alignment variations as perceived by the test personnel, as well as being limited by the proximity of the measured wheel rail forces to critical limits.

The track geometry variations built into the perturbed track sections remained stable during the tests. The pretest and posttest geometry measurements made on the perturbed track sections are discussed in Appendix A.

2.2 TEST CONSIST DESCRIPTION

As shown in Figure 2-9, the test consist was made up of a GP-9 locomotive, a data acquisition vehicle (T-7); and two test cars, one equipped with the 1:20 taper instrumented wheelsets, and the other with worn profile (Heumann) instrumented wheelsets.

Three types of freight cars were tested: 100-ton open-top hoppers, 100-ton tank cars, and 70-ton TOFC flatcars. The specifications of these cars are shown in Table 2-2. A complete series of test runs were made, with the cars both loaded and empty. The general sequence of test runs was low, medium, and high speed, with both unloaded and loaded hoppers, then loaded and unloaded tank cars, and last the empty and loaded TOFC flatcars.

TABLE 2-2. CAR PARAMETERS

Car Type	Wheel Profile	Loaded Weight On Rail (lb)	Tare Weight On Rail (lb)	Truck Center Spacing
100 Ton Open Hopper	AAR 1/20	235,100	59,900	40 ft 6 in
	Heumann	232,980	60,200	40 ft 6 in
100 Ton Tank Car	AAR 1/20	262,700	83,250	53 ft 10.8 in
	Heumann	262,100	84,150	53 ft 10.8 in
70 Ton TOFC Flat Car	AAR 1/20	182,950	61,850	65 ft 11.4 in
	Heumann	159,450	61,850	65 ft 11.4 in
T-7 Instrumentation Car	AAR 1/40	166,150	NA	59 ft 6.6 in
GP 9 Locomotive	AAR 1/20	264,900	NA	34 ft

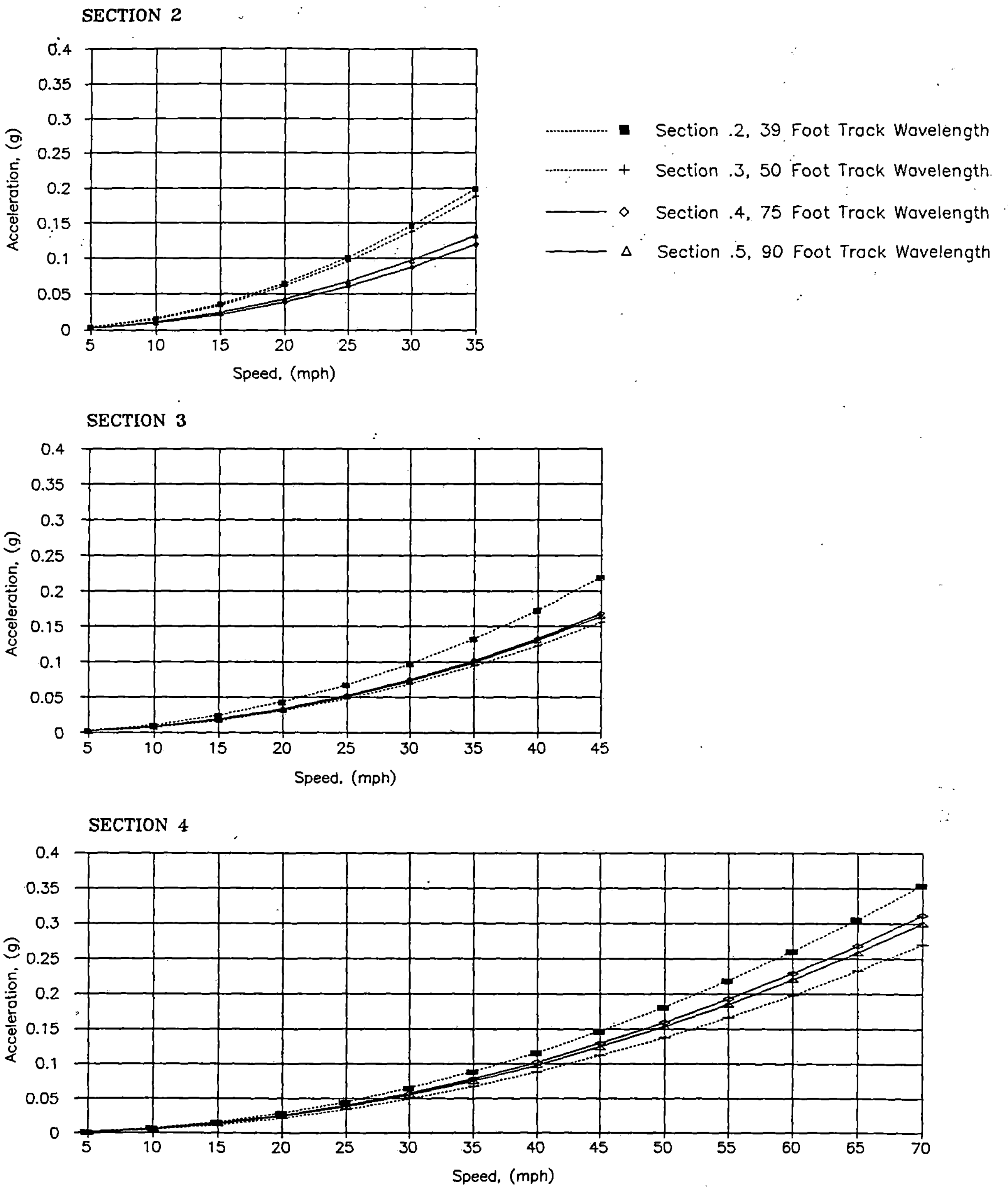


FIGURE 2-8. ACCELERATION OF POINT PERFECTLY FOLLOWING SPECIFIED ALIGNMENT VARIATION

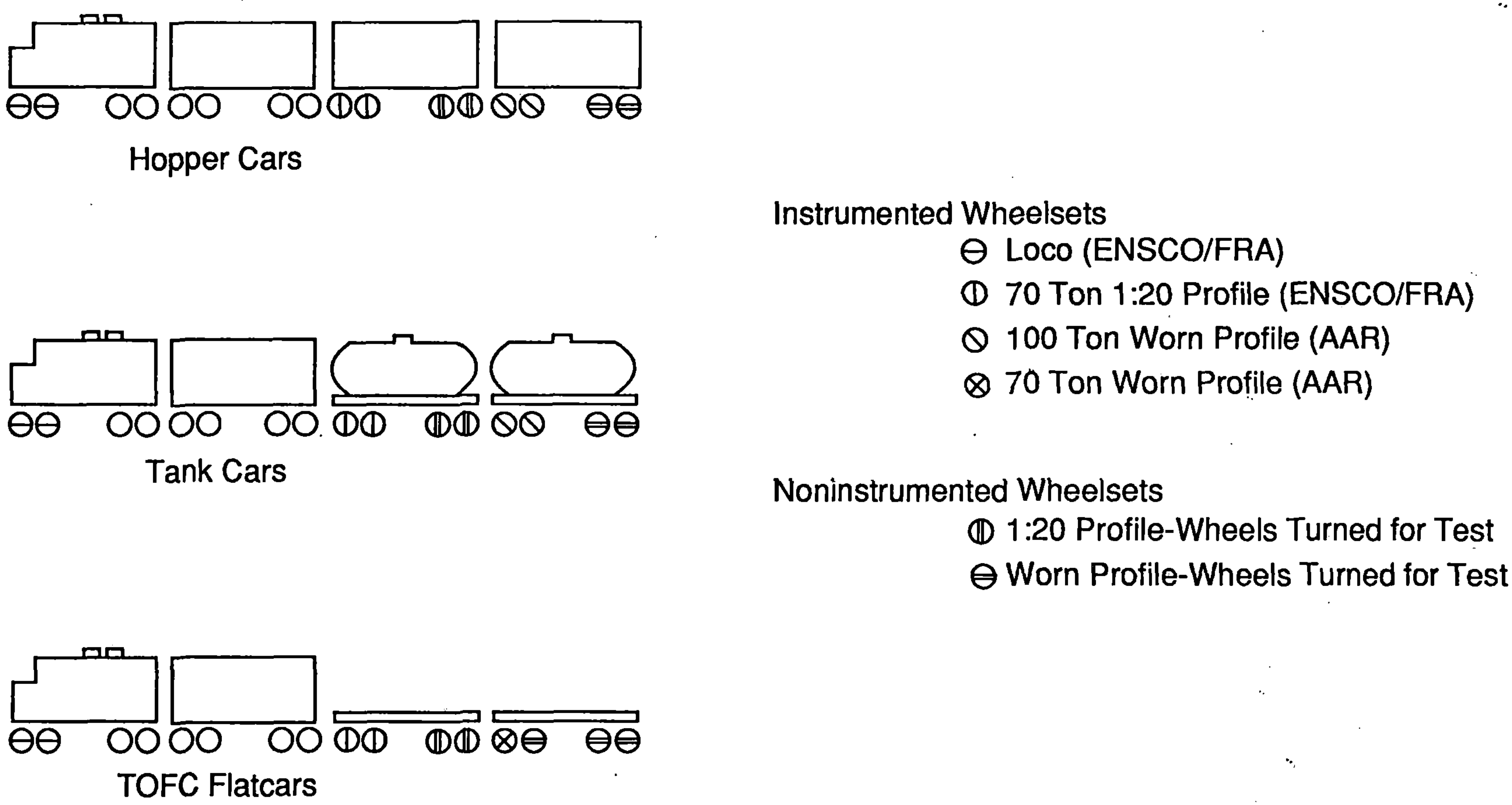


FIGURE 2-9. CONSIST CONFIGURATIONS

2.3 TEST CONSIST INSTRUMENTATION

Table 2-3 provides a summary of the measurements and transducers used in the VTI test. Since only two 100 ton instrumented wheelsets were available for the tests, the 70 ton instrumented wheelsets were used with the AAR 1/20 wheel profile for the 100 ton cars. The 70 ton wheelsets were accommodated in standard 100 ton trucks through a special bearing adapter. The wheels were trued to the desired wheel profile prior to the tests. The 70 ton instrumented wheelsets used in the 1984 tests were the same as those used in tests of 100 ton cars in Bennington, New Hampshire, and in Starr, Ohio.

TABLE 2-3. TRANSDUCER SUMMARY

Measurement	Location	Transducer
Vertical/Lateral Wheel Force 1:20	Locomotive and A-end of 1st test car	Locomotive wheelsets instrumented by ASEA
Lateral/Vertical and Longitudinal Wheel Force - Worn Profile	A-end of 2nd test car (TTX flatcar only will have one wheelset excluding longitudinal force	Two 100-ton wheelsets instrumented by ITTRI
Carbody Acceleration (Lateral and Vertical)	1st test car	Eight 5g linear accelerometer
Carbody Roll	A- and B-end 1st car gyro's	Two 20/sec rate
Truck Rotation	A-truck both test cars	Four 5 inch string pots
Truck Spring Nest Displacement	A-truck both test cars	Four 5 inch string pots
Speed	T-7 car	Tachometer
ALD	Sensor w/each instrumented wheelset truck, targets in track	Three magnetic sensors built by ENSCO
Track Geometry	All test zones	T-6 track geometry measurement vehicle & surveyor equipment
Video	L-4 wheel both test cars	Two cameras and two monitors
Lateral Rail Deflection (Wayside Dynamics)	Two per perturbation-location segment	20 Fishscales and 8 +5 inch stringpots
Lateral Rail Deflection (Static)	One location per 50'and 90' (last cycle) excluding 4.3 and 4.5 segments	605 rail calibration car
Frictional Rail Force (Static)	4.5 segments	
Wheel and Rail Profile (BR)	One rail profile per section (2.2, 3.2 and 4.2) on undisturbed track	British Rail wheel profilometer
Truck Suspension	Bolster to sideframe lateral & vertical clearance, spring height, side bearing clearance, center pin to side bearing contact point, wear plate wear	Vernier calipers
Car and Truck Center Plate Dimensions	Each test car	Vernier calipers
Test consist Dimensions	Each test car	Tape measure
Test car Weight	Each test car	TTC track scale, strain gage rail section
Truck Characterization		
Vertical Spring Rate/Snubber Force	Each truck from each test car	Rail Dynamics lab equipment
Lateral Spring Rate/Snubber Force	Each truck from each test car	Rail Dynamics lab equipment
Rolling Spring Rate/Snubber Force	Each truck from each test car	Rail Dynamics lab equipment

Measurements of the truck characteristics indicated that the truck parameters were consistent with those that would be expected for service worn trucks with snubber friction of approximately 2 kips per spring group.

The data acquisition system (DAS) used during the 1984 Vehicle-Track Interaction Test was the FRA General Purpose Data Acquisition Vehicle (T-7). The onboard data acquisition system (Hewlett Packard 1000 minicomputer) was configured to accept signals at a sample rate of 256 Hz coming from the transducers listed above. Additionally, the DAS processed the locomotive wheelset data in near real time.

2.4 TEST CONDUCT

A total of 220 test runs were made during the conduct of the 1984 VTI test over the six test zones. The order of VTI consist testing was: empty hopper car, loaded hopper car, loaded tank car, empty tank car, empty flatcar, and loaded flatcar. Table 2-4 presents a summary of the matrix of the test. Included in this table are the dates, test zone, run numbers, actual speed ranges, and test results comments.

TABLE 2-4. VTI-TEST EVENTS SUMMARY EMPTY HOPPER CAR CONSIST

Date	Test Zone	No. Of Runs	Run Number	Actual Speed Range (mph)	Comments
10/25/84 10/26/84	4.2-4.5	2 4	9-1-1 to 10-1-1 & 31-1-1 to 34-1-1	40-45 30-45	L/V exceeds threshold for locomotive at 45 mph and for car 2 flanged wheel at 35 mph & above
10/25/84 10/26/84	2.2-2.5	9 4	1-1-1 to 7-1-1 (Greasy) 25-1 to 27	5-30 5-15	L/V exceeds 0.75 for car 1 on unflanged wheel at 15 mph only and all speeds for car 2 on flanged wheel on nongreased track
10/25/84 10/26/84	3.2-3.5	3 4	21-1-1 to 22-1-2 & 28-1-1 to 30	25-30 20-30	L/V exceeds 0.75 for car 2 on flanged wheel at 20 mph and above
10/25/84 10/26/84	3.6	3 4	21-1-1 to 22-1-2 & 28-1-1 to 30-1-1	25-30 20-30	L/V exceeds 0.75 for car 2 on flanged wheel at 25 mph and above
10/25/84	2.6	7	15-1-1 to 20-1-2 (Greasy)	5-30	L/V exceeds 0.75 for 2 on flanged wheel at 15 mph and above
10/25/84	1.1	4	11-1-1 to 14-1-1	5-20	Both cars below threshold, for car 2, L/V spikes occur at 5 and 10 mph
10/26/84	RTT Hunting	2	23-24	50,55	Check hunting of cars 1 and 2
10/30/84	Fast	3	35 to 37-2, 37-1 Abort	25,34,45	Check steady state curving
Total		49	1-1 to 37-1	5-45*	

TABLE 2-4. VTI-84 TEST EVENTS SUMMARY LOADED HOPPER CONSIST (Continued)

Date	Test Zone	No. Of Runs	Run Number	Actual Speed Range (mph)	Comments
10/31/84	2.2-2.5	8	38-1-1 to 44-1-2	5-27.5	40-1-1 - aborted L/V exceeds 0.75 for locomotive at 23 mph and L/V equals threshold for car 2 on flanged wheel at 25 mph and above
10/31/84	1.1	4	45-1-1 to 48-1-1	5-20	L/V significantly below the threshold of 0.75 for all runs for both cars
10/31/84	2.6	7	49-1-1 to 54-1-1	10-30	L/V exceeds the threshold of 0.75 only at 30 mph for car 1 on un-flanged wheel and only at 10 mph for car 2 on flanged wheel
10/31/84	4.2-4.5	6	55-1-1 to 60-1-1	25-50	L/V exceeds 0.75 for locomotive at 40 and above and for car 2 at 50 mph only
10/31/84	3.2-3.5	6	61-1-1 to 65-1-2	20-32.5	L/V = 0.80 for locomotive at 32.5 mph. L/V below threshold for cars 1 and 2 at all speeds
10/31/84	3.6	6	61-1-1 to 48-1-1	20-32.5	L/V = 0.80 for locomotive at 32.5 mph. L/V below threshold for cars 1 and 2
Total		37	38-1-1 to 65-1-2	5-50*	

TABLE 2-4. VTI-84 TEST EVENTS SUMMARY LOADED TANK CAR CONSIST (Continued)

Date	Test Zone	No. Of Runs	Run Number	Actual Speed Range (mph)	Comments
11/17/84	Balloon Loop	7	66-72	10-30	Hostle runs
11/17/84 11/19/84	1.1	6 1	73-76 and 99	5-20	L/V exceeds 0.75 threshold for car 1 on unflanged wheel at 5 mph on 11/17 and at 20 mph on 11/19
11/17/84	2.2-2.5	7	77-83	5-20	L/V exceeds 0.75 for locomotive at 15 mph and above
11/19/84	3.2-3.5	8	84-91	5-32	L/V exceeds threshold for car 1 on unflanged wheel at 32 mph
11/19/84	3.6	8	84-91	5-32	L/V at 0.75 threshold for car 1 on un-flanged wheel at 32 mph
11/19/84	2.6	8	92-100	5-27.5	L/V exceeds threshold for car 1 on unflanged wheel at 27.5 mph only
11/19/84	4.2-4.5	7	101-107	20-42.5	L/V exceeds threshold for car 1 on unflanged wheel at 42.5 mph only
Total		52	66-107	5-42.5*	

Perturbed zones only.

TABLE 2-4. VTI-84 TEST EVENTS SUMMARY EMPTY TANK CAR CONSIST (Continued)

Date	Test Zone	No. Of Runs	Run Number	Actual Speed Range (mph)	Comments
11/20/84	4.2-4.5	5	108-112		L/V exceeds 1.0 for car on the flanged wheel at 35 and 36 mph
11/20/84	2.6	4	113-116		L/V exceeds threshold for car 2 on flanged wheel at zone exit and all speeds
11/20/84	1.1	7	117-123	0-20	L/V exceeds threshold for car 1 on unflanged wheel at 6 mph only and for car 2 on unflanged wheel at 7.5 mph only
11/20/84	2.2-2.5	6	124-129	5-18	L/V exceeds threshold for car 2 on flanged wheel at all speeds and unflanged wheel at some speeds
11/20/84	3.6	7	130-136	10-25	L/V exceeds threshold for car 2 on left side at zone exit at 15 mph and above
11/20/84	3.2-3.5	7	130-136	10-25	L/V exceeds threshold for car 2 on flanged wheel at 25 mph and above
11/20/84 Hunting	RTT Test Clockwise	3	137-139	45,50	Car 2 hunts 3-4 times as much as car 1
Total		39	108-139	5-36*	

Perturbed zones only.

TABLE 2.4. VTI-84 TEST EVENTS SUMMARY EMPTY FLAT CAR CONSIST (Continued)

Date	Test Zone	No. Of Runs	Run Number	Actual Speed Range (mph)	Comments **
12/3/84	1.1	7	140-146	5-20	L/V exceeds 1.0 for car 2 on unflanged wheel at all speeds and for flanged wheel at 7.5 and 10.5 mph
12/4/84	2.2-2.5	7	147-153	5-17.5	L/V exceeds 1.0 for car 2 at all speeds
12/4/84	3.2-3.5	8	154-161	5-30	L/V exceeds 0.9 for car 2 on the flanged wheel at all speeds
12/4/84	3.6	8	154-161	5-30	L/V exceeds the threshold for car 2 on the flanged wheel at all speeds
12/4/84	4.2-4.5	9	162, 166-173	17.5-45	L/V between 0.7 and 0.85 for car 2 on flanged wheel at all speeds
12/4/84	RTT Hunting	3	163-165	40,50,60	Check hunting of cars.
12/4/84	2.6	4	174-177	5-10	L/V exceeds 1.2 for car 2 at all speeds and L/V at threshold for car 1 on flanged wheel at 10 mph only.
Total		46	140-177	5-45*	

Perturbed zones only.
*** Car #2 W/S data is questionable.*

TABLE 2-4. VTI-84 TEST EVENTS SUMMARY LOADED FLAT CAR CONSIST (Continued)

Date	Test Zone	No. Of Runs	Run Number	Actual Speed Range (mph)	Comments **
12/6/84	1.1	5	178-182	5-10	L/V exceeds threshold easily for car 1 and 2 at all speeds for the unflanged wheel
12/6/84	4.2-4.5	7	183-189	20-40	All data below threshold
12/6/84	2.2-2.5	8	190-197	5-25	L/V exceeds threshold for locomotive and for car 2 on flanged wheel at 15 mph and above
12/6/84	3.2-3.5	8	198-205	5-30	L/V exceeds threshold for locomotive at 25 mph only and for car 2 on flanged wheel at 28 mph and above
12/6/84	3.6	8	198-205	5-30	L/V exceeds threshold on the flanged wheel for car 2 at 20 mph and above
12/6/84	2.6	8	206-213	5-20	L/V exceeds threshold for locomotive at 12.5 mph only and for car 2 at all speeds
12/7/84	Fast	4	214-217	25,35,45	Check steady state curving
Total		48	178-217	5-40*	

**Perturbed zones only.*
***Car #2 W/S data is questionable.*

Three analog strip chart recorders (eight channel) on T-7 were used to monitor various channels for test preparation, data analysis, and quality control. One recorder displayed locomotive data, the second recorder displayed test car 1 data, and the third recorder displayed test car 2 data. This data was used for safety monitoring and subsequent data reduction of critical transducer outputs.

For the locomotive, the measurements monitored during testing included: lead axle left and right rail lateral forces; lead axle left and right lateral to vertical force ratios; the sum of lateral to vertical wheel rail force ratios on the lead axle, and the vertical force on the left lead wheel. For the test cars, the measurements that were monitored were: lead axle left and right lateral forces; lead axle left and right lateral to vertical force ratios; carbody roll angle, and vertical force on the left lead wheel.

Table 2-5 lists the safety criteria specified for conduct of the tests. However, the criteria actually used in the test conduct were somewhat more subjective. The ride vibration experienced in the locomotive was often the limiting consideration in the higher speed test zones. The peak to peak accelerations were significantly larger than those normally experienced in revenue operation, especially considering the repetitive exposure in the testing.

Table 2-6 shows the peak carbody accelerations measured at selected speeds. For a fatigue limit of 2 minutes at frequencies below 2 Hz, the International Standards Organization recommends a limit of 0.2 g rms, or 0.3 g peak. The actual level of accelerations experienced by personnel in the instrumentation car and in the cab of the locomotive were large enough to cause concern to the test personnel.

TABLE 2-5. SAFETY LIMITS
(From On Board Data)

Derailment	Caution	Halt Test
Rail Rollover/ Gage Widening	L/V > 0.75 or Lateral Wheel Load of 0.80 of Static Wheel Load	Truck Side > 0.70 $\frac{L1 + L2}{V1 + V2} > 0.70$
Panel Shift *	Same as Above	Truck L/V >0.62 $\frac{L1+L2+L3+L4}{V1+V2+V3+V4} > 0.62$
Wheel Climb	Same as Above	L/V, Axle Sum 1.25
Roll Angle **	6° Peak to Peak/Cycle; +/- 40% of Vertical Static Wheel Load	9° Peak to Peak/Cycle; +/- 90% of Vertical Static Wheel Load

** Additional criteria - wayside movement 1/2", halt test*
*** Roll angle safety limits not applicable in test segment 1.1*

TABLE 2-6. TYPICAL MEASURED PEAK CAR BODY ACCELERATIONS

Car Type	Speed (mph)	Section No.	Wavelength (ft)	Car Body Accelerations (g)		
				A End	Center	B End
Loaded Tank	20	2.2	39	0.22	0.09	0.16
		2.3	50	0.42	0.13	0.30
		2.4	75	0.25	0.16	0.19
		2.5	90	0.31	0.11	0.17
Loaded Tank	32.5	3.2	39	0.30	0.26	0.31
		3.3	50	0.36	0.29	0.35
		3.4	75	0.41	0.27	0.41
		3.5	90	0.36	0.24	0.36
Loaded Tank	42.5	4.2	39	0.26	0.08	0.23
		4.3	50	0.47	0.28	0.32
		4.4	75	0.53	0.39	0.53
		4.5	90	0.36	0.33	0.37
Loaded Hopper	32.5	3.2	39	0.11	0.08	0.10
		3.3	50	0.27	0.25	0.25
		3.4	75	0.41	0.20	0.36
		3.5	90	0.32	0.18	0.38
Loaded Hopper	50	.2	39	0.10	0.08	0.10
		4.3	50	0.11	0.09	0.10
		4.4	75	0.23	0.19	0.34
		4.5	90	0.62	0.18	0.58

In addition, the wheelsets showed much larger vertical force variations than were expected. Figures 2-10 to 2-13 show typical locomotive strip chart records obtained in a low speed run on segments 2.2 to 2.5, while Figures 2-14 to 2-17 are strip chart records for the loaded hopper car over the same track segments and speed illustrating the large fluctuations observed in the vertical force channel. The variations were probably the result of crosstalk and large sensitivities in the vertical bridges to wheelset position on the rail. These uncertainties lead directly to uncertainties in the computed lateral to vertical force ratios. These uncertainties coupled with the unanticipated behavior of the Heumann profile compared to the AAR profile resulted in a more cautious evaluation of the onboard measurements.

As a result of scheduling constraints, the tests were conducted between October and December 1984. Adverse weather conditions also resulted in delays and additional costs. As a result, there was no opportunity to conduct repeat tests to verify unusual results, or to evaluate critical response in accordance with the pretest safety criteria. The shorter days and poor weather were contributing factors in stopping tests prior to obtaining data over the full range of speeds.

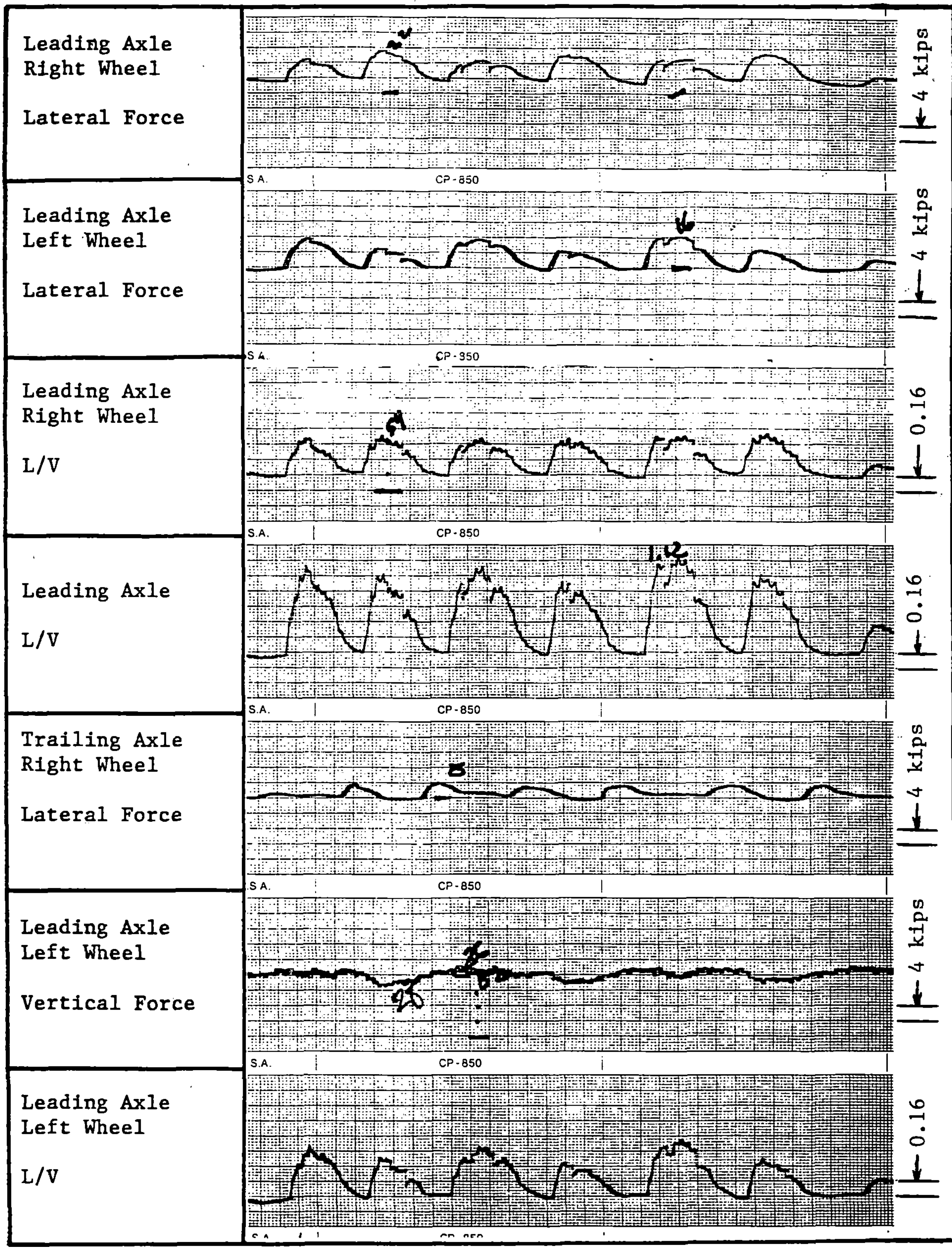


FIGURE 2-10. LOCOMOTIVE - STRIP CHART DATA - SECTION 2.2, 39' WAVELENGTH, 2.25" PEAK TO PEAK, RUN 77, 5 MPH

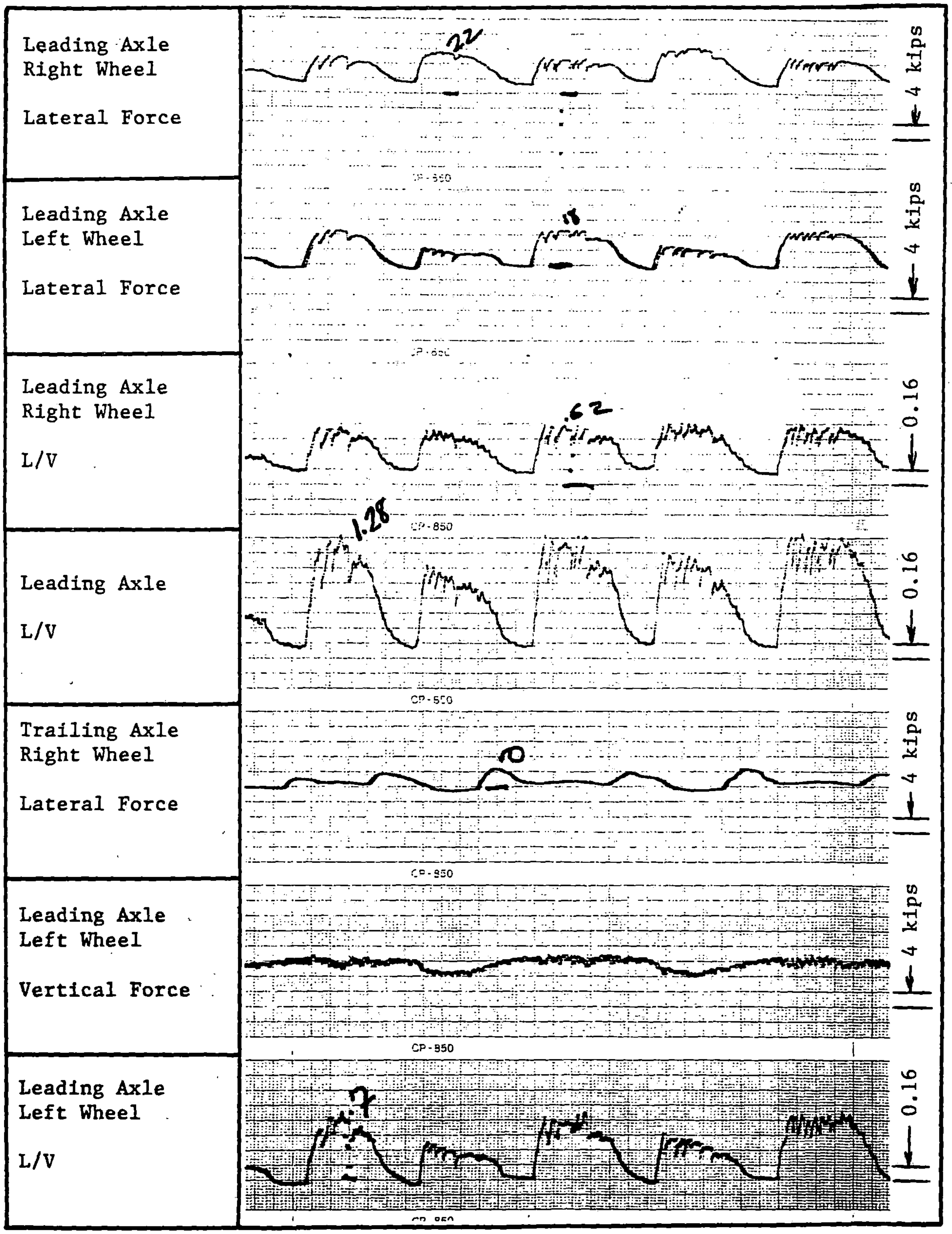


FIGURE 2-11. LOCOMOTIVE - STRIP CHART DATA - SECTION 2.3, 50' WAVELENGTH, 3.5" PEAK TO PEAK, RUN 77, 5 MPH

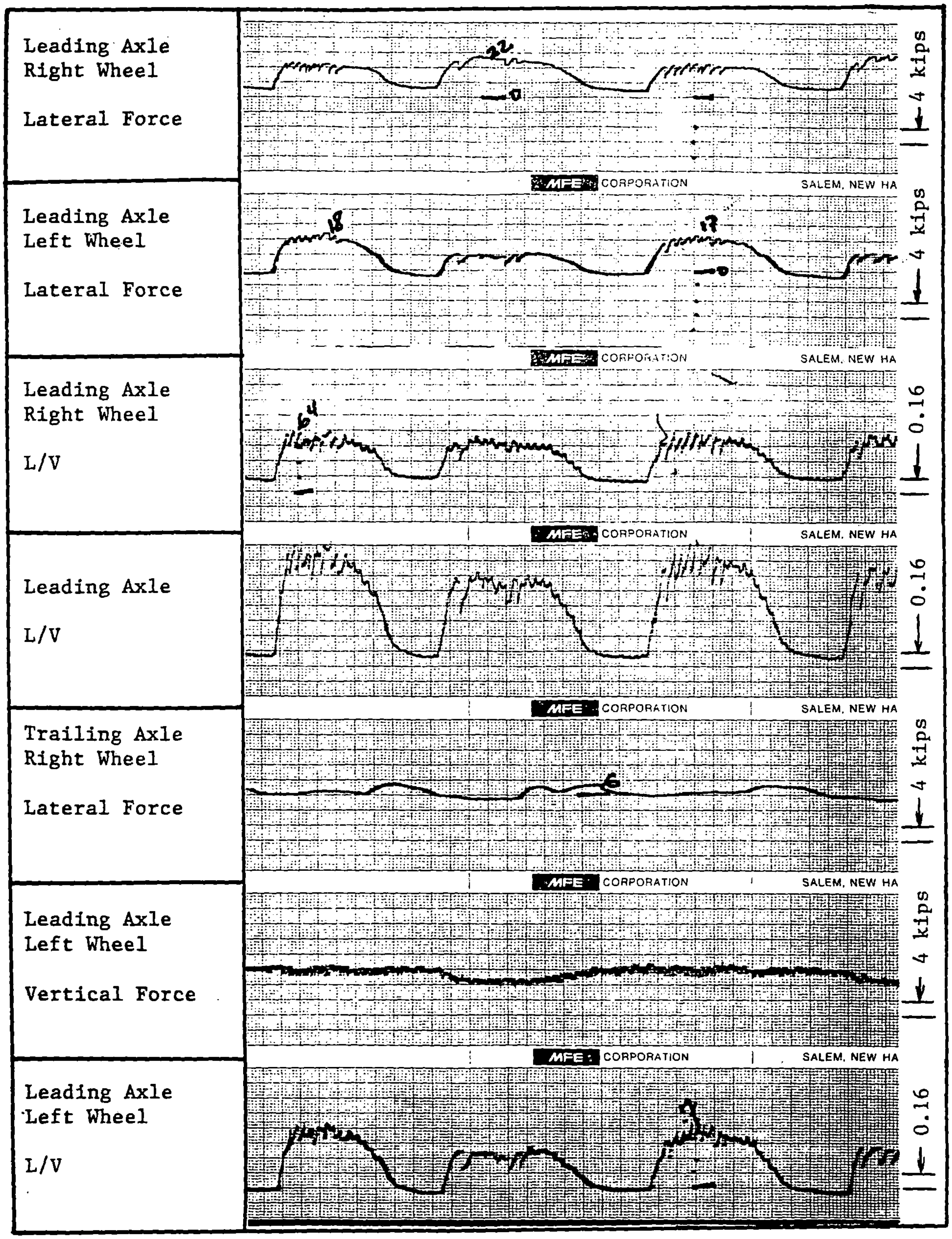


FIGURE 2-12. LOCOMOTIVE - STRIP CHART DATA - SECTION 2.4, 75' WAVELENGTH, 5.0" PEAK TO PEAK, RUN 77, 5 MPH

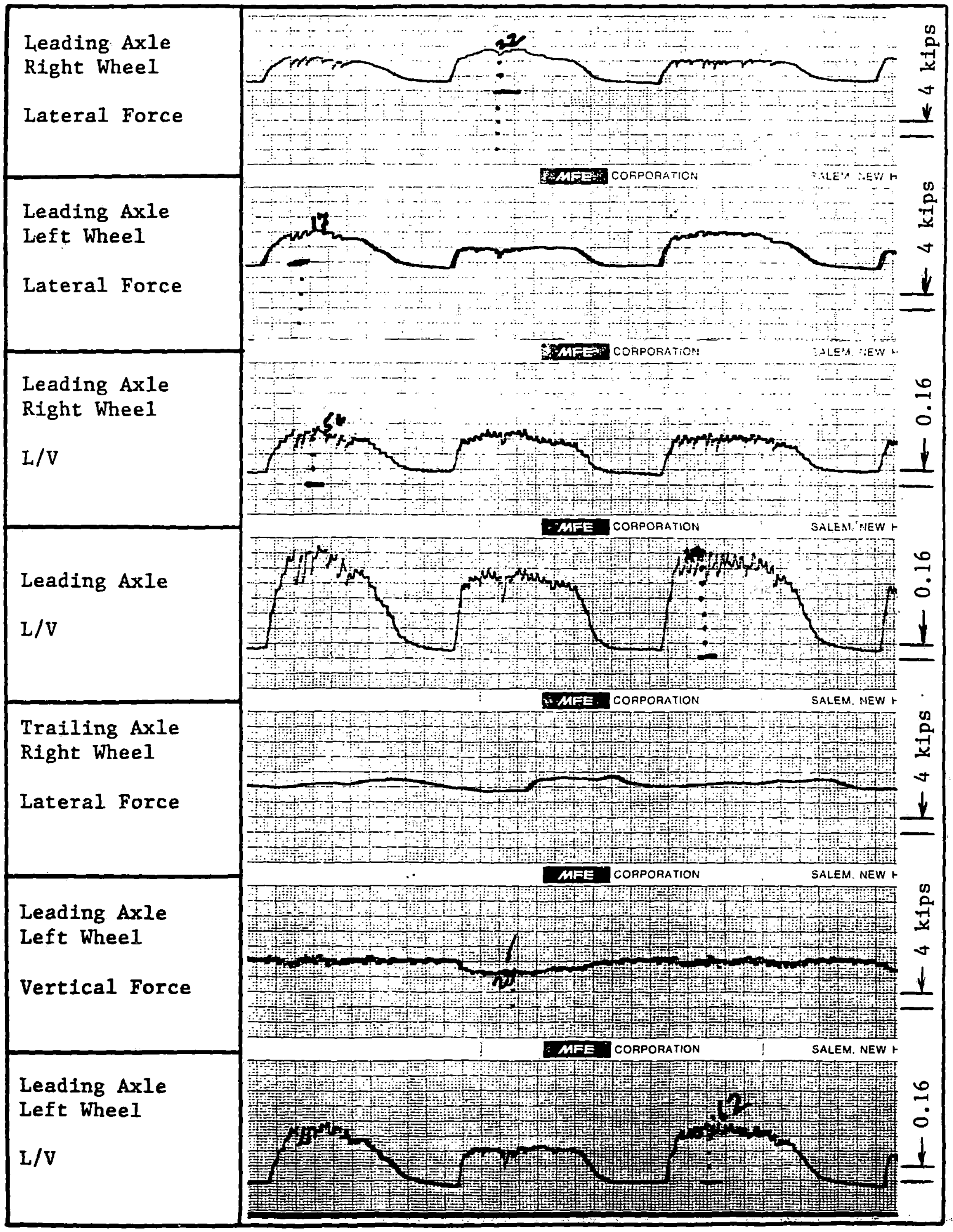


FIGURE 2-13. LOCOMOTIVE - STRIP CHART DATA - SECTION 2.5, 90' WAVELENGTH, 8.0" PEAK TO PEAK, RUN 77, 5 MPH

1/20 AAR Wheel Profile

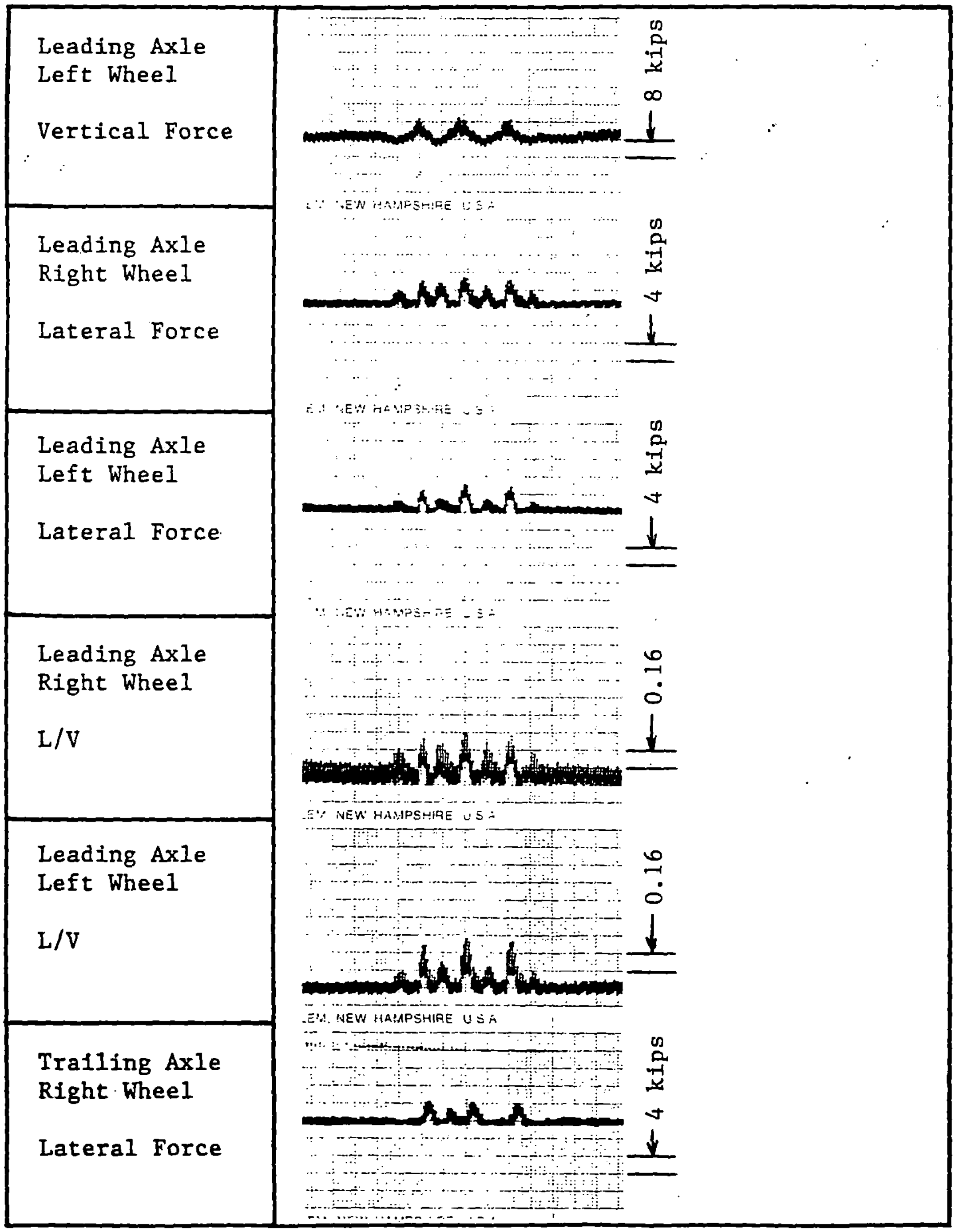


FIGURE 2-14. LOADED HOPPER CAR - STRIP CHART DATA - SECTION 2.2, 39' WAVELENGTH, 2.25" PEAK TO PEAK, RUN 38-1-1, 5 MPH

1/20 AAR Wheel Profile

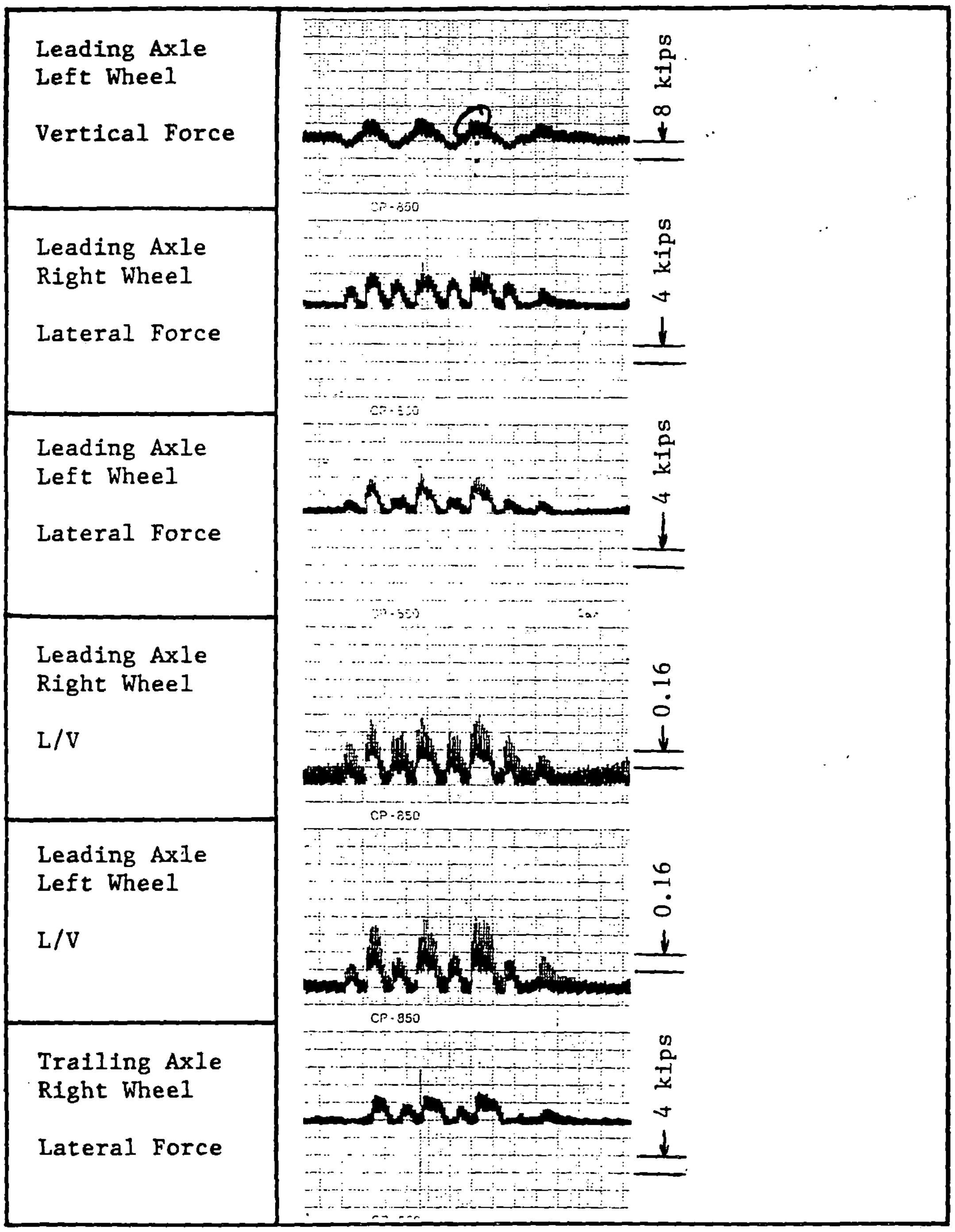


FIGURE 2-15. LOADED HOPPER CAR - STRIP CHART DATA - SECTION 2.3, 50' WAVELENGTH, 3.5" PEAK TO PEAK, RUN 38-1-1-, 5 MPH

1/20 AAR Wheel Profile

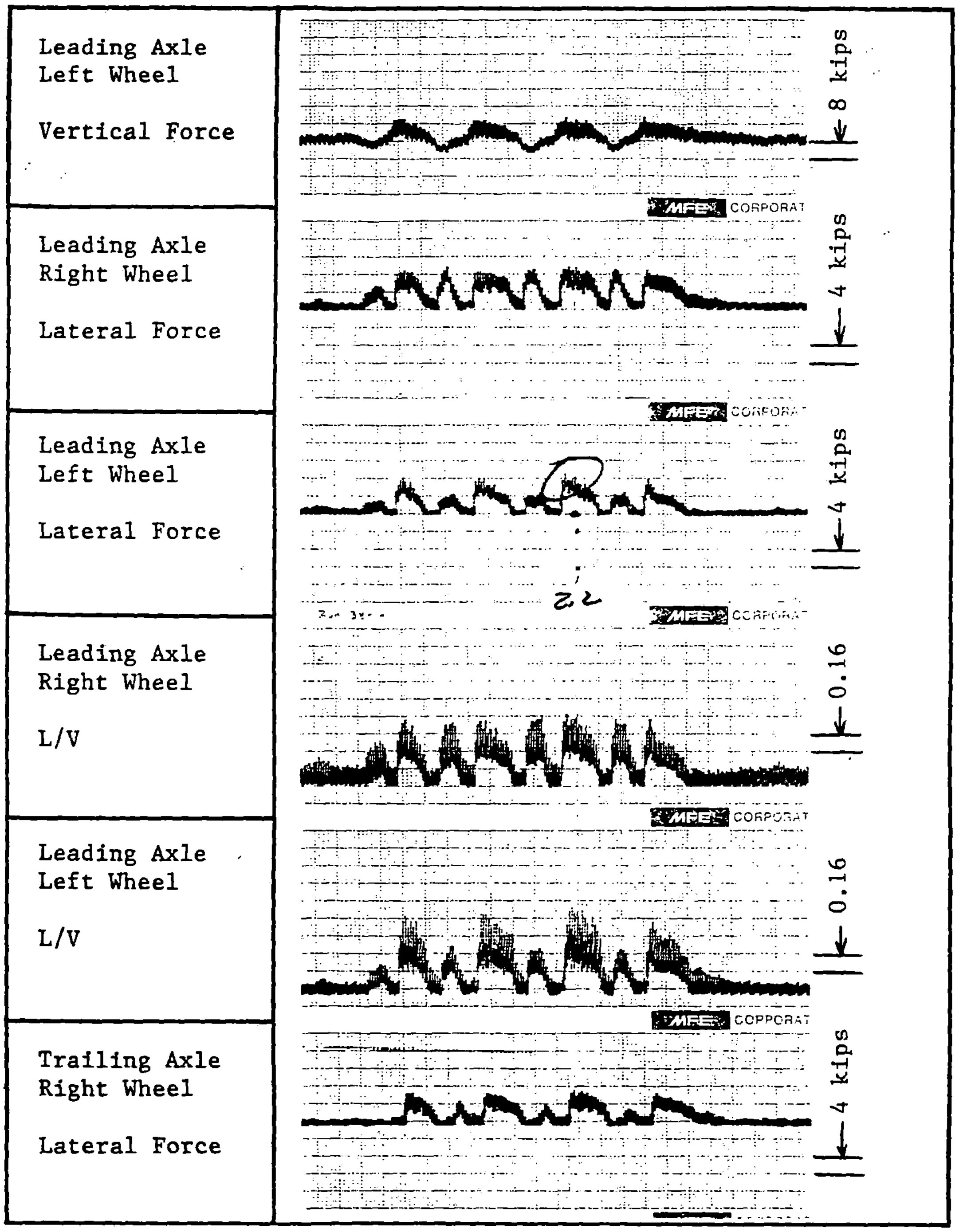


FIGURE 2-16. LOADED HOPPER CAR - STRIP CHART DATA - SECTION 2.4, 75' WAVELENGTH, 5.0" PEAK TO PEAK, RUN 38-1-1, 5 MPH

1/20 AAR Wheel Profile

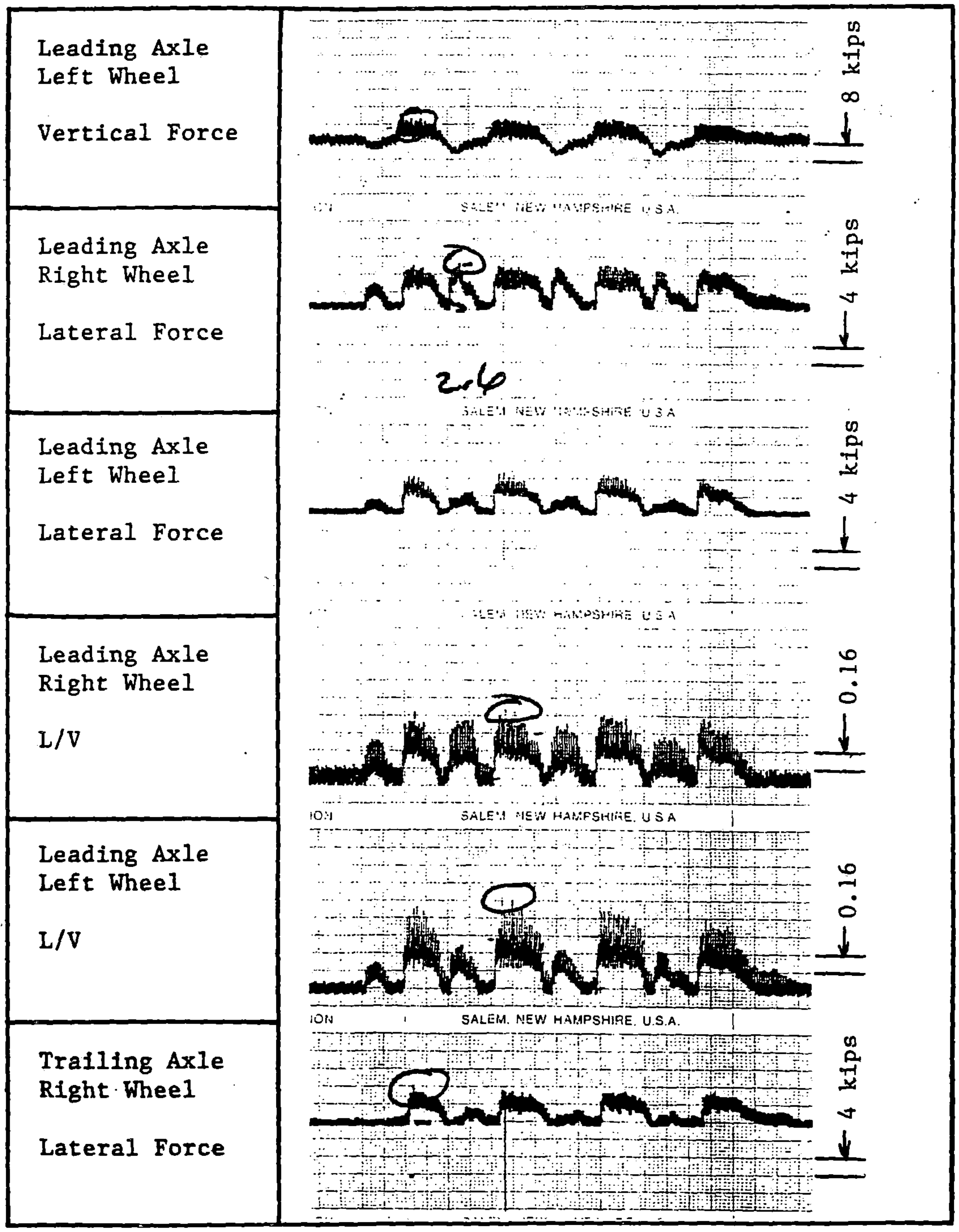


FIGURE 2-17. LOADED HOPPER CAR - STRIP CHART DATA - SECTION 2.5, 90' WAVELENGTH, 8.0" PEAK TO PEAK, RUN 38-1-1, 5 MPH

3. TEST RESULTS

This section summarizes the results obtained from the tests conducted over the sinusoidally varying alignment zones. The wavelengths of 39 feet, 50 feet, 75 feet, and 90 feet were selected to provide a representative spectrum of alignment irregularity wavelengths that can be expected in revenue track. The amplitudes of the perturbations were selected from analytical simulation studies conducted with the "SIMCAR" computer program to produce the most severe condition that could safely be traversed by all of the test consists over the designated speed ranges. The amplitudes are generally more severe than those which would normally be expected in revenue service.

The test cars included hopper cars, tank cars, and flatcars in both fully loaded and empty condition, with both standard AAR 1/20 profile wheels, and with Heumann profile wheels.

The test results are presented in the form of plots of the peak lateral wheel forces and peak wheel L/V ratios as a function of test speed. Parameters for the plots include wheel profiles, car types, car weights, irregularity wavelengths, and speed ranges.

The data generated by the freight car wheelsets with the AAR profile is believed to be in error at low speeds and reports values much lower than expected. In addition, the data from the freight car is inconsistent with the data obtained on the locomotive in these tests, and from previous test data.

The largest wheel rail forces measured during the tests were produced by the locomotive in segment 4.4 (75 foot wavelength) at a speed of 50 mph, with a peak measured lateral force of about 42 kips. The corresponding L/V ratio was 0.9. For the freight cars, the largest lateral wheel rail load was about 24 kips as measured in segment 2.3 (50 foot wavelength) with the tank car at a speed of 20 mph.

With the exception of the 39 foot wavelength segments and the unexpected results produced by the AAR profile wheelsets at low speed, the lateral forces and L/V ratios measured by the Heumann profile wheels and by the AAR profile wheels were generally of comparable magnitudes. In the 39 foot segments, the AAR profile wheels (including the locomotive) produced much smaller lateral forces than the Heumann profile wheels. It is believed that this results from a smaller effective flange clearance for the Heumann profile wheels than for the AAR profile wheels.

The following paragraphs provide a more detailed description of the wheel rail forces measured for each of the cars and configurations tested.

3.1 LOCOMOTIVE

3.1.1 TRACK SEGMENTS 2.2 TO 2.5

The peak lateral force measured on the left and right wheels of the lead axle of the locomotive are shown in Figure 3.1-1 for the low speed track segments 2.2 to 2.5. The lateral wheel forces at track wavelengths of 75' and 90' are relatively constant with speed at a level of about 20 kips. The wheel forces at 39' track wavelength are about 3 kips lower than the forces at the 75' and 90' wavelengths, and are also relatively insensitive to speed. However, for the alignment irregularity at the 50' wavelength, the lateral wheel forces are significantly sensitive to speed, increasing from 18 kips at 5 mph to 30 kips at 28 mph.

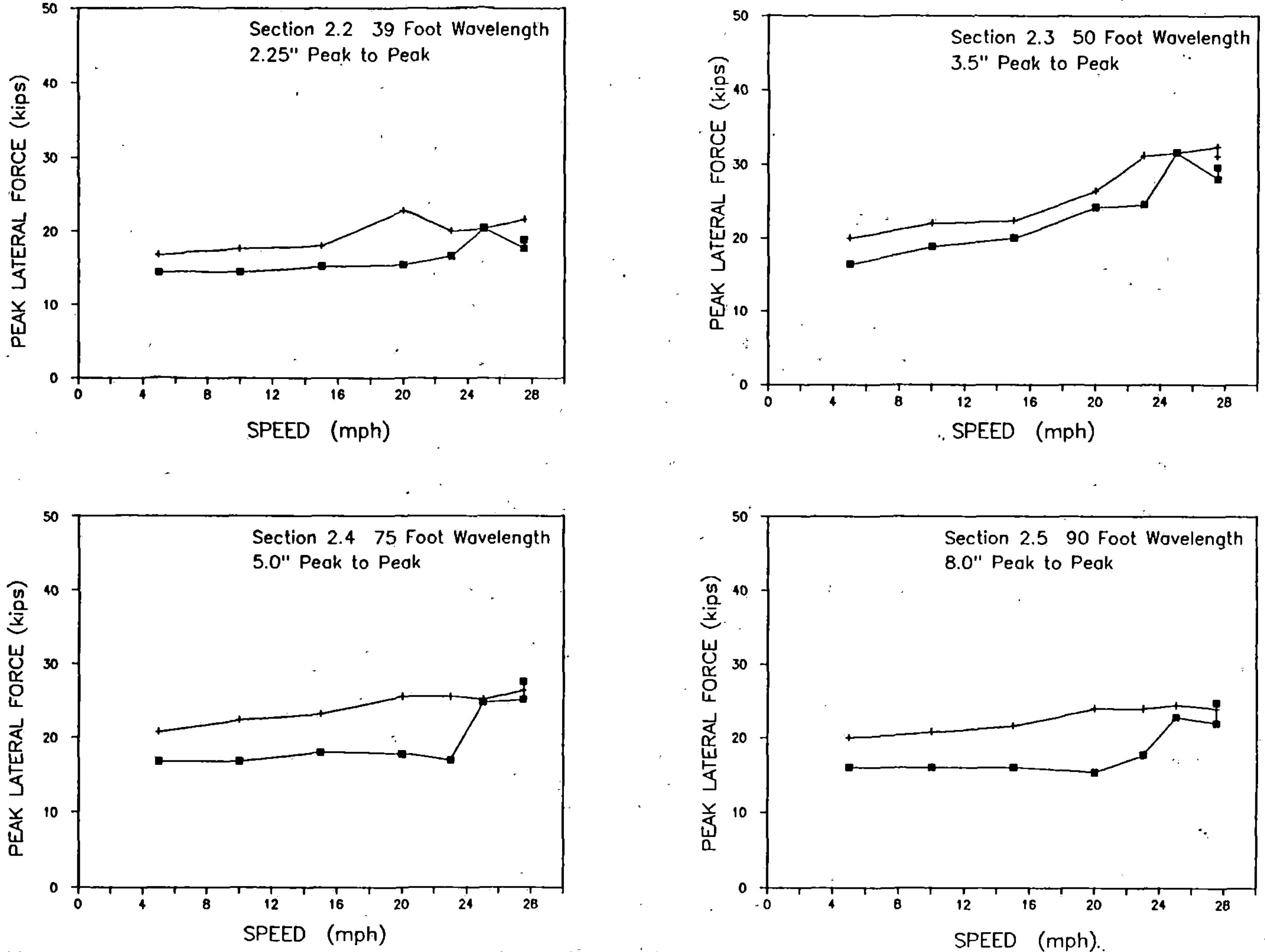
Except at 26 mph, the peak lateral wheel forces measured for the right wheel is 2 to 8 kips lower than for the left wheel. This is surprising considering the symmetry of the alignment perturbations.

As shown in Figure 3.1-2, the locomotive L/V ratios show erratic fluctuations with speed. These fluctuations are due in part to difficulties in reading the vertical force measurement signals which were corrupted by noise and possible sensitivity to lateral position. For track wavelengths of 50', 75', and 90', the L/V ratios fluctuate between 0.65 to 0.9 with speed. At the 75' track wavelength, the L/V ratios are less erratic and remain high over a greater part of the speed range than the L/V ratios at the 50' or 90' wavelengths. The L/V ratios at the 39' track wavelength are lower than in the other wavelength segments and vary between 0.5 to 0.7.

3.1.2 TRACK SEGMENTS 3.2 TO 3.5

For track segments 3.2 to 3.5, the locomotive lateral wheel forces are near constant with speed at all wavelengths (Figure 3.1-3). As in segments 2.2 to 2.5, the lateral wheel forces are lowest at the 39' track wavelength with force values of 14 kips. At the 50' track wavelength, the lateral wheel forces are 18 kips. The lateral forces at both 75' and 90' track wavelengths are 20 to 24 kips. The increase in lateral force with speed observed in the data for the low speed 50 foot wavelength segment (segment 2.3) is not observed in the intermediate speed 50 foot wavelength segment (segment 3.3), even though data was obtained over an overlapping speed range.

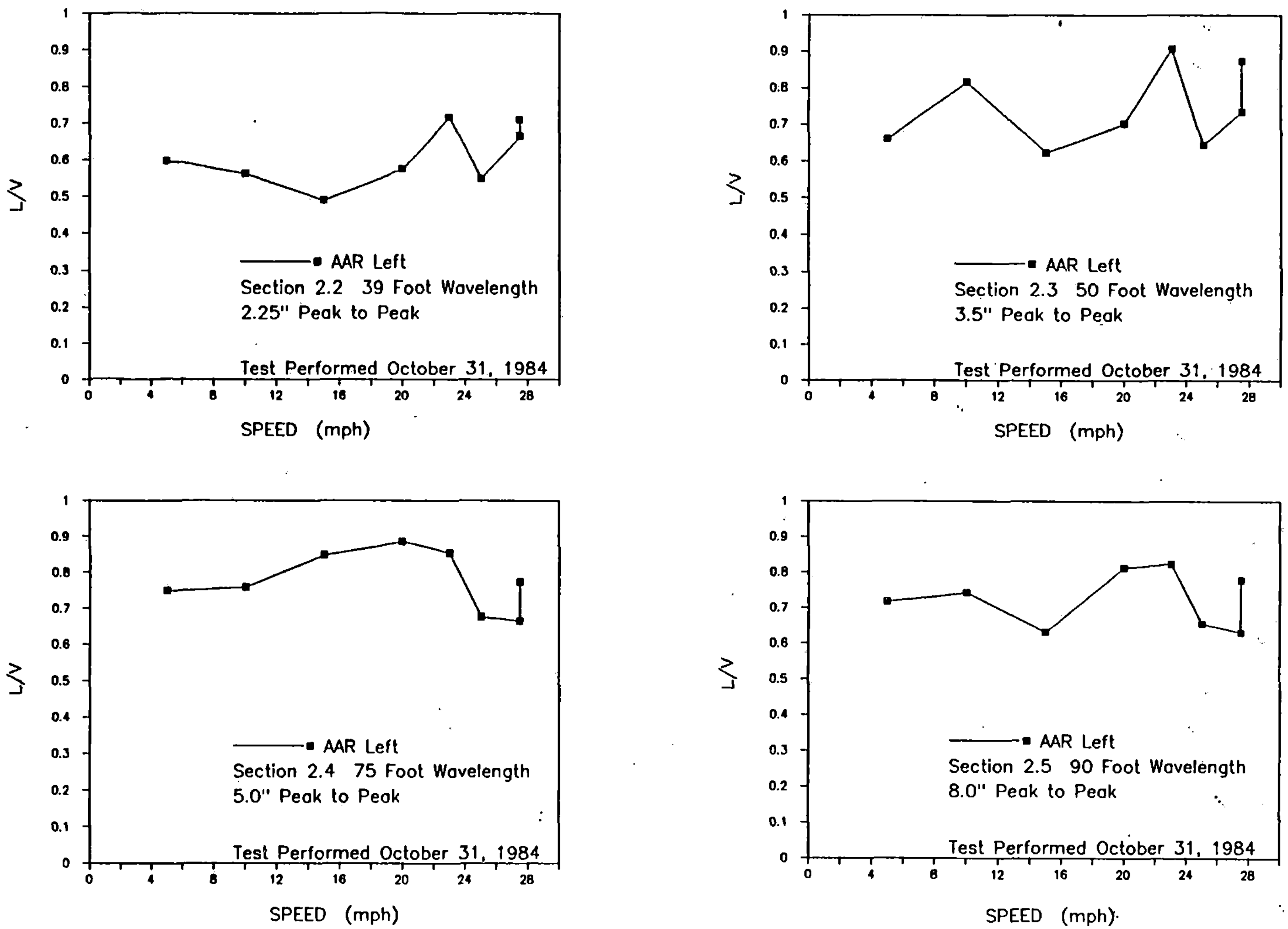
The reduction in track alignment variation amplitudes from those in segments 2.2 to 2.5 resulted in a lowering of the lateral wheel forces at the 39' and 50' track wavelengths, but had little effect on the wheel forces at 75' and 90' wavelengths. Reducing the alignment amplitude in the 50 foot wavelength segment from 3.5 inches to 1.75 inches appears to have had the effect of eliminating the speed dependence of the lateral forces observed in segment 2.3 over comparable speed ranges.



Measurements for the locomotive were made on the loaded hopper car consist.

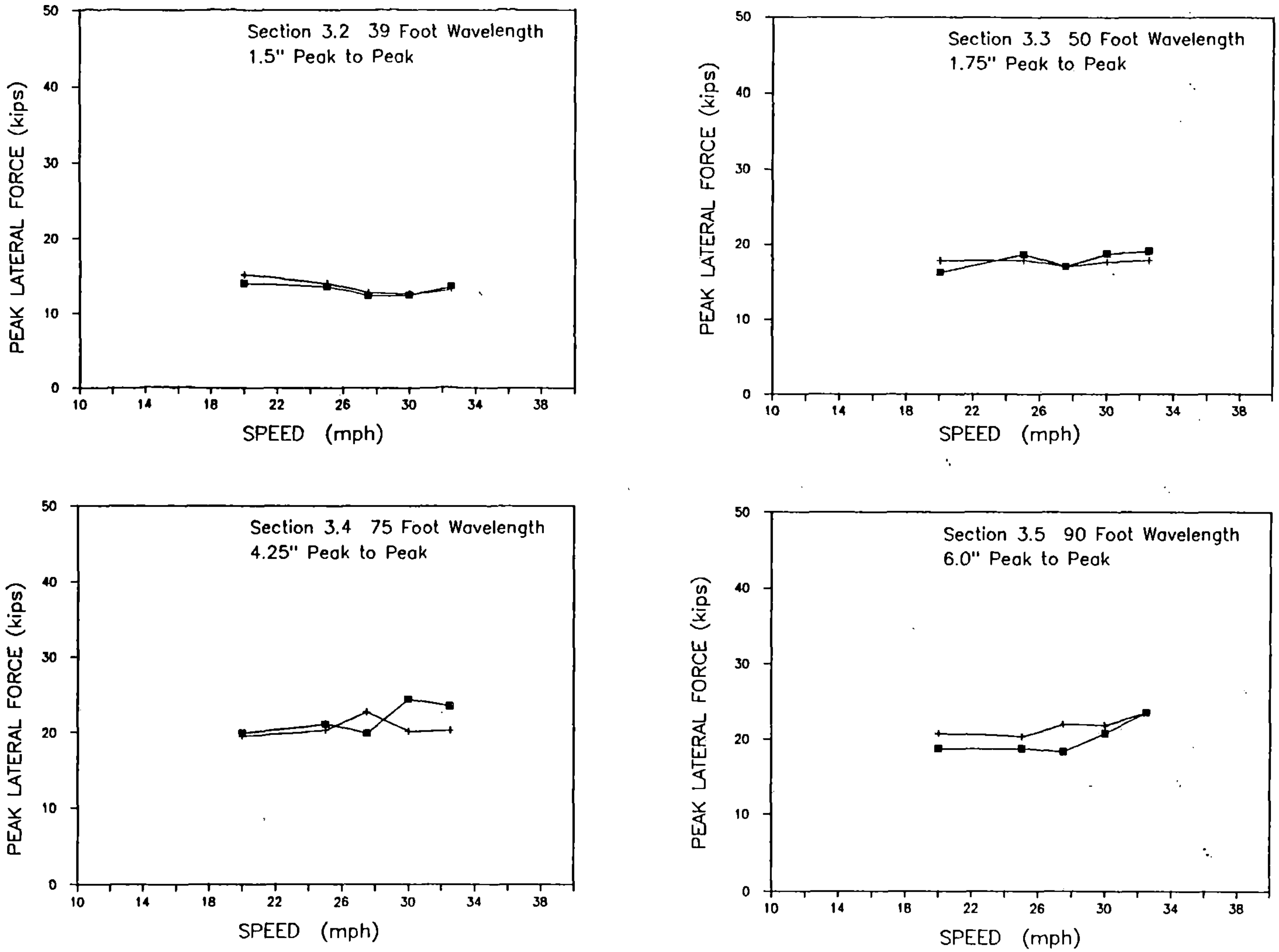
■ AAR Right   + AAR Left

FIGURE 3.1-1 LOCOMOTIVE - PEAK LATERAL WHEEL FORCES AT LOW SPEED TEST SECTION



Measurements for the locomotive were made on the loaded hopper car consist.

FIGURE 3.1-2 LOCOMOTIVE - PEAK LATERAL TO VERTICAL WHEEL FORCE RATIOS AT LOW SPEED TEST SECTION



Measurements for the locomotive were made on the loaded hopper car consist.

■ AAR Right   + AAR Left

FIGURE 3.1-3 LOCOMOTIVE - PEAK LATERAL WHEEL FORCES AT INTERMEDIATE SPEED TEST SECTION

The behavior of the locomotive L/V ratios for track segments 3.2 to 3.5 is similar to that of the corresponding lateral wheel forces (Figure 3.1-4). An L/V ratio of about 0.45 was measured at the 39' track wavelength, which, like the lateral wheel forces, are lower than at any of the other wavelengths. At the 50' track wavelength, the L/V ratios are about 0.55, with the highest L/V ratios occurring at track wavelengths of 75' and 90', where L/V ratios range from about 0.65 to 0.75. The L/V ratios in segments 3.2 to 3.5 do not show the sharp fluctuation with speed that was observed in the higher amplitude "low speed" test segments 2.2 to 2.5.

3.1.3 TRACK SEGMENTS 4.2 TO 4.5

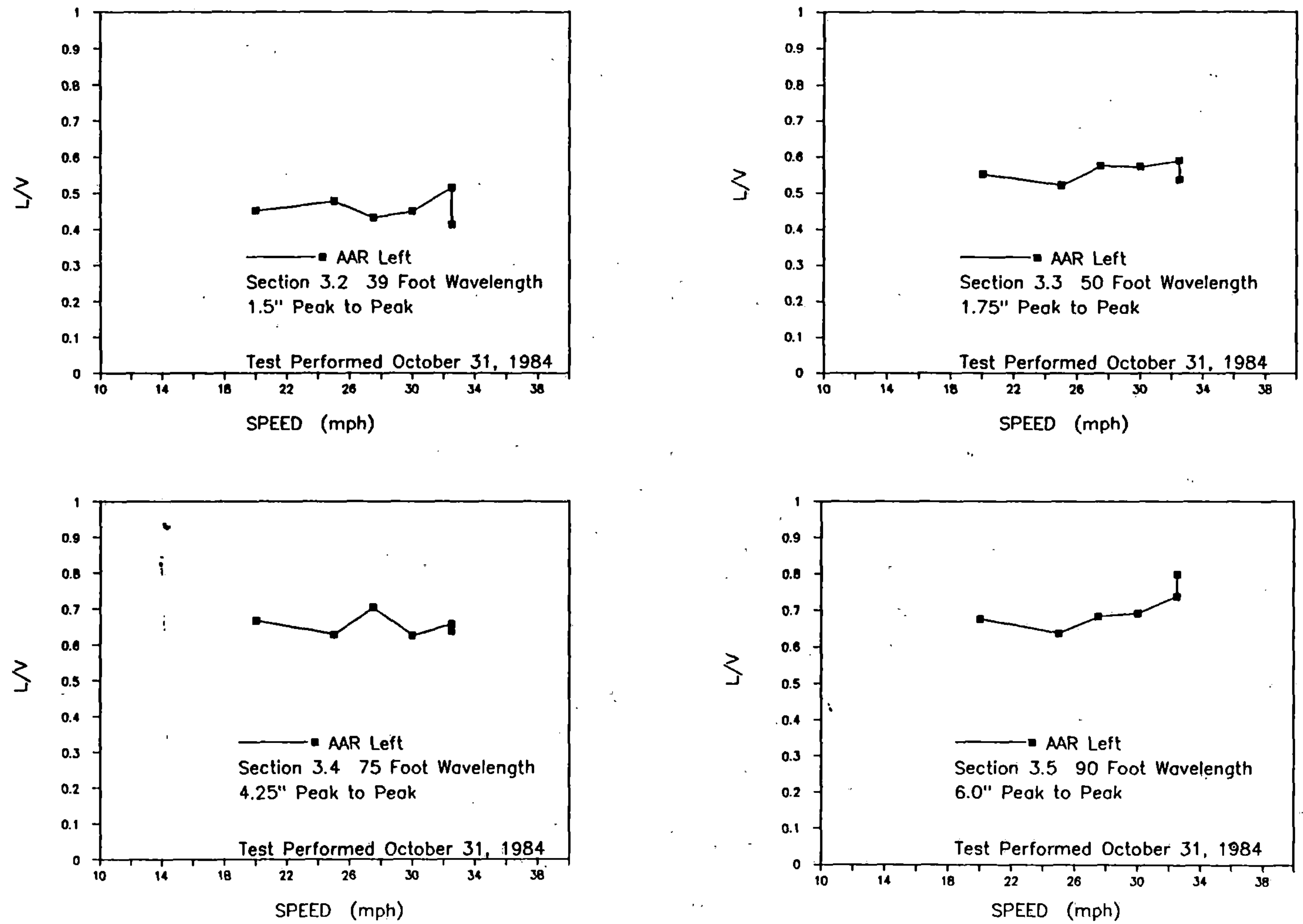
The locomotive lateral wheel forces measured in test segments 4.2 to 4.5 show a significant dependence on speed for the 75 foot and 90 foot alignment variation wavelengths (Figure 3.1-5). The smallest lateral wheel forces were measured at the 39' alignment variation wavelength, with the lateral wheel forces varying from 2 kips to 9 kips over the speed range tested (24 to 50 mph).

The measured lateral wheel forces at the 50', 75', and 90' alignment variation wavelengths are relatively constant for speeds from 24 to 35 mph, but increase significantly at speeds above 35 mph. The lateral wheel forces for the 50' alignment variation wavelength remain constant at about 15 kips for speeds up to about 40 mph. At higher speeds, the right wheel lateral force begins to increase with speed, reaching 21 kips at 50 mph, while the left wheel lateral force remains constant throughout the speed range.

At the 75 foot alignment variation wavelength, the lateral wheel forces start at 17 to 20 kips at 25 mph, and remain constant until about 36 mph. Above 36 mph, there is a steep increase in the right wheel forces to a level of 42 kips at 50 mph. The sharp increase in lateral force occurs at a slightly higher speed for the left wheel than it does for the right wheel. This behavior is repeated at the 90' wavelength alignment variation, except that the increase in the lateral wheel forces is not as steep. The right wheel lateral force reaches 31 kips at 50 mph.

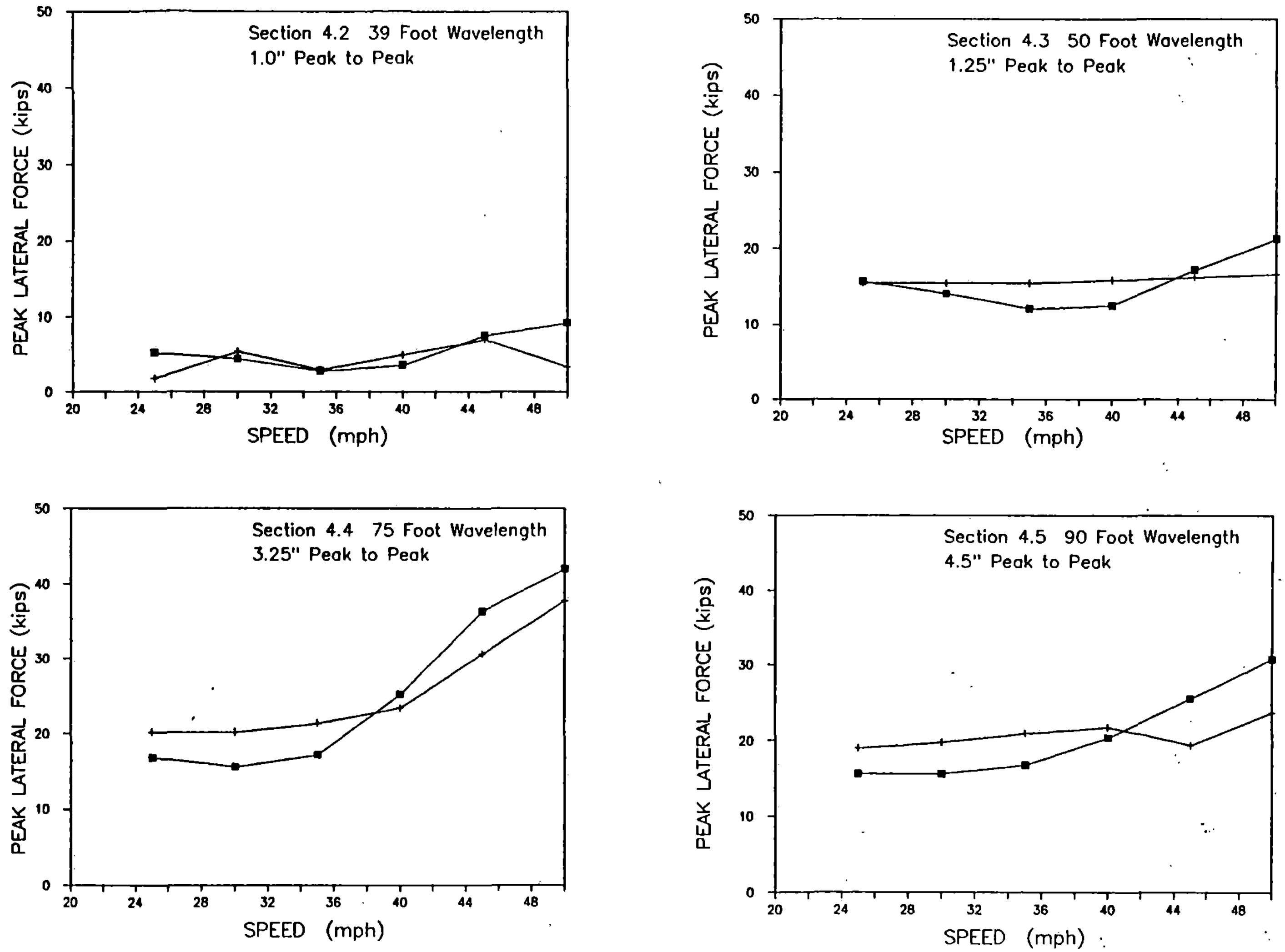
The reduction in amplitude of the alignment perturbations from those in segment 3.2 to 3.5 do not appear to show comparable reductions in the lateral forces measured on the 50, 75 and 90 foot wavelengths at comparable speeds. However, the reduction in amplitude of the alignment variation at 39 feet from 1.5 to 1.0 inches peak to peak shows a dramatic reduction in the wheel rail forces.

The L/V ratios for the locomotive measured at track segments 4.2 to 4.5 exhibit a pattern very similar to the lateral wheel forces (Figure 3.1-6). At the 39' alignment variation, the L/V ratios vary between 0.05 to 0.23 over the speed range. For the 50 foot wavelength perturbation, the L/V ratios fluctuate between 0.45 to 0.57. The highest L/V ratios occur in the 75 foot wavelength segment with an L/V ratios of 0.6 at a speed of 25 mph, and



Measurements for the locomotive were made in the loaded hopper car consist

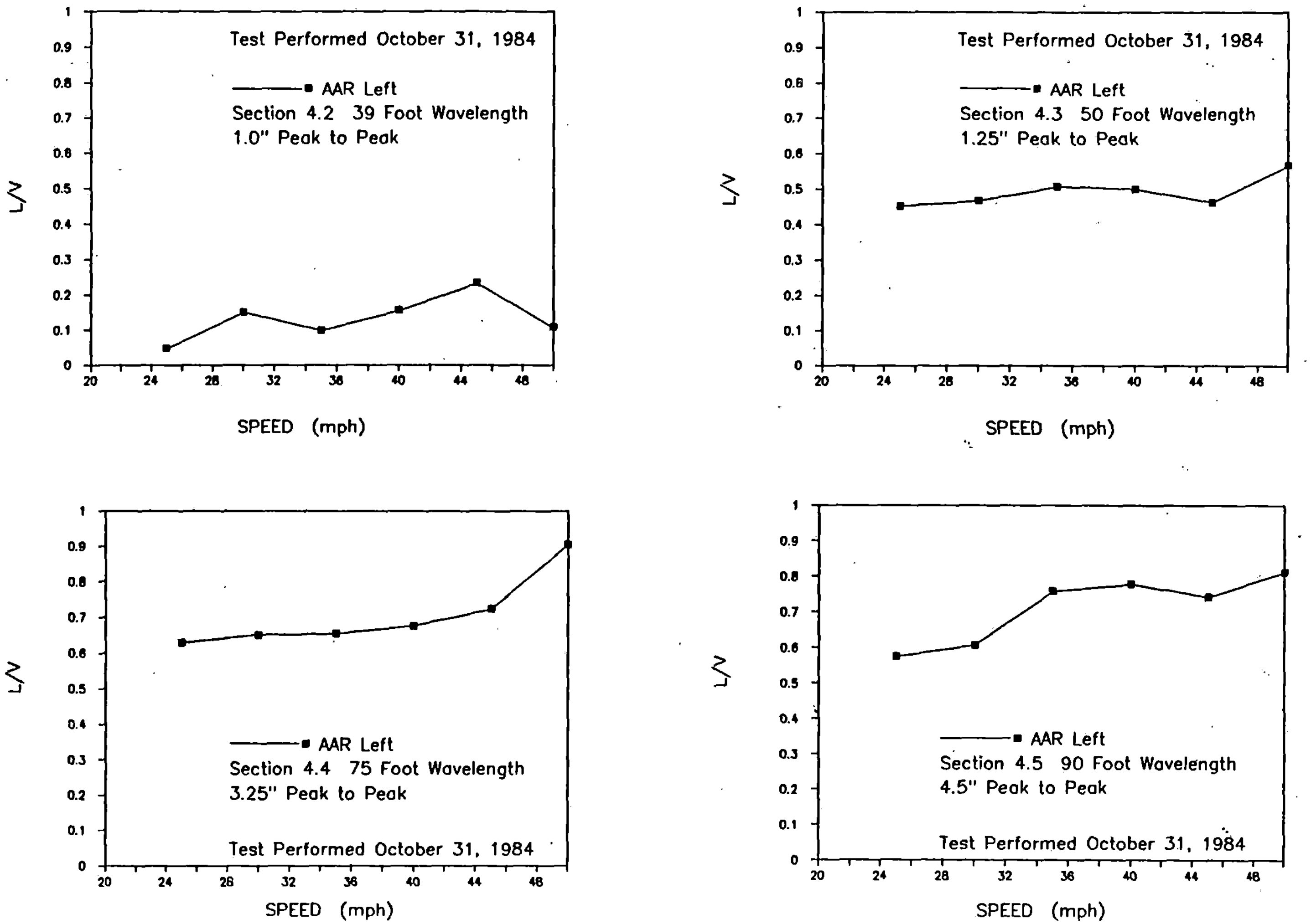
FIGURE 3.1-4 LOCOMOTIVE - PEAK LATERAL TO VERTICAL WHEEL FORCE RATIOS AT INTERMEDIATE SPEED TEST SECTION



Measurements for the locomotive were made on the loaded hopper car consist.

■ AAR Right + AAR Left

FIGURE 3.1-5 LOCOMOTIVE - PEAK LATERAL WHEEL FORCES AT HIGH SPEED TEST SECTION



Measurements for the locomotive were made on the loaded hopper car consist.

FIGURE 3.1-6 LOCOMOTIVE - PEAK LATERAL TO VERTICAL WHEEL FORCE RATIOS AT HIGH SPEED TEST SECTION

increasing to 0.9 at 50 mph. At the 90' wavelength, the L/V ratios are slightly lower than those measured at the 75' wavelength, with a maximum L/V ratio of 0.8 at 50 mph.

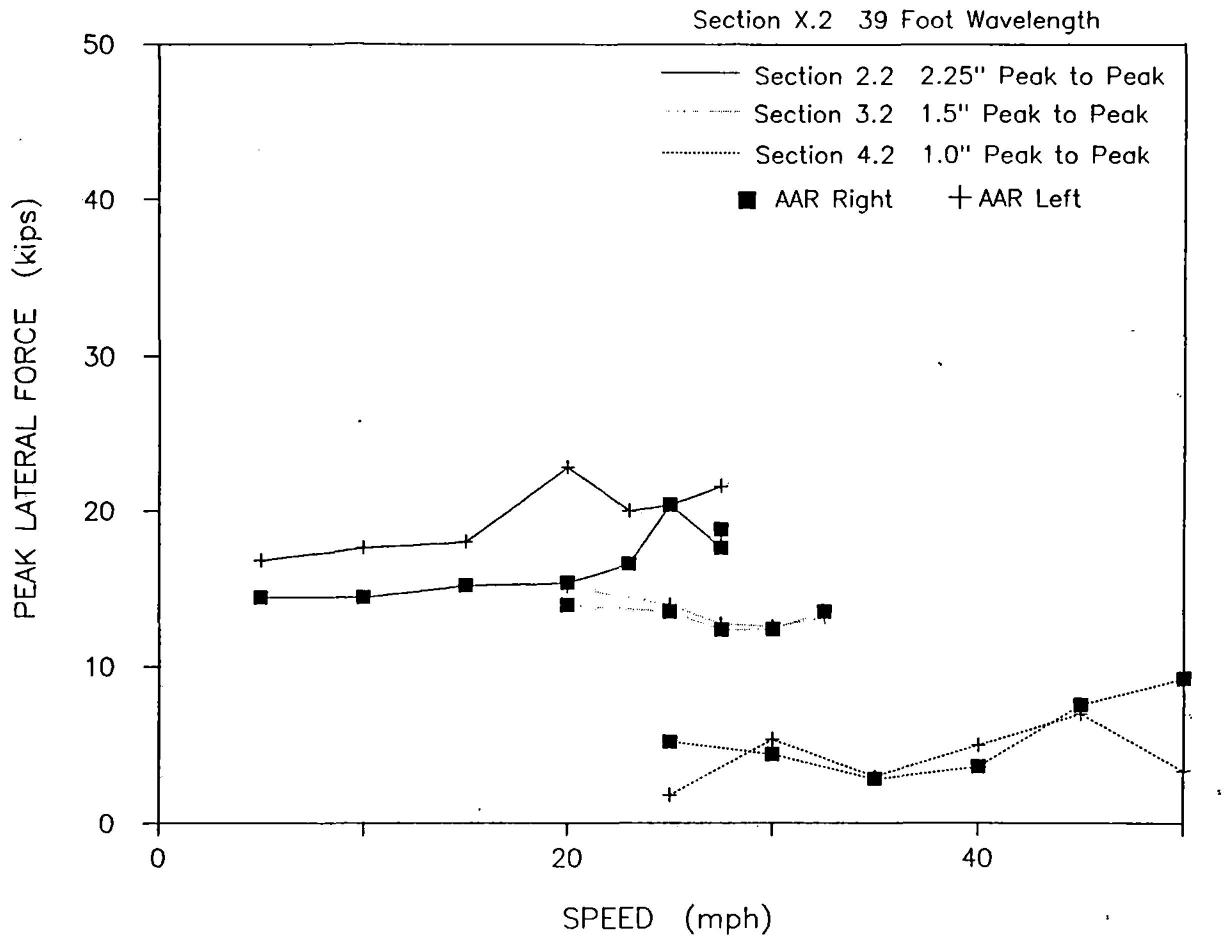
3.1.4 SUMMARY OF LOCOMOTIVE TEST RESULTS

The GP 9 locomotive used in these tests produced the highest levels of lateral forces observed in the testing. In each speed zone, the locomotive behavior had the effect of limiting the maximum test speed. In the large amplitude zone, the 50 foot wavelength produced the most critical behavior. In the small amplitude test zone of the 75 foot wavelength, the locomotive produced lateral wheel rail forces reaching 42 kips. At the 50 foot wavelength and the 39 foot wavelength, the nature of the vehicle track dynamic interaction appears to be strongly dependent on the amplitude of the irregularity. These observations are discussed more fully in the following paragraphs.

The 39 foot wavelength alignment irregularity acts to produce a lateral and roll mode input to the locomotive through the 34 foot truck center spacing. Within each of the 39 foot segments, the wheel rail forces are relatively insensitive to speed. Figure 3.1-7 shows the peak lateral wheel force in each segment plotted versus speed. The reduction in perturbation amplitude from 2.25 inches to 1.5 inches resulted in a reduction of peak lateral wheel rail forces from an average of 19 kips to 15 kips at 20 mph. However, the reduction in amplitude from 1.5 inches to 1.0 inches produced a dramatic reduction in peak lateral forces. At a speed of 30 mph, the 1.5 inch amplitude perturbation produced a force of about 13 kips, while the 1.0 inch perturbation produced a peak force of about 4 kips. The small peak lateral forces may result from the flange clearance being comparable to the perturbation amplitude, permitting the axles to pass through the segment without fully responding to the perturbation.

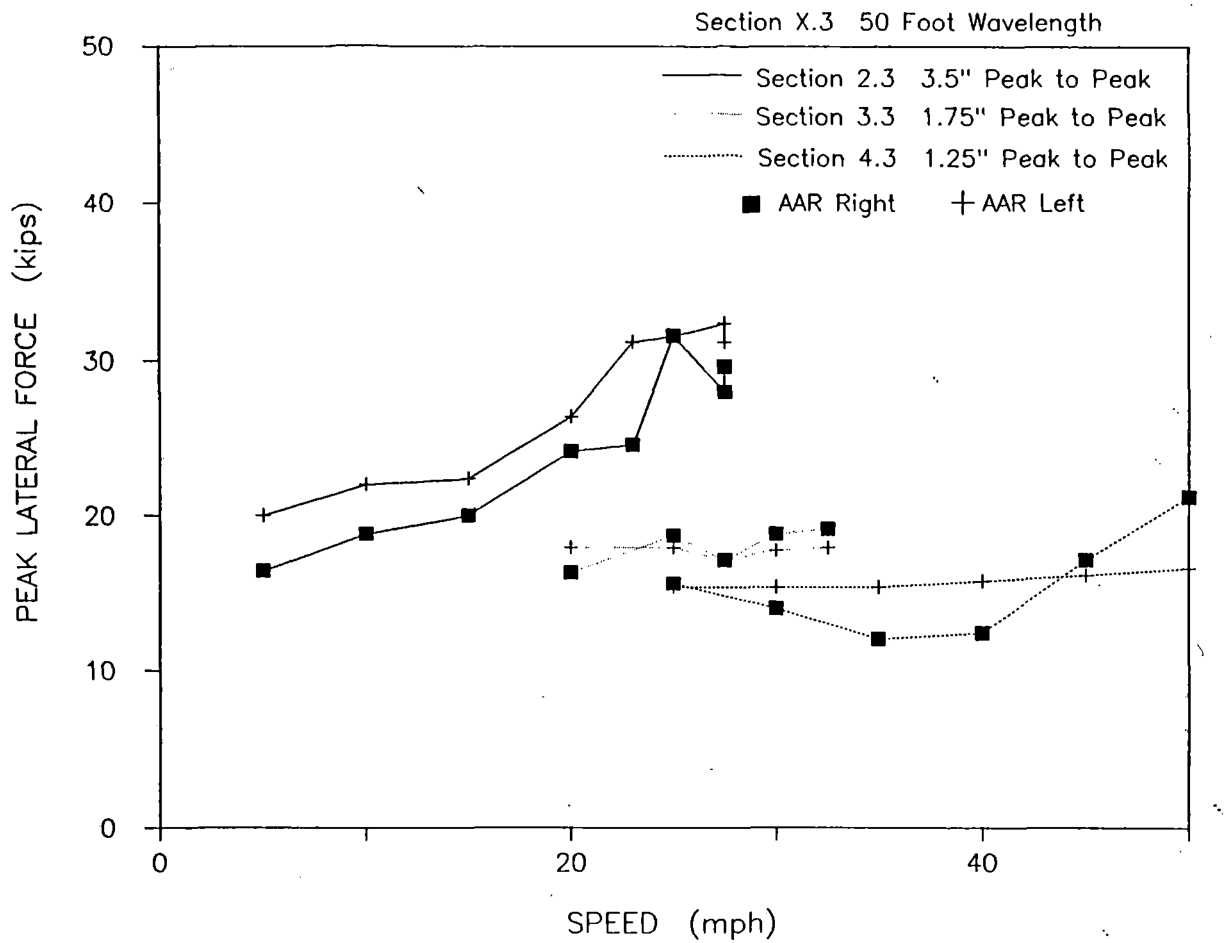
The 50 foot wavelength alignment irregularity combined with the 34 foot truck center spacing acts to excite a combined lateral, roll, and yaw mode response (Figure 3.1-8). At the 3.5 inch peak to peak amplitude, the locomotive peak lateral forces increase dramatically with speed from about 18 kips at 5 mph to 30 kips at 28 mph. The lateral to vertical wheel rail force ratios of 0.9 measured for the locomotive lead axle wheels in this segment caused the segment 2 speeds to be limited to 28 mph in the tests.

The reduction in amplitude from 3.5 inches to 1.75 inches appears to have totally eliminated the speed dependence of the peak lateral forces. The peak lateral forces for the 1.75 inch peak to peak amplitude are relatively constant at a level of about 18 kips over the same speeds for which the lateral forces were increasing with speed at the 3.5 inch amplitude. The reduction in amplitude to 1.25 inches produces only a small change in the peak lateral forces (from about 18 kips to 15 kips).



Measurement for the locomotive were made on the loaded hopper car consist.

FIGURE 3.1-7 LOCOMOTIVE - PEAK LATERAL WHEEL FORCES AT 39 FOOT TRACK WAVELENGTH TEST SECTIONS



Measurements for the locomotive were made on the loaded hopper car consist.

FIGURE 3.1-8 LOCOMOTIVE - PEAK LATERAL WHEEL FORCES AT 50 FOOT TRACK WAVELENGTH TEST SECTIONS

The 75 foot wavelength alignment irregularity coupled with the 34 foot truck center spacing results in almost a pure locomotive yaw mode excitation (Figure 3.1-9). For speeds up to 35 mph, the peak lateral forces for all of the 75 foot segments remained relatively constant with speed at a level of above 20 kips for all three irregularity amplitudes (5.0, 4.25 and 3.25 inches peak to peak). At speeds above 35 mph, the peak forces increased dramatically to a level of above 40 kips at a speed of 50 mph. The wheel lateral to vertical force ratio at 50 mph of 0.9 appears to be following an increasing trend. This behavior resulted in the maximum test speed being limited to 50 mph for all of the alignment tests conducted.

The 90 foot wavelength coupled with the 34 foot truck center spacing excites a combined lateral, roll, and yaw mode input (Figure 3.1-10). In these test segments, the lateral force behavior is similar to that observed in the 75 foot segments, with the peak lateral forces being constant with speed at a level of about 18 kips for all three perturbation amplitudes (8.0, 6.0 and 4.5 inch peak to peak) until a speed of about 35 mph. The increase in force is not as severe as the 75 foot segment and reaches a peak value of 30 kips at 50 mph.

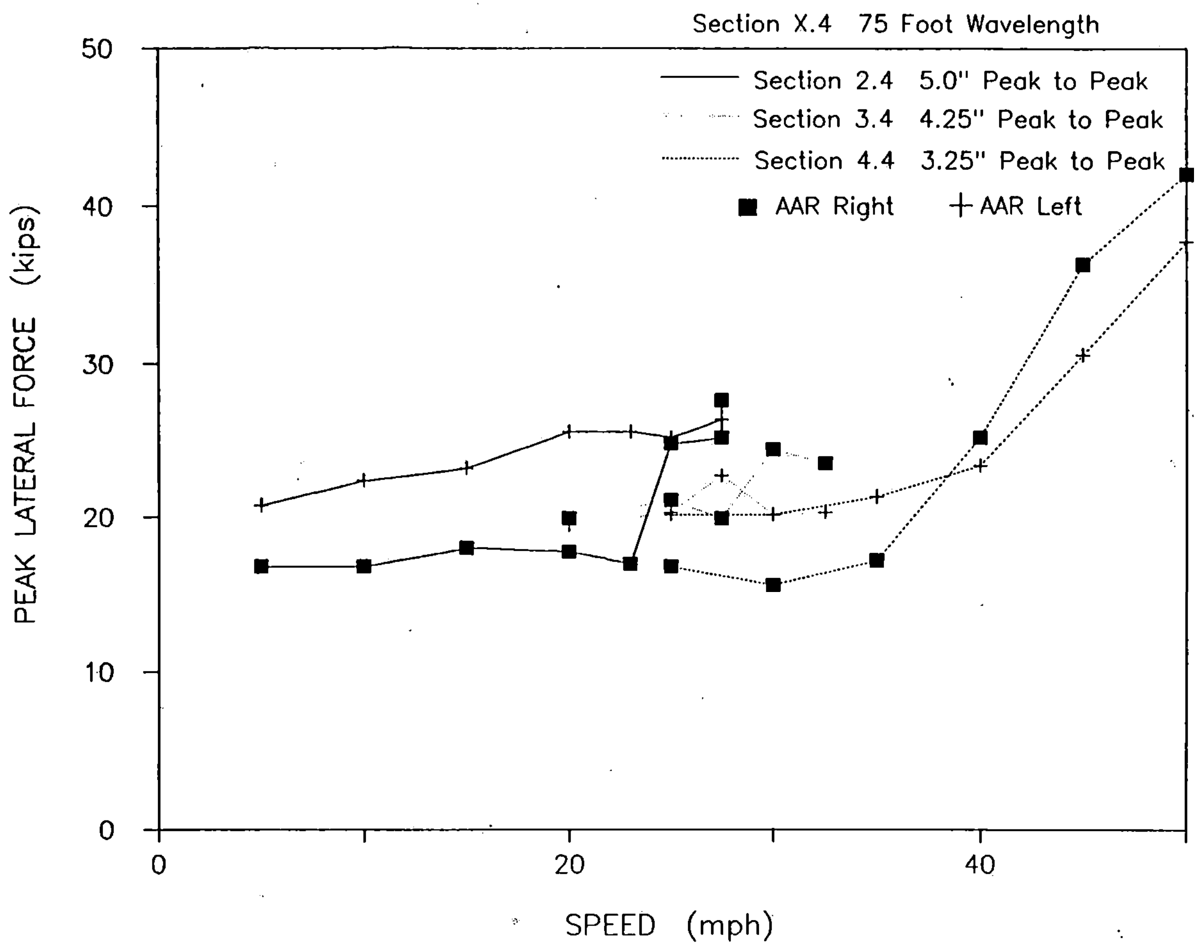
3.2 LOADED HOPPER CAR

3.2.1 TRACK SEGMENTS 2.2 TO 2.5

The measured lead axle wheel lateral forces for the loaded hopper cars in segments 2.2 to 2.5 are shown in Figure 3.2-1. The measurements obtained from the two instrumented trucks indicate large differences in behavior of the two wheel profiles at the lower speeds. The peak forces measured with the Heumann profile wheels remain relatively constant with speed, while those measured with the AAR profile wheels appear to increase with speed. Although the track geometry is sinusoidal and symmetrical, there is a significant difference in force levels measured on the left and right wheels.

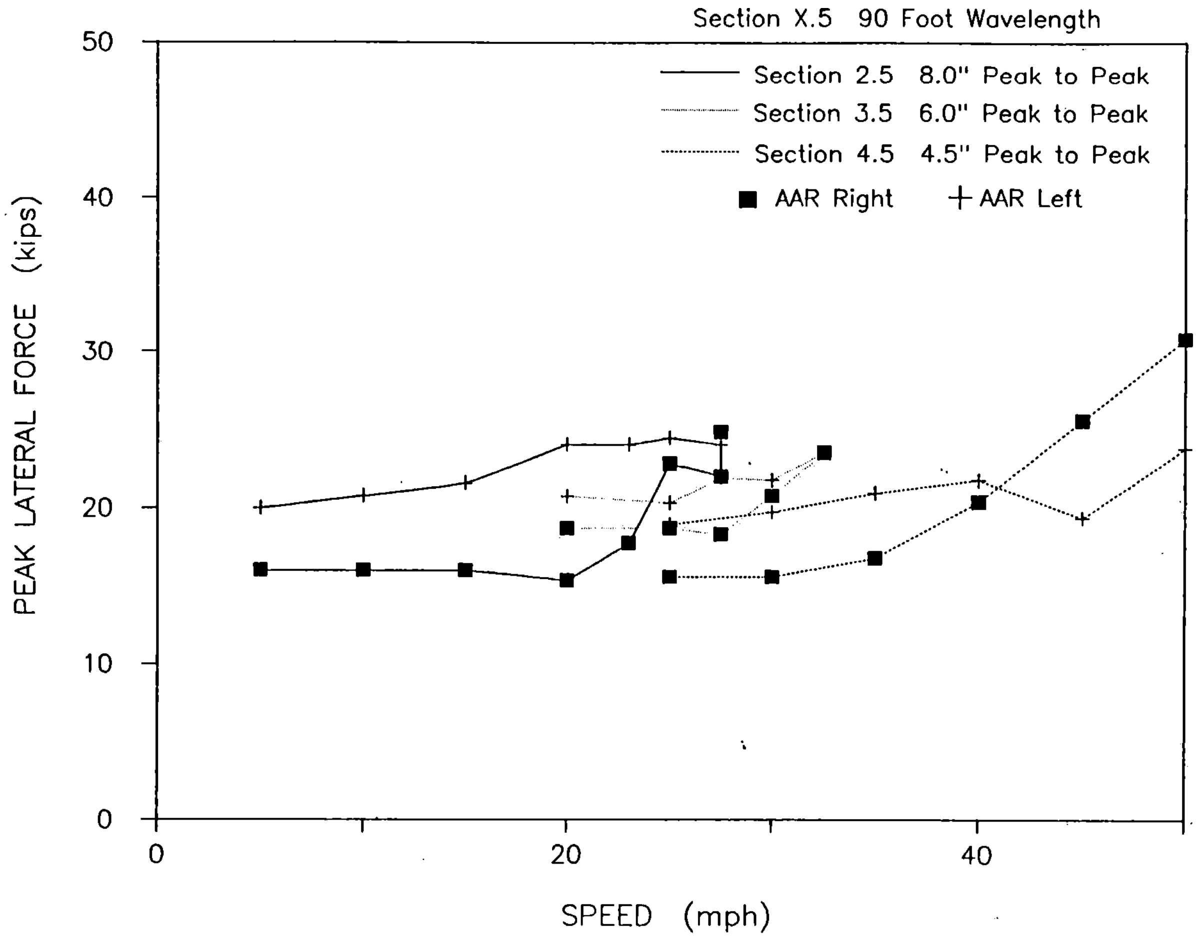
For the Heumann profile wheels, the forces remain relatively constant at a level of about 16 kips with speed for the 90 foot wavelength alignment irregularity. The data obtained in the 39 foot and 50 foot variations show a slight increase of force level with speed. The peak force at 28 mph was about 20 kips at the 39 foot wavelength and about 22 kips for the 50 foot wavelength. At the 75 foot wavelength alignment variation, the force on the right lead wheel increases from 18 kip at 5 mph to about 24 kips at 28 mph.

For the AAR profile wheels, the lowest lateral wheel forces occur in the 39' wavelength segment, where the forces increase from 5 kips at 5 mph to 14 kips at 28 mph. This speed sensitivity for the AAR profile wheels is repeated on all of the alignment wavelengths. With increasing speeds, the forces measured on the AAR profile wheels increase to approach the level of the force measured on the Heumann profile wheels for the 39 foot and 50 foot wavelengths. At the 75 and 90 foot wavelengths, the forces measured on the AAR profile wheels exceed those measured for the Heumann profile wheels at the higher speeds.



Measurements for the locomotive were made on the loaded hopper car consist.

FIGURE 3.1-9 LOCOMOTIVE - PEAK LATERAL WHEEL FORCES AT 75 FOOT TRACK WAVELENGTH TEST SECTIONS



Measurements for the locomotive were made on the loaded hopper car consist.

FIGURE 3.1-10 LOCOMOTIVE - PEAK LATERAL WHEEL FORCES AT 90 FOOT TRACK WAVELENGTH

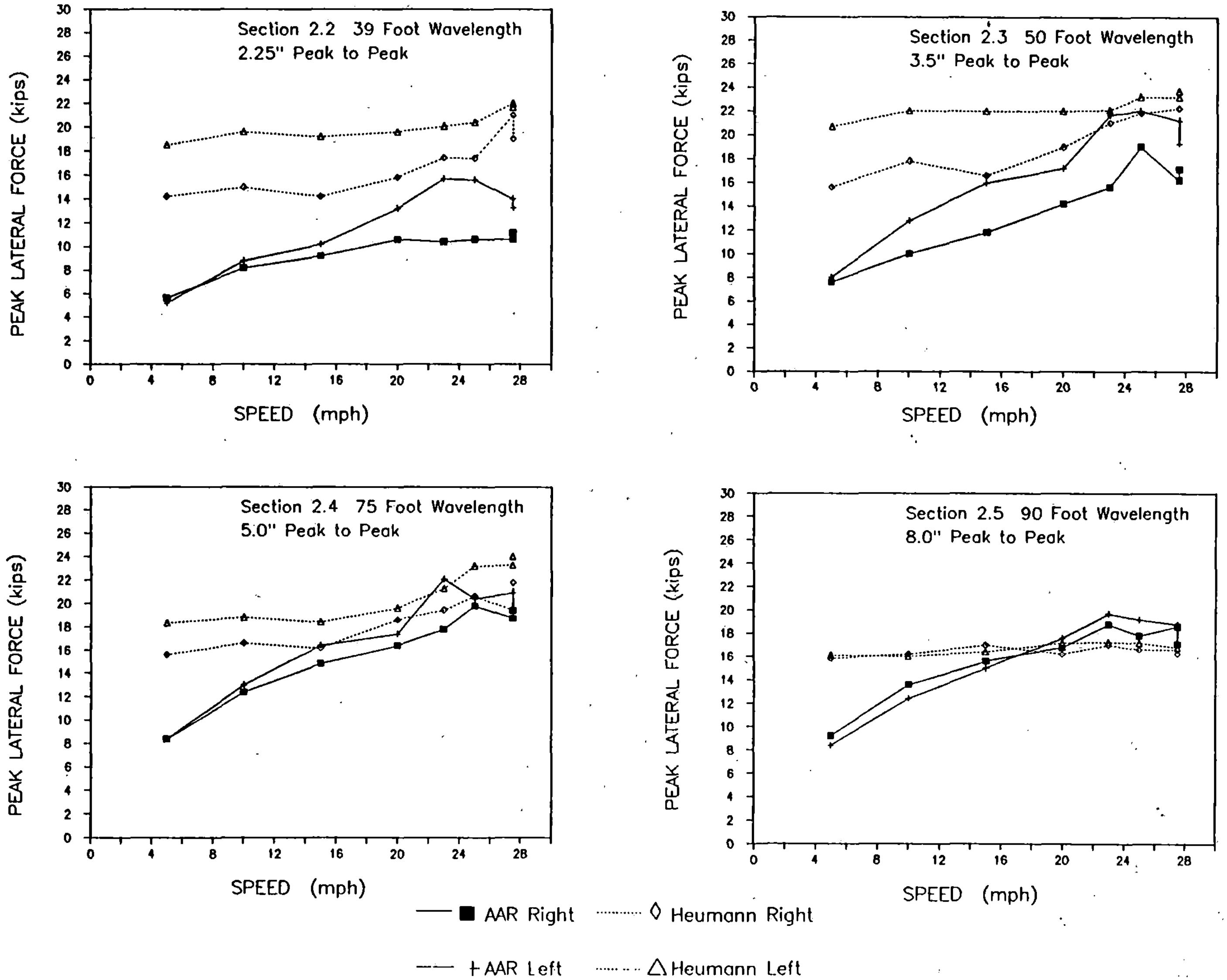


FIGURE 3.2-1 LOADED HOPPER CAR - PEAK LATERAL WHEEL FORCES AT LOW SPEED TEST SECTION

As discussed in Section 4, the lateral forces recorded in this set of tests from the instrumented wheelsets with the AAR profile used for the freight cars, are not consistent with either analytical predictions or previous test results. It is suspected that an instrumentation error existed in all of the tests using the instrumented AAR profile truck that corrupted the low speed measurements. However, the source and nature of this error are not known at this time.

The peak lateral to vertical force ratios measured in segments 2.2 to 2.5 are shown in Figure 3.2-2. For the Heumann profile wheels, the L/V ratios remain essentially constant with speed at a level of about 0.5, except at the longer wavelengths, where the L/V ratios decrease slightly with speed. This behavior is consistent with that of the peak lateral forces measured for the Heumann profile wheels.

The L/V ratios recorded for the AAR profile wheels are inconsistent with the lateral forces presented above in that they would imply large wheel unloading at low speed.

The L/V ratios for the AAR profile wheels follow those of the Heumann profile wheels for the 39' wavelength starting at about 0.4 at 5 mph, and increasing to 0.65 at 28 mph. At the longer wavelengths (50, 75 and 90 feet), the L/V ratios for the AAR profile wheels are higher than those for the Heumann profile wheels, increasing with speed from 0.55 at 5 mph to 0.7 at 28 mph. This result is surprising since the Heumann profile wheels report higher lateral forces than the AAR profile wheels. It is believed that instrumentation errors resulted in the AAR profile wheels reporting both lower lateral forces and more wheel unloading than actually occurred, especially at low speed.

3.2.2 TRACK SEGMENTS 3.2 TO 3.5

The peak lead axle lateral forces measured in segments 3.2 to 3.5 are shown in Figure 3.2-3. At the 75 foot and 90 foot wavelengths, both wheel profiles generate about the same force levels. At the 75 foot wavelength, the peak forces measured for the Heumann profile wheels increase from about 16 kips at 20 mph to 21 kips at 30 mph. For the 90 foot wavelength, the peak force for the Heumann profile wheels was about 20 kips. At the 50 foot wavelength, the peak lateral forces measured by the Heumann profile wheels are larger than those obtained with the AAR profile wheels, with both sets of forces increasing with speed. For the Heumann profile wheels, the peak forces increase from about 16 kips to about 20 kips.

For the 39 foot wavelength alignment variation, there is a dramatic difference in force levels for the two wheel profiles, with the peak forces for the AAR profile at a level of about 4 kips, and the Heumann profile producing between 12 and 17 kips. The reduction in amplitude of the 39 foot wavelength perturbation from 2.25 inches to 1.5 inches peak to peak resulted in a much larger reduction in force for the AAR profile than for the Heumann profile.

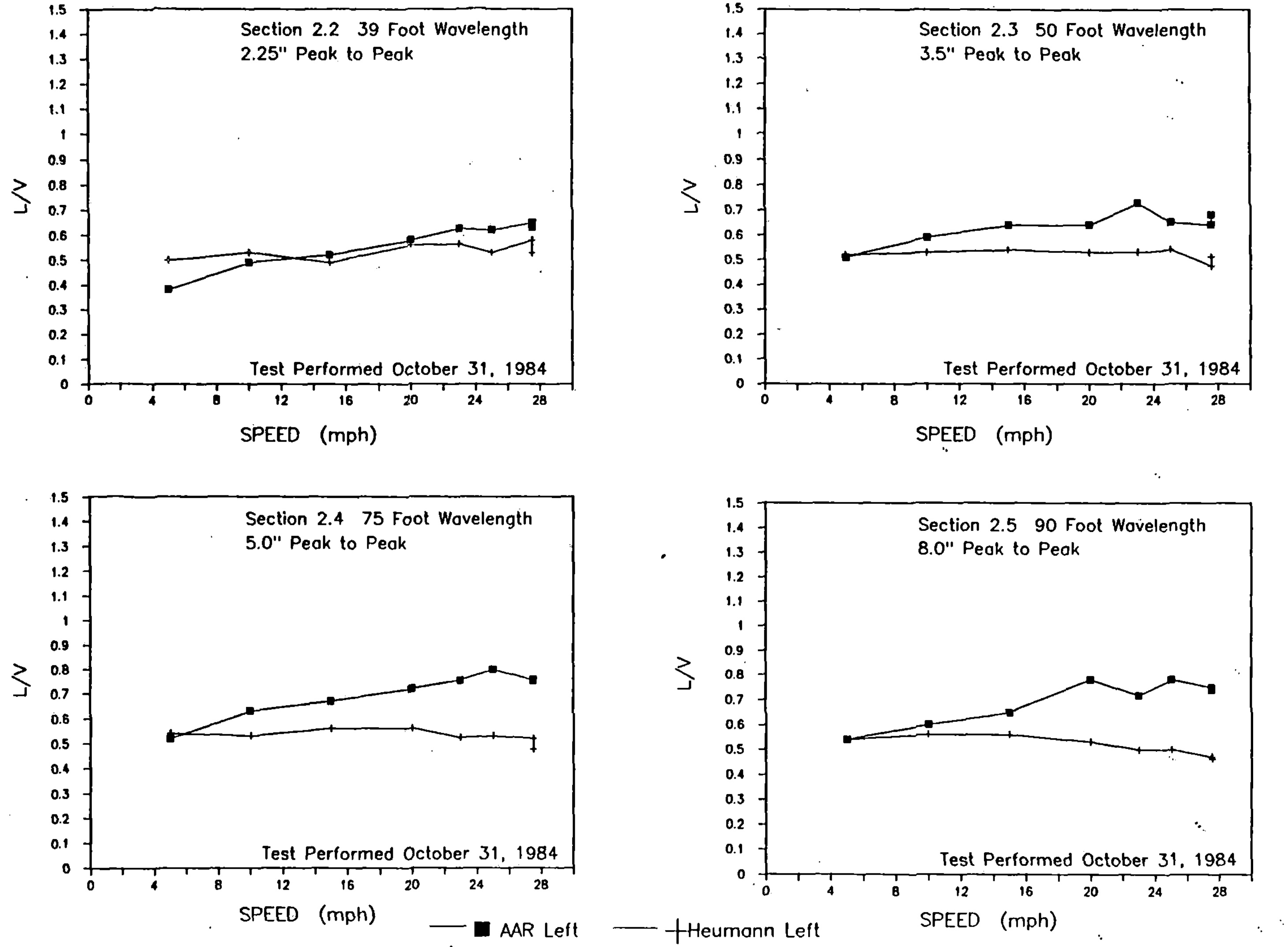


FIGURE 3.2-2 LOADED HOPPER CAR - PEAK LATERAL TO VERTICAL WHEEL FORCE RATIOS AT LOW SPEED TEST SECTIONS

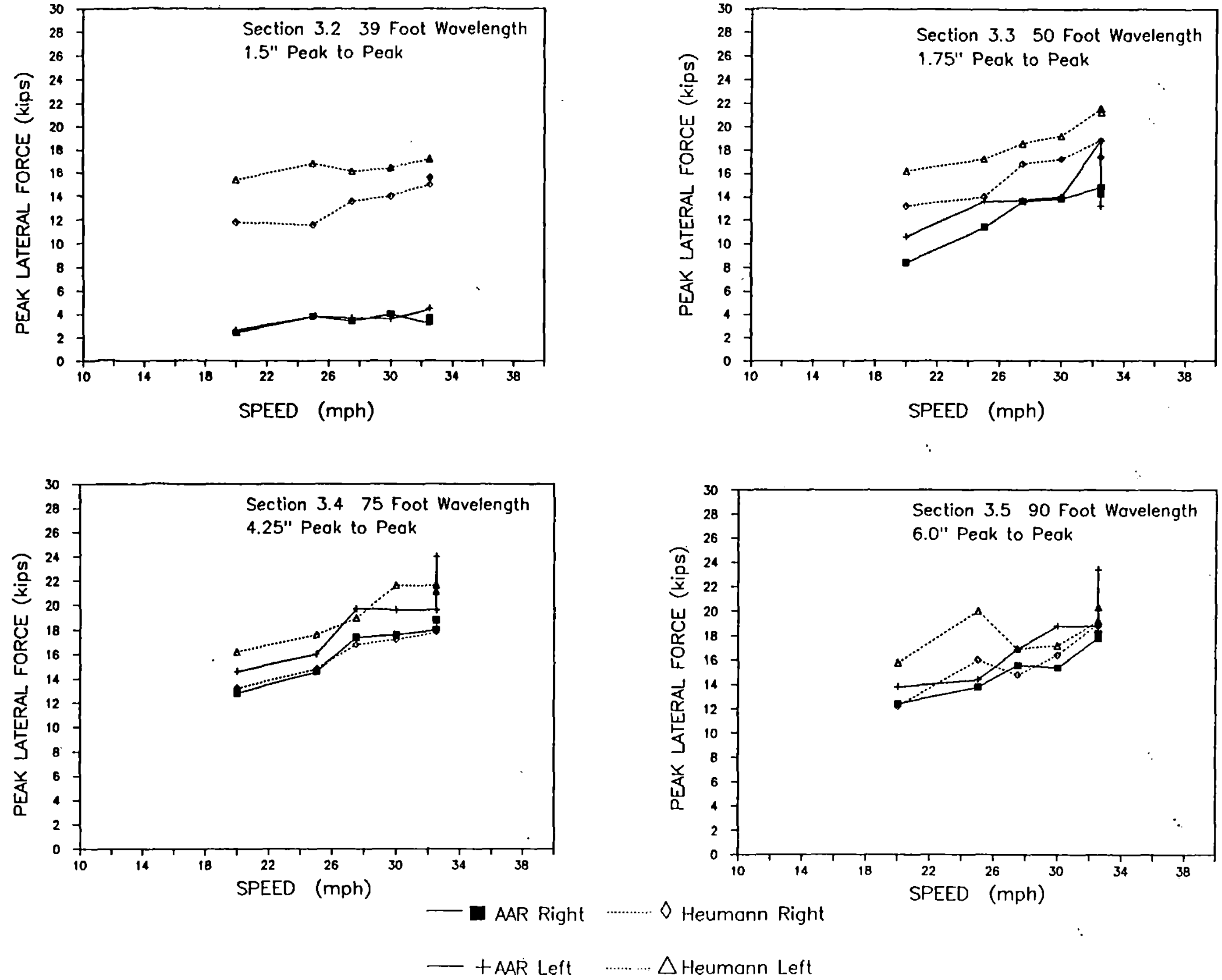


FIGURE 3.2-3 LOADED HOPPER CAR - PEAK LATERAL WHEEL FORCES AT INTERMEDIATE SPEED TEST SECTION

The L/V ratios for the loaded hopper cars at track segments 3.2 to 3.5 are shown in Figure 3.2-4. The L/V ratios for the AAR profile wheel at 39' track wavelength is about 0.12, which is the lowest L/V ratios for these segments. For track wavelengths above 39', the L/V ratios for both wheel profiles are between 0.3 and 0.55. There is a very slight sensitivity of the L/V ratios to speed. Reducing the track alignment amplitudes from those in segments 2.2 to 2.5 resulted in lower L/V ratios on both wheel profiles, with the drop being much greater for the AAR profile wheels.

3.2.3 TRACK SEGMENTS 4.2 TO 4.5

The peak lateral wheel forces measured for the loaded hopper car in segments 4.2 to 4.5 are shown in Figure 3.2-5. The effect of reducing the track alignment amplitudes is a lowering of the lateral forces for both wheel profiles by about 3 to 6 kips. The lateral forces for the AAR profile wheels at the 39' track wavelength remain constant with speed at a 1 kip level, which is 2 kips lower than in segment 3.2. The Heumann profile wheels peak lateral forces for the 39 foot wavelength increase from about 10 kips at a speed of 25 mph to about 14 kips at 50 mph. At the 50, 75, and 90 foot wavelengths, the lateral wheel forces increase by about 4 to 8 kips over a speed range of 25 to 50 mph for both wheel profiles. There is a large separation in force levels of about 7 kips between the right and left wheels for both wheel profiles at all but the 39' track wavelength.

Variations in track wavelengths for the loaded hopper car at track segments 4.2 to 4.5 have some effect on the L/V ratios of the AAR profile wheels, but the L/V ratios for the Heumann profile wheels are about the same at all wavelengths (Figure 3.2-6). The L/V ratios for the AAR profile wheels are only about 0.1 at a track wavelength of 39', increasing to about 0.2 at the 50' wavelength, and reach 0.5 at 75' and 90' wavelengths. For the Heumann profile wheels, L/V ratios of 0.5 were measured at all the track wavelengths. The L/V ratios for both wheel profiles are not very sensitive to speed. A reduction in the track alignment amplitudes has the effect of lowering the L/V ratios significantly for the AAR profile wheels, but only slightly for the Heumann profile wheels.

3.2.4 SUMMARY OF LOADED HOPPER CAR TEST RESULTS

The largest peak force measured for the loaded hopper car for this set of tests was about 24 kips at a speed of 28 mph, in the 5.0 inch peak to peak, 75 foot wavelength alignment perturbation. In the low speed test segments, the instrumented wheelset for the AAR profile appears to be reporting both lateral and vertical forces that are smaller than those believed to have existed. Compared to the locomotive wheel force behavior, the loaded hopper car wheel forces showed relatively little sensitivity to speed. The strongest speed sensitivities appeared in the 50 foot and 75 foot wavelength segments in the intermediate speed zone.

The lateral wheel forces measured with the Heumann profile wheels are larger than those obtained from the AAR profile wheelset in almost all of the tests. However, for the 39 foot wavelength, the difference is especially dramatic. For the 1.0 inch peak to peak, and

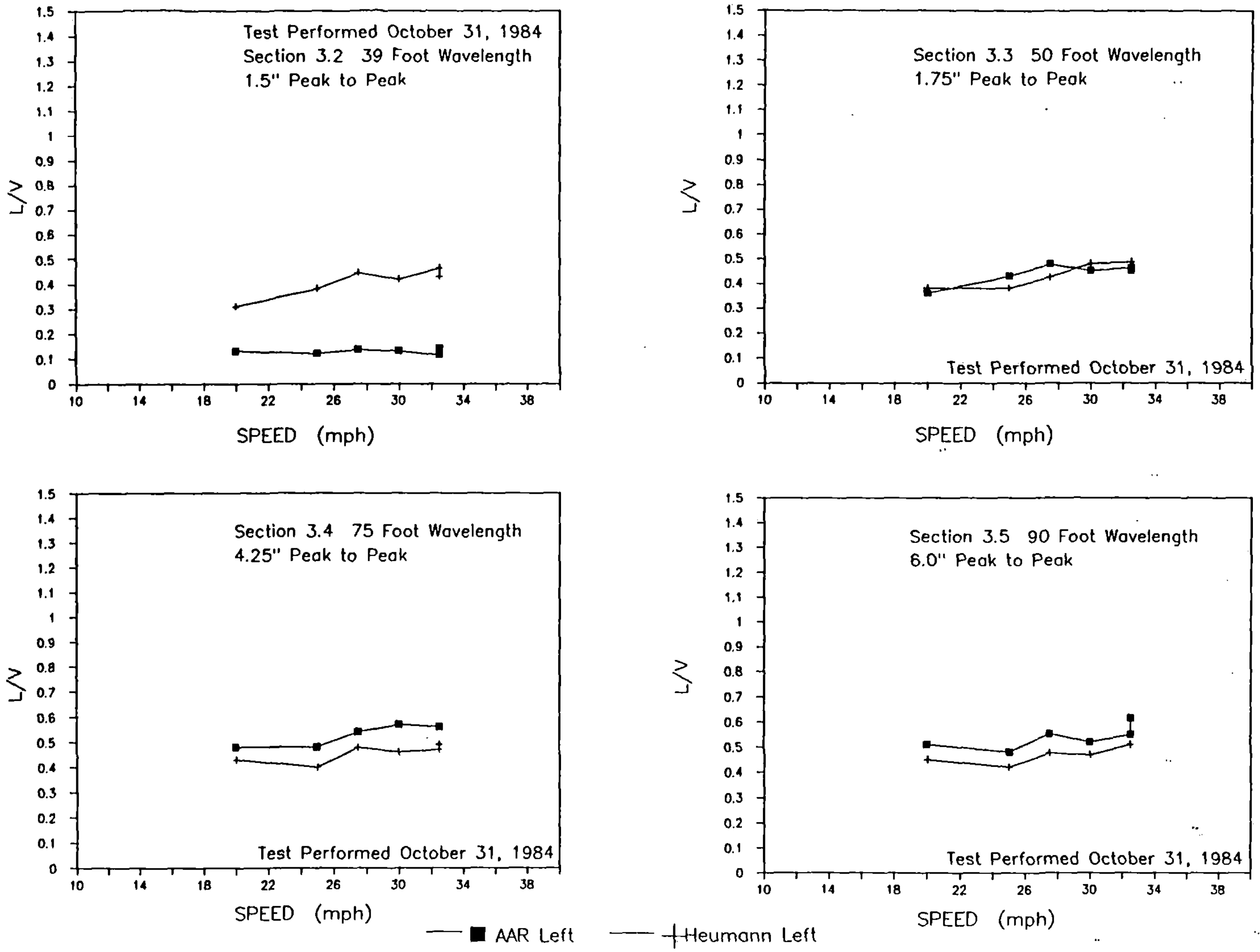


FIGURE 3.2-4 LOADED HOPPER CAR - PEAK LATERAL TO VERTICAL WHEEL FORCE RATIOS AT INTERMEDIATE SPEED TEST SECTION

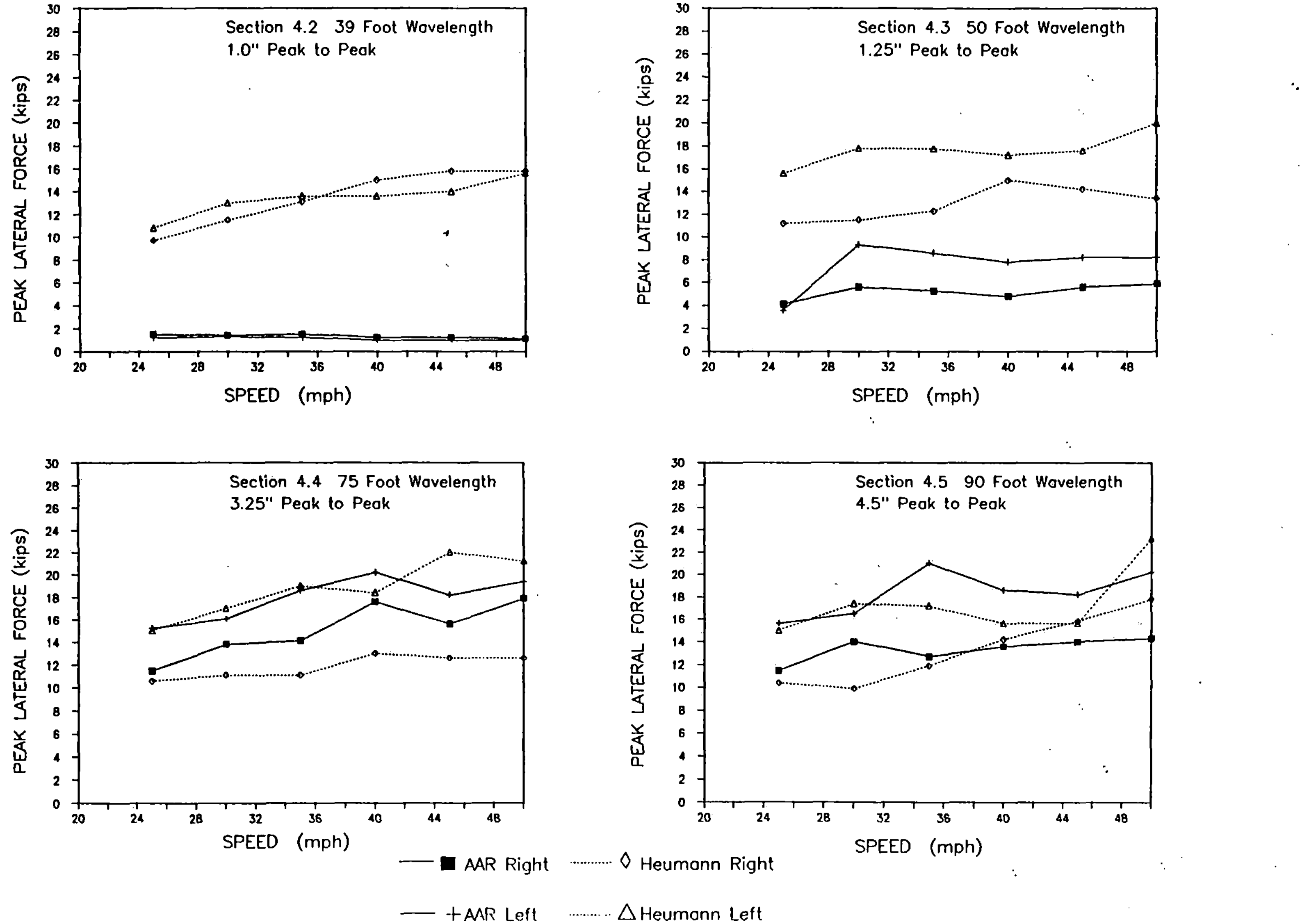


FIGURE 3.2-5 LOADED HOPPER CAR - PEAK LATERAL WHEEL FORCES AT HIGH SPEED TEST SECTION

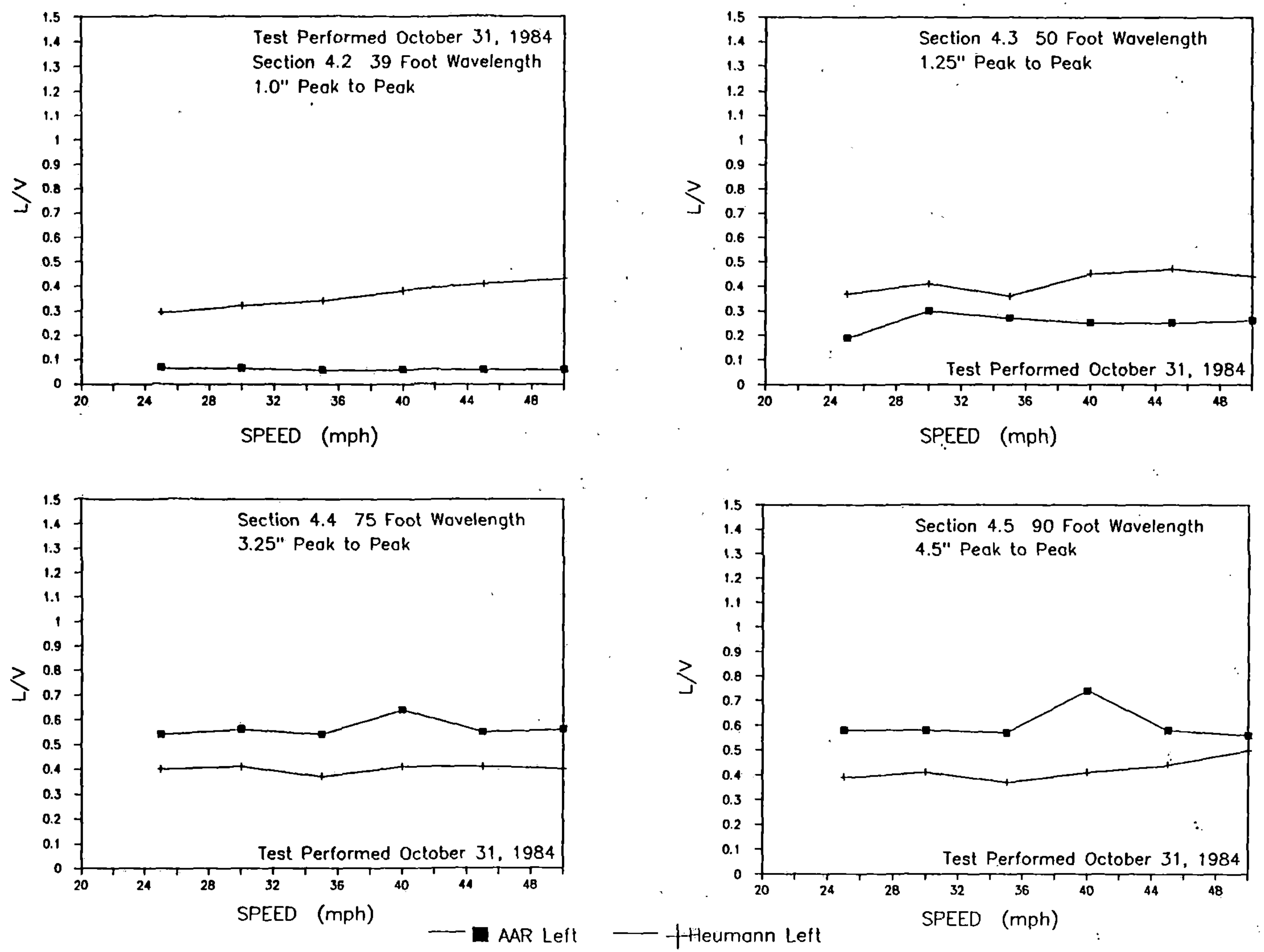


FIGURE 3.2-6 LOADED HOPPER CAR - PEAK LATERAL TO VERTICAL WHEEL FORCE RATIOS AT HIGH SPEED TEST SECTION

1.5 inch peak to peak, 39 foot wavelength variations, the peak lateral forces measured on the AAR profile wheels are comparable to those that would be expected on perfect tangent track at low speed. The lower peak lateral wheel forces may result from a larger effective flange clearance for the AAR profile wheelsets than for the Heumann profile wheelsets.

3.3 LOADED TANK CAR

The peak lateral forces measured in the tests of the loaded tank car are shown in Figures 3.3-1 to 3.3-3. Within the experimental error of the tests, the results are essentially the same as those obtained for the loaded hopper car. The largest peak lateral forces measured for the loaded tank car ~~was~~ were about 25 kips at a speed of 20 mph at the 3.5 inch peak to peak, 50 foot wavelength segment, and at the 5.0 inch peak to peak, 75 foot wavelength segment. The peak forces for the tank car are generally larger than those for the hopper car at the same speed and condition. Since the axle load on the tank car is about 10% larger than the hopper car, the lateral forces would be expected to be about 10% higher.

For the loaded tank car, the data was obtained over a speed range of 4 mph to 34 mph over the intermediate speed segments 3.2-3.5. For the 90 foot wavelength, the data shows a gentle increase in peak force with speed from about 15 kips to about 18 kips for the Heumann profile wheels. For the other wavelengths, the data is a little more erratic. However, the trend is similar.

In the higher speed range test segments, the peak lateral forces are essentially constant with speed from 20 to 42 mph at each wavelength for the Heumann profile wheels. The AAR profile wheels report essentially the same force levels for the 50 foot, 75 foot, and 90 foot wavelength segments, with the exception of some erratic behavior at speeds above 40 mph. As in the loaded hopper car data, the AAR profile wheels experience much lower forces in the 39 foot wavelength segment than the Heumann profile wheels.

The L/V ratios for the three speed sections are shown in Figures 3.3-4 to 3.3-6

3.4 LOADED FLAT CAR

The peak lateral forces measured for the loaded flatcars tested are shown in Figures 3.4-1 to 3.4-3. The force speed characteristics are similar to those of the loaded tank car and loaded hopper car. The lateral force levels measured for the flatcar are about 30% smaller than those for the loaded hopper car. The lower lateral force levels are accounted for by the lower weights of the loaded flat cars (183,000 lb. and 159,000 lb. on the rail).

With the exception of the 3.5 inch peak to peak, 50 foot wavelength segment, the peak lateral wheel forces for the Heumann profile wheels are relatively insensitive to speed. At the 3.5 inch peak to peak, 50 foot wavelength, the peak lateral force increases from about 13 kips at

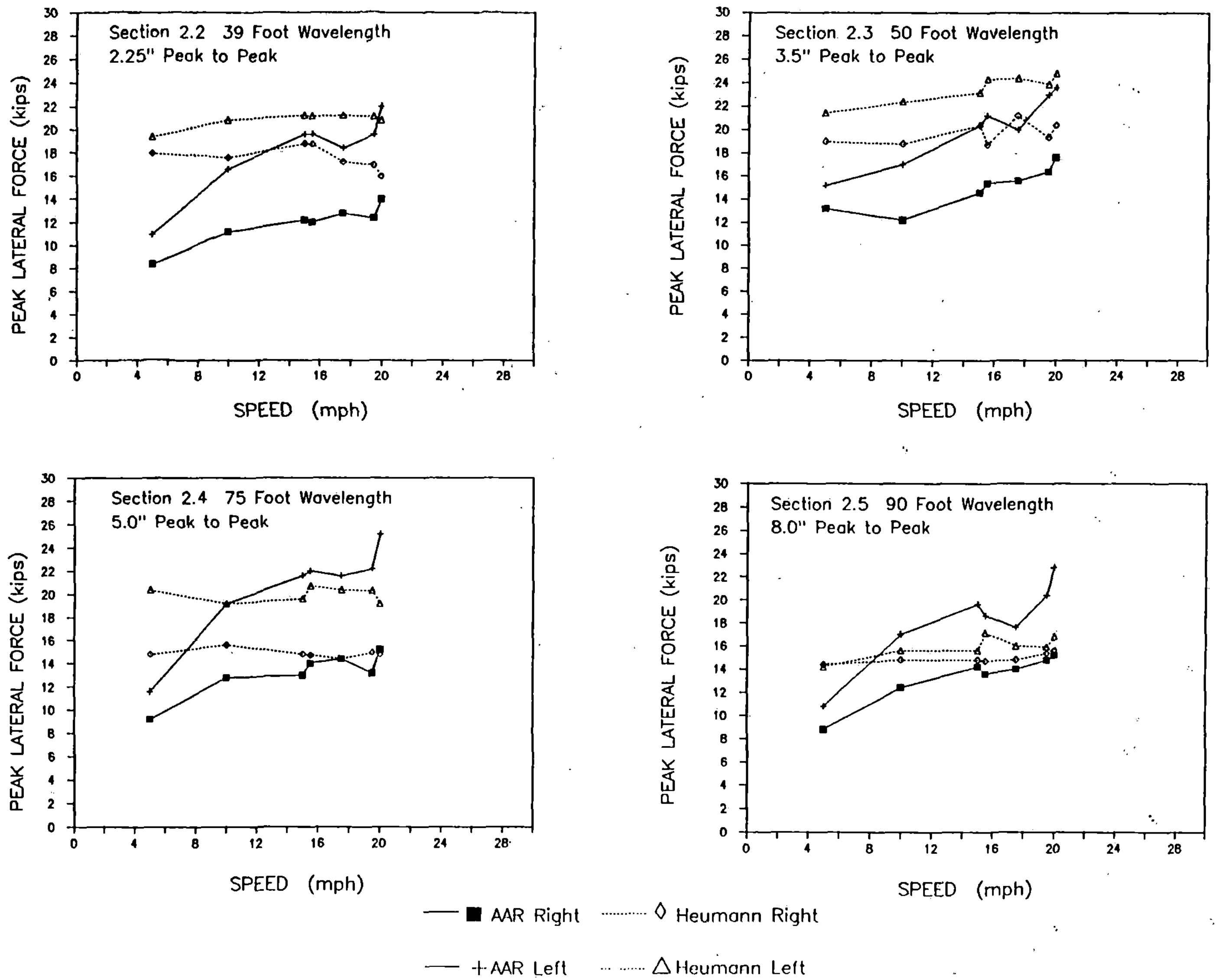


FIGURE 3.3-1 LOADED TANK CAR - PEAK LATERAL WHEEL FORCES AT LOW SPEED TEST SECTION

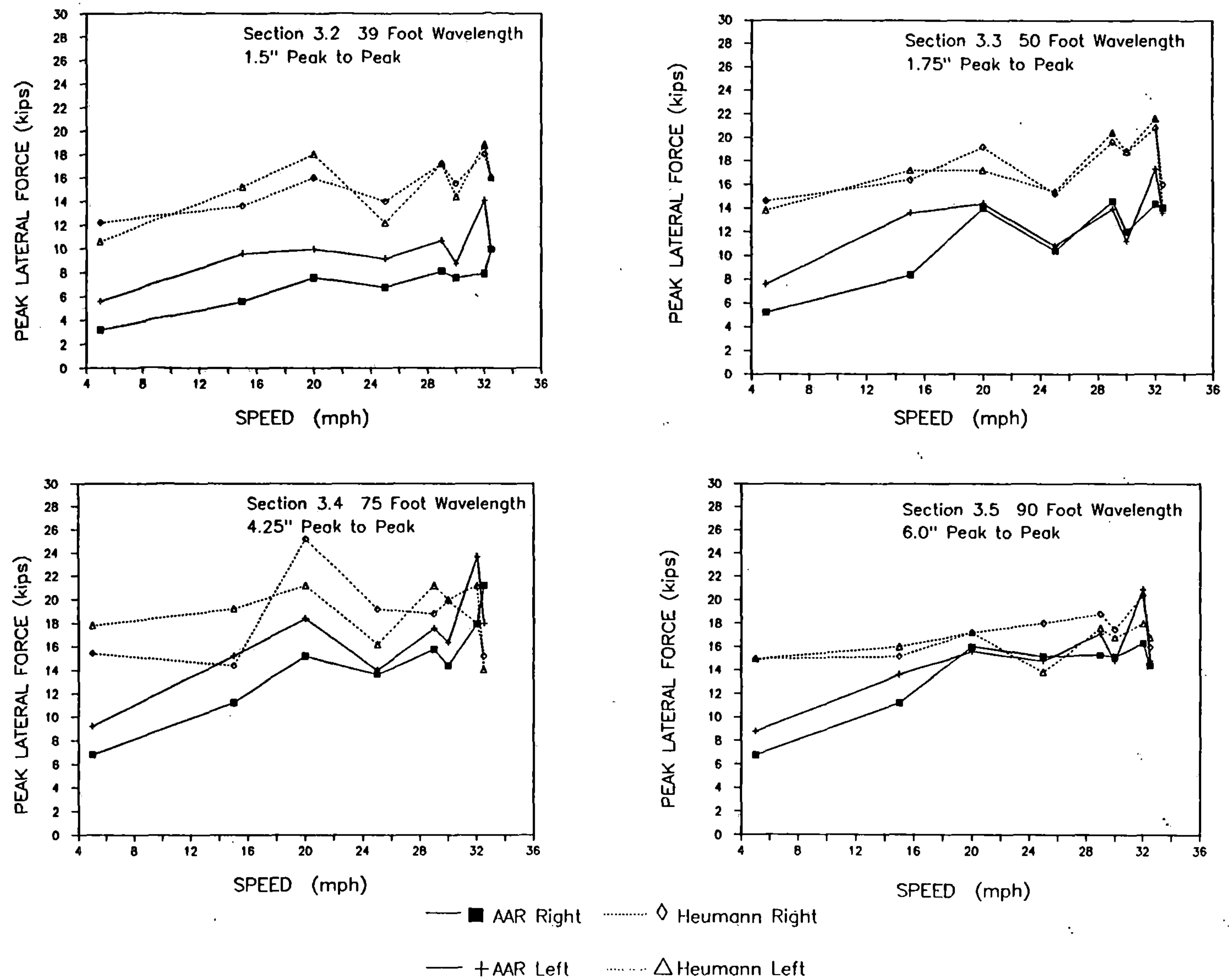


FIGURE 3.3-2 LOADED TANK CAR - PEAK LATERAL WHEEL FORCES AT INTERMEDIATE SPEED TEST SECTION

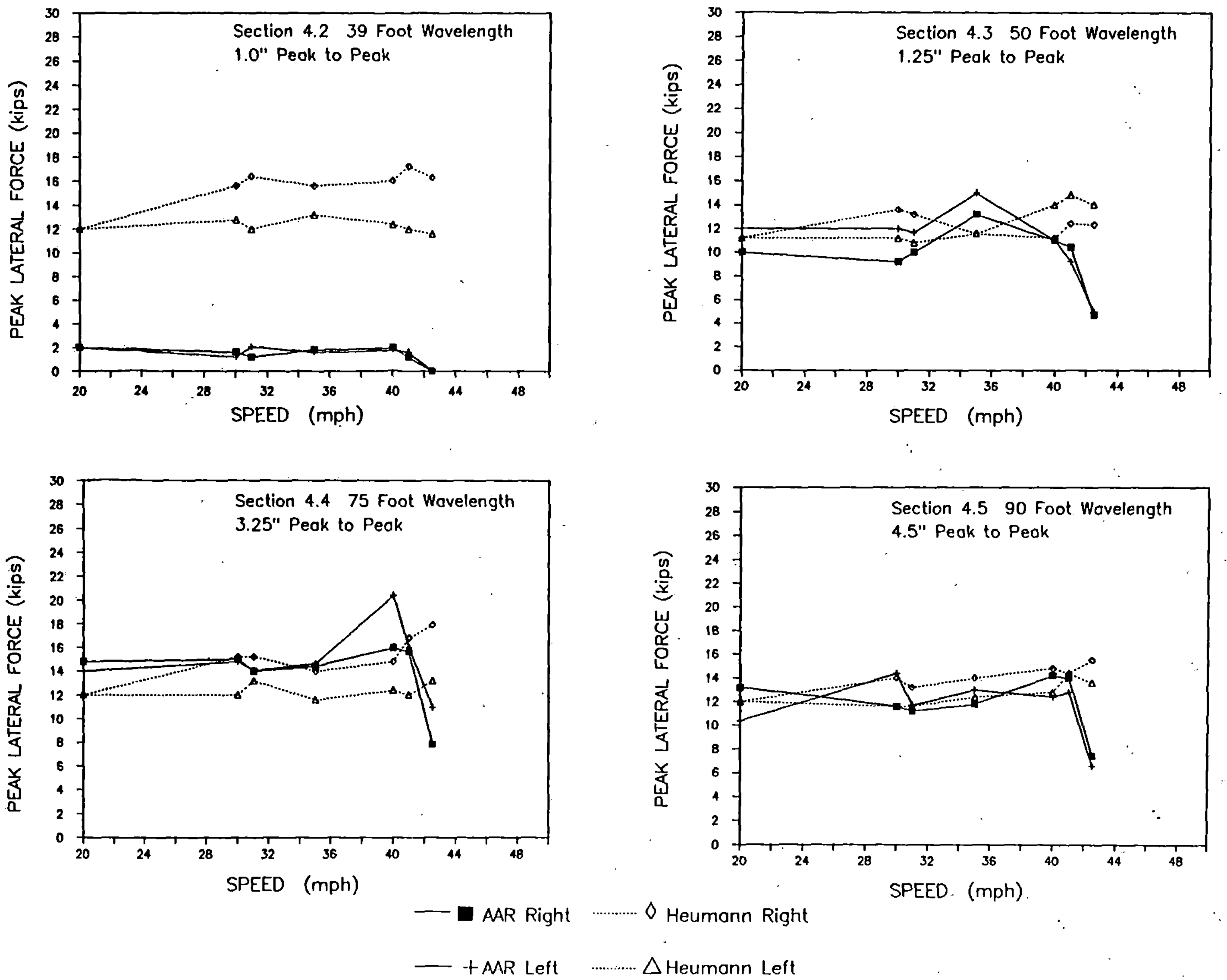


FIGURE 3.3-3 LOADED TANK CAR - PEAK LATERAL WHEEL FORCES AT HIGH SPEED TEST SECTION

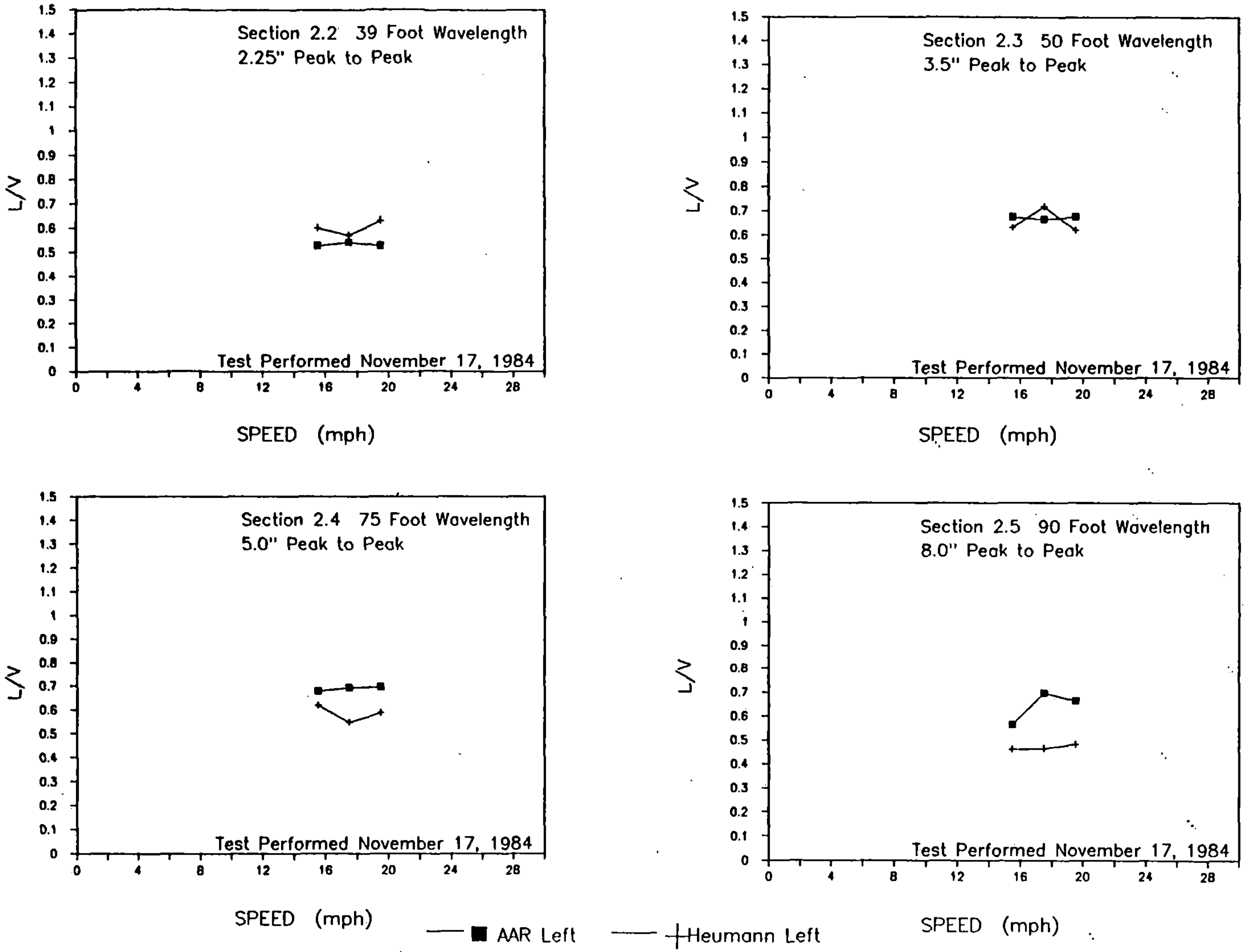


FIGURE 3.3-4 LOADED TANK CAR - PEAK LATERAL TO VERTICAL WHEEL FORCE RATIOS AT LOW SPEED TEST SECTION

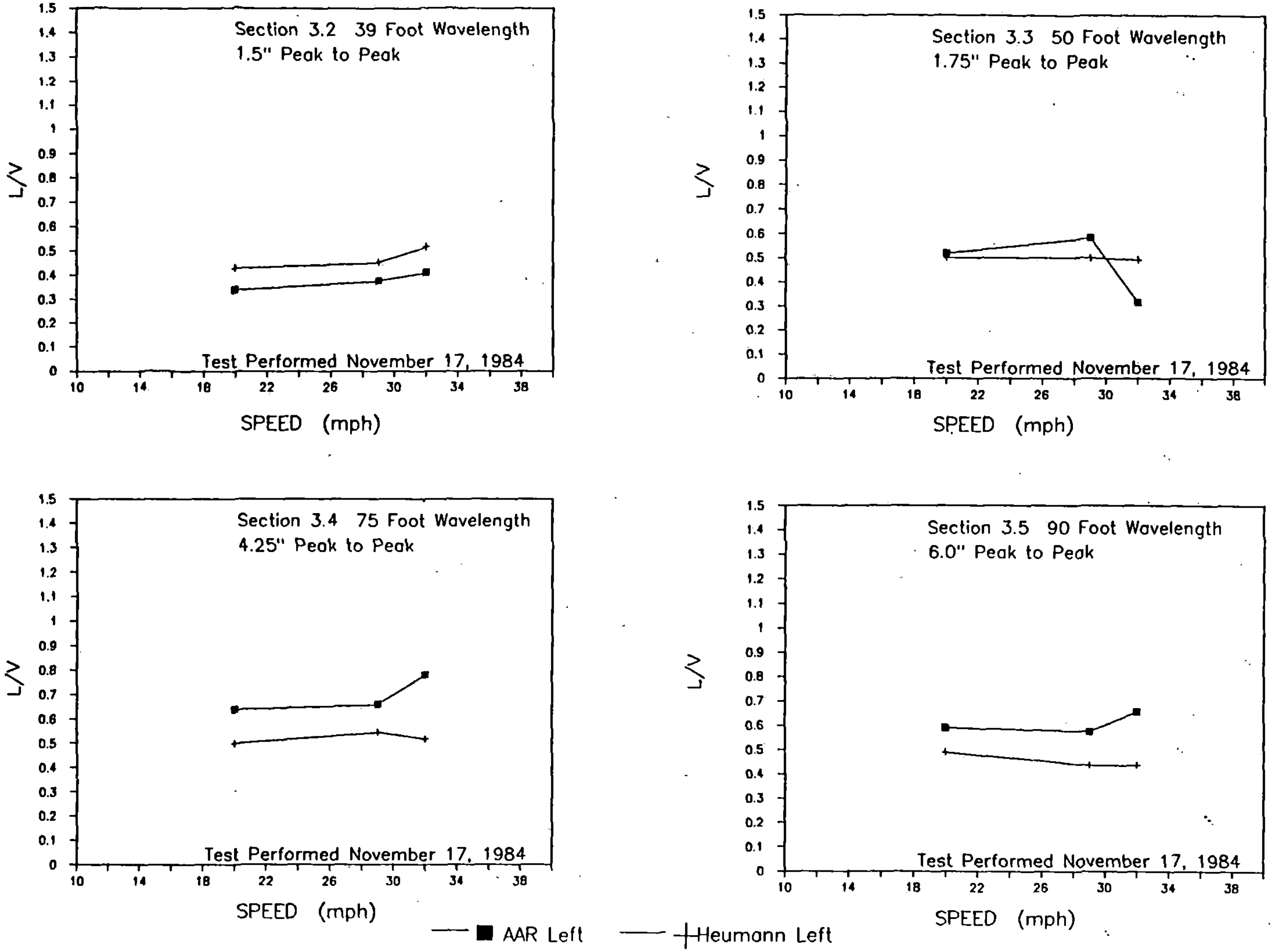


FIGURE 3.3-5 LOADED TANK CAR - PEAK LATERAL TO VERTICAL WHEEL FORCE RATIOS AT INTERMEDIATE SPEED TEST SECTION

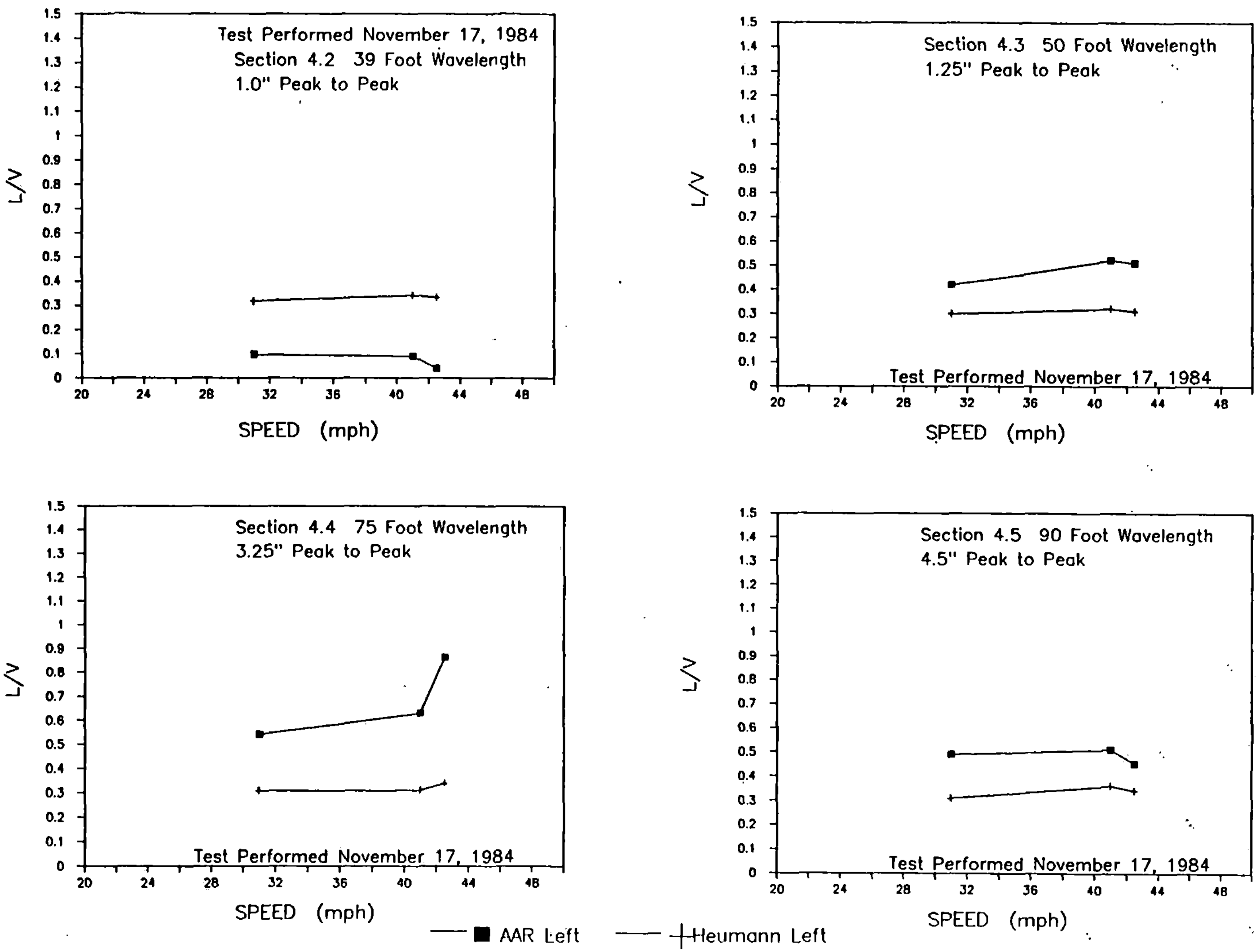


FIGURE 3.3-6 LOADED TANK CAR - PEAK LATERAL TO VERTICAL WHEEL FORCE RATIOS AT HIGH SPEED TEST SECTION

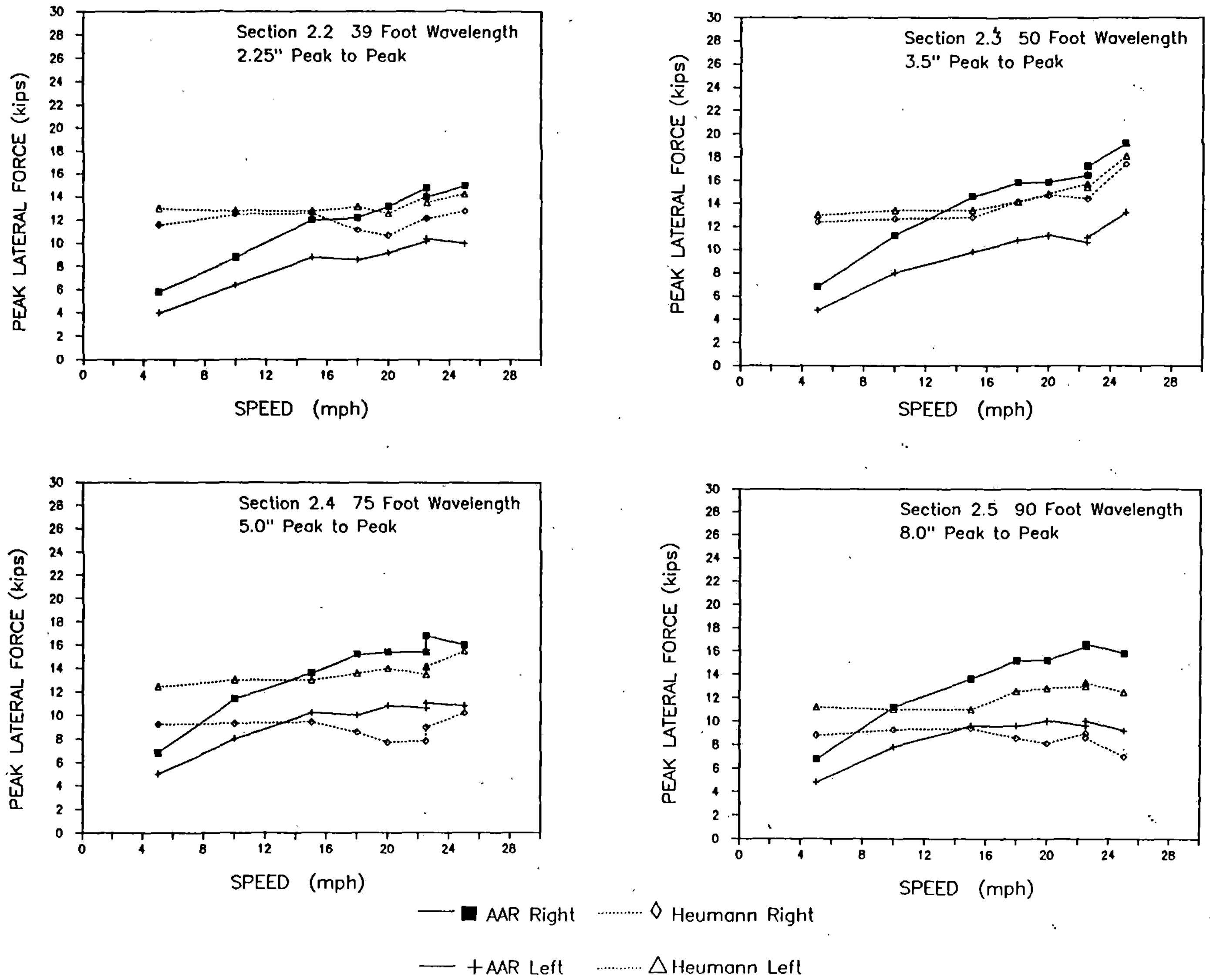


FIGURE 3.4-1 LOADED FLAT CAR - PEAK LATERAL WHEEL FORCES AT LOW SPEED TEST SECTION

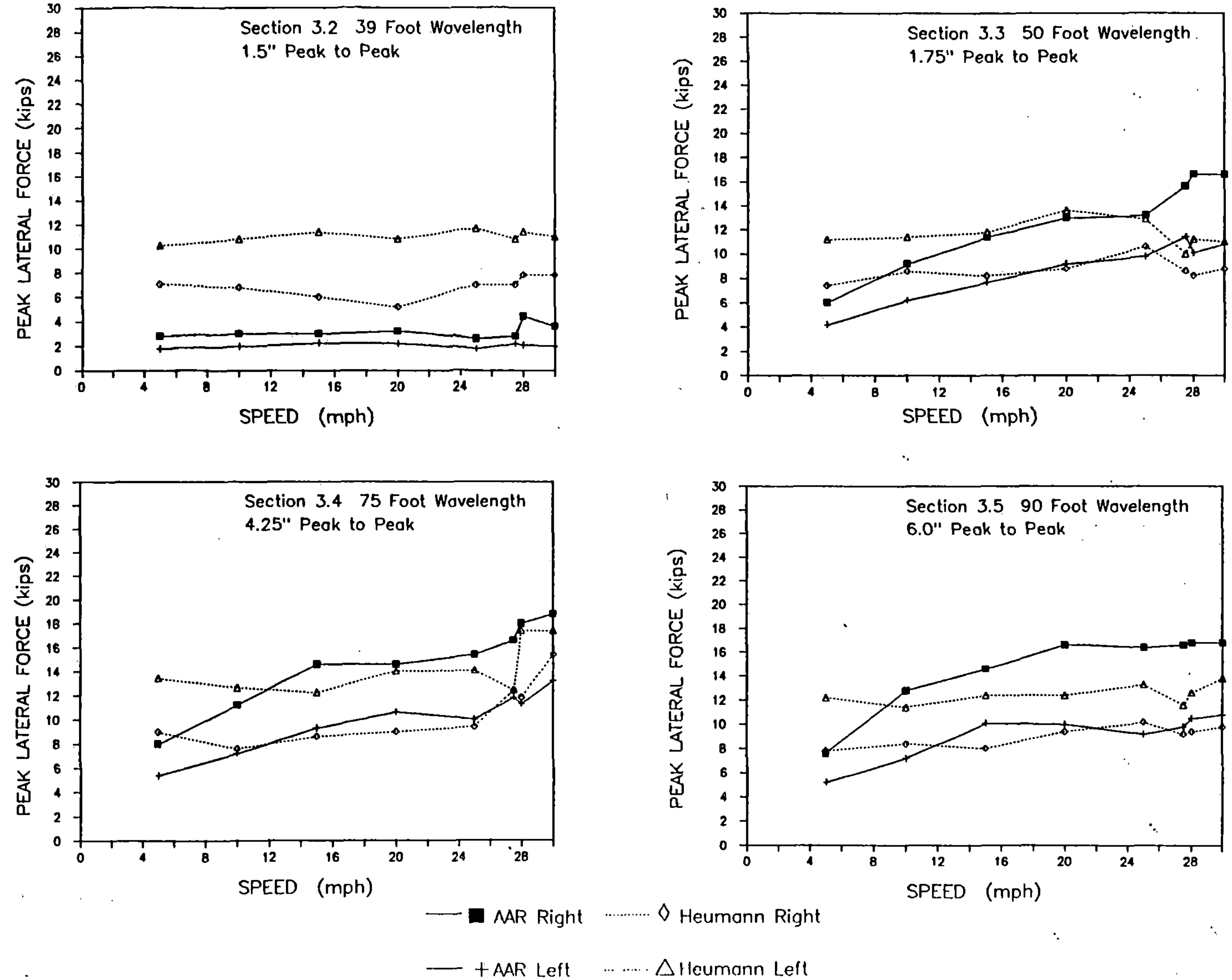


FIGURE 3.4-2 LOADED FLAT CAR - PEAK LATERAL WHEEL FORCES AT INTERMEDIATE SPEED TEST SECTION

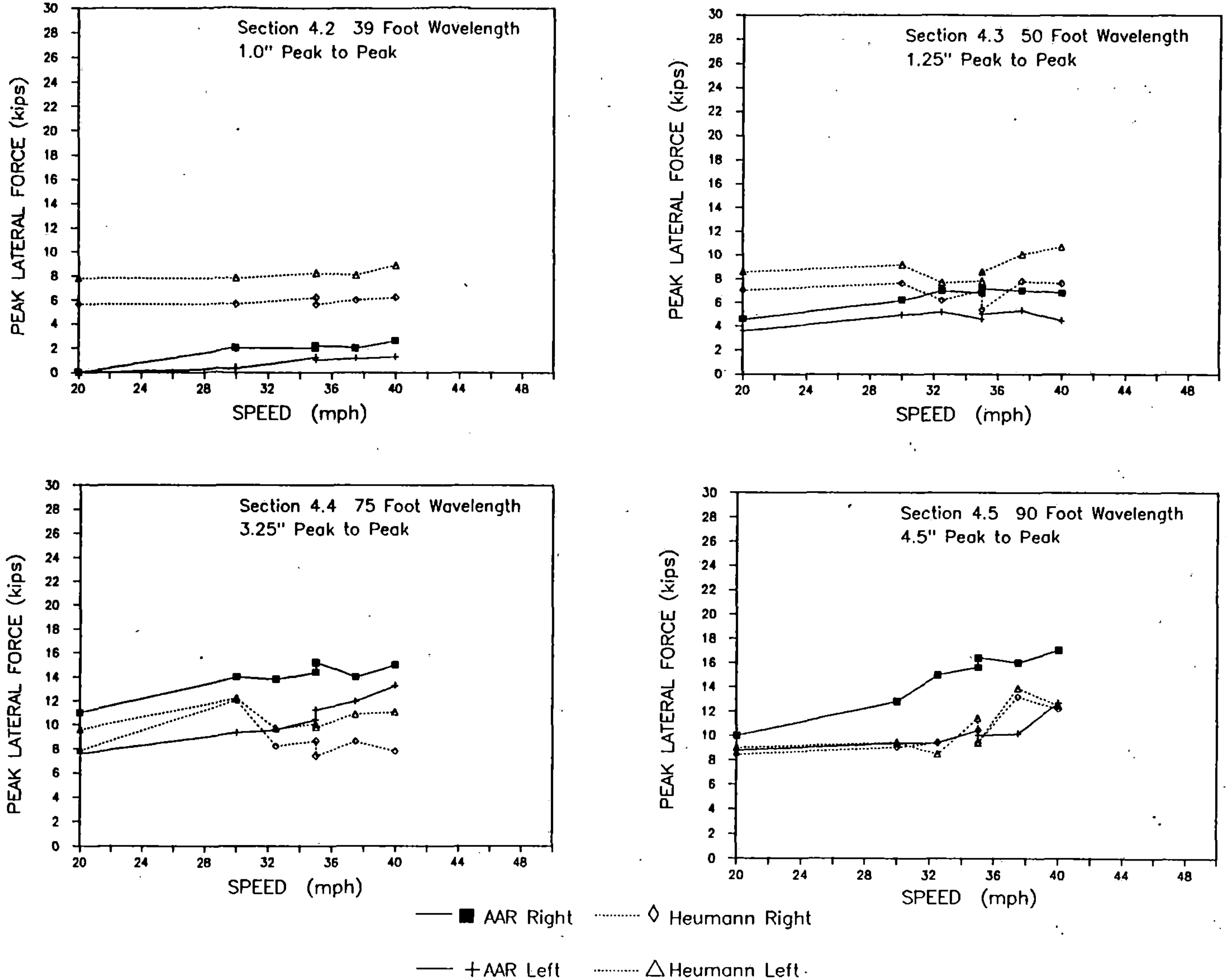


FIGURE 3.4-3 LOADED FLAT CAR - PEAK LATERAL WHEEL FORCES AT HIGH SPEED TEST SECTION

15 mph, to about 18 kips at 26 mph. The speed sensitivity at the 50 foot wavelength disappears when the perturbation amplitude is reduced to 1.75 inch peak to peak. The lateral to vertical wheel force ratios as shown in Figures 3.4-4 to 3.4-6 show a similar behavior with the 3.5 inch peak to peak, 50 foot wavelength irregularity, producing an L/V ratio of about 0.9 at 26 mph.

3.5 THE EMPTY HOPPER CAR

3.5.1 TRACK SEGMENTS 2.2 TO 2.5

In tests of the empty hopper car consist travelling over track segments 2.2 to 2.5, the rail surface was contaminated with oil. This resulted in much smaller lateral forces and lateral to vertical force ratios than anticipated for dry rail conditions. The lateral wheel forces are about the same for both wheel profiles. The force speed characteristics are also similar at each alignment variation wavelength (Figure 3.5-1). At low speeds of 5 to 15 mph, the lateral force levels for both wheel profiles range from 1 to 3 kips in each of the segments. As speed increased, the lateral wheel forces in the 39, 75, and 90 foot wavelength segments increased to 6 kips at 30 mph for both wheel profiles. At the 50' wavelength segment, the lateral peak wheel forces increased more rapidly to more than 8 kips at 30 mph.

The L/V ratios measured for the two wheel profiles of the empty hopper car in track segments 2.2 to 2.5 are shown in Figure 3.5-2. At the 39' and 50' track wavelengths, both wheel profiles have L/V ratios of 0.25 to 0.35 at speeds below 20 mph. Above 20 mph, the Heumann profile L/V ratios climb steeply, until at 30 mph, the L/V ratios are 0.64 and 0.88 at the 39' and 50' track wavelengths respectively. For the 75' and 90' wavelength segments, the L/V ratios of the AAR profile wheels were slightly higher than they were at the shorter wavelengths, while the L/V ratios for the Heumann profile wheels were less speed sensitive, and slightly lower than they were at the shorter wavelength segments.

3.5.2 TRACK SEGMENTS 3.2 TO 3.5

For the remaining tests, the runs were conducted under dry rail conditions. In track segments 3.2 to 3.5, the lateral wheel forces were measured at the two speeds of 25 and 30 mph with several measurements made at each speed (Figure 3.5-3). The lowest lateral wheel forces are from 1.5 to 3 kips in the AAR profile wheels at the 39' track wavelength. For the Heumann profile wheels at the 39' track wavelength, and for both wheel profiles at wavelengths above 39', the lateral wheel forces are all in the range of 3 to 6 kips.

The L/V ratios for track segments 3.2 to 3.5 are shown in Figure 3.5-4.

3.5.3 TRACK SEGMENTS 4.2 TO 4.5

The test results for the empty hopper car in the high speed track segments 4.2 to 4.5 indicate a greater variation in lateral force response for the AAR profile wheels than for the Heumann profile wheels (Figure 3.5-5). A distinct characteristic of the test results in the 39' wavelength

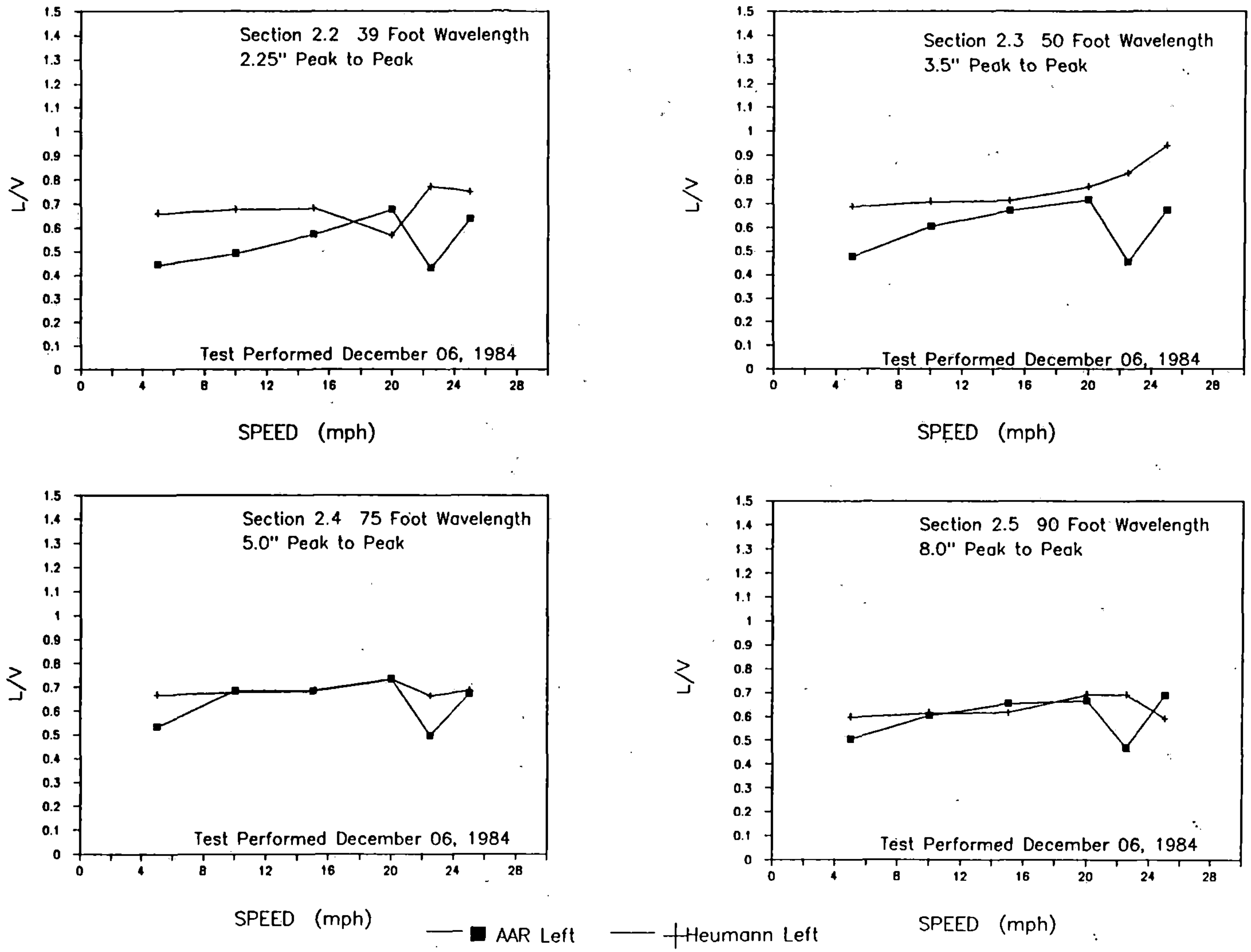


FIGURE 3.4-4 LOADED FLAT CAR - PEAK LATERAL TO VERTICAL WHEEL FORCE RATIOS AT LOW SPEED TEST SECTION

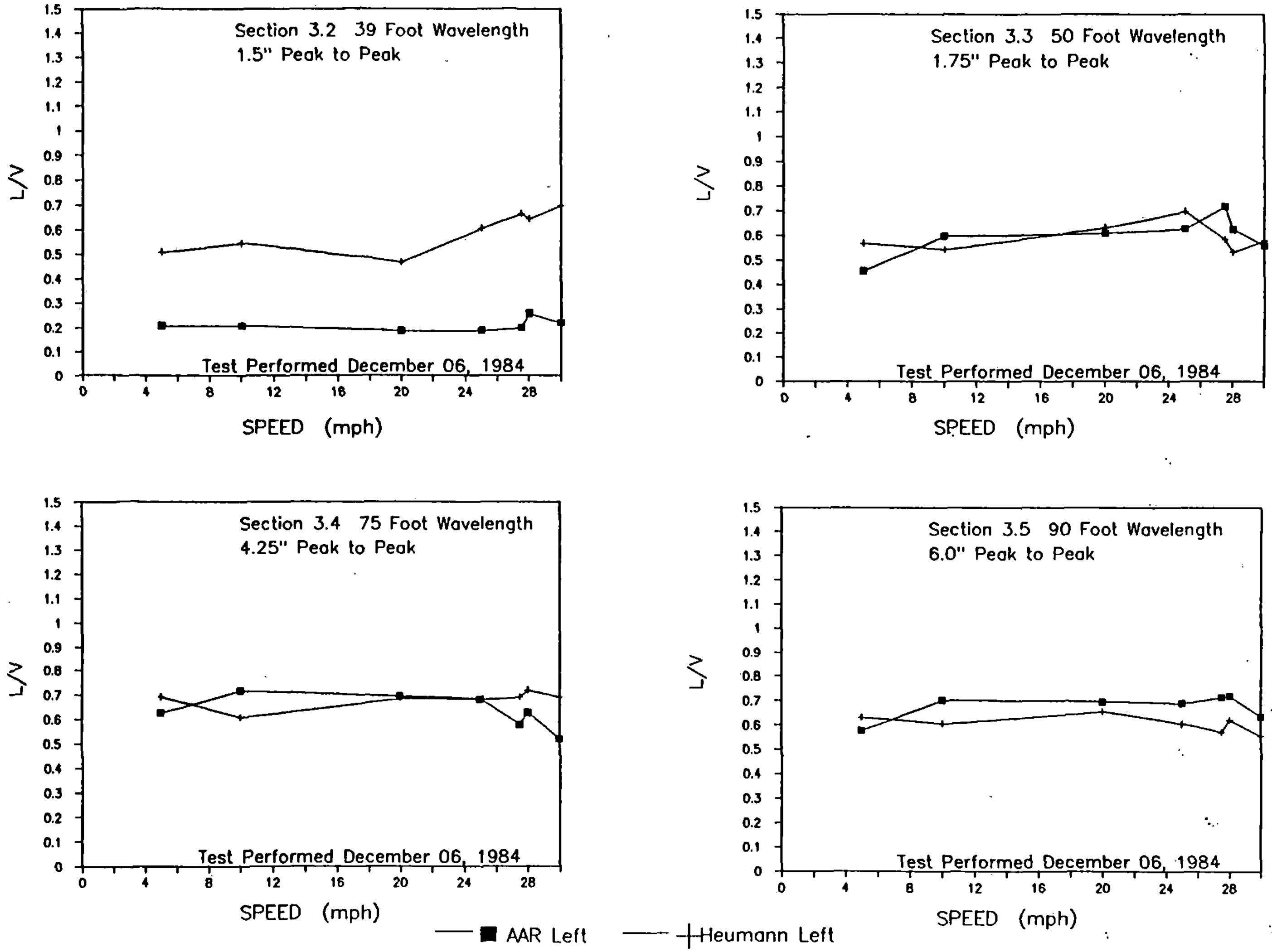


FIGURE 3.4-5 LOADED FLAT CAR - PEAK LATERAL TO VERTICALWHEEL FORCE RATIOS AT INTERMEDIATE SPEED TEST SECTION

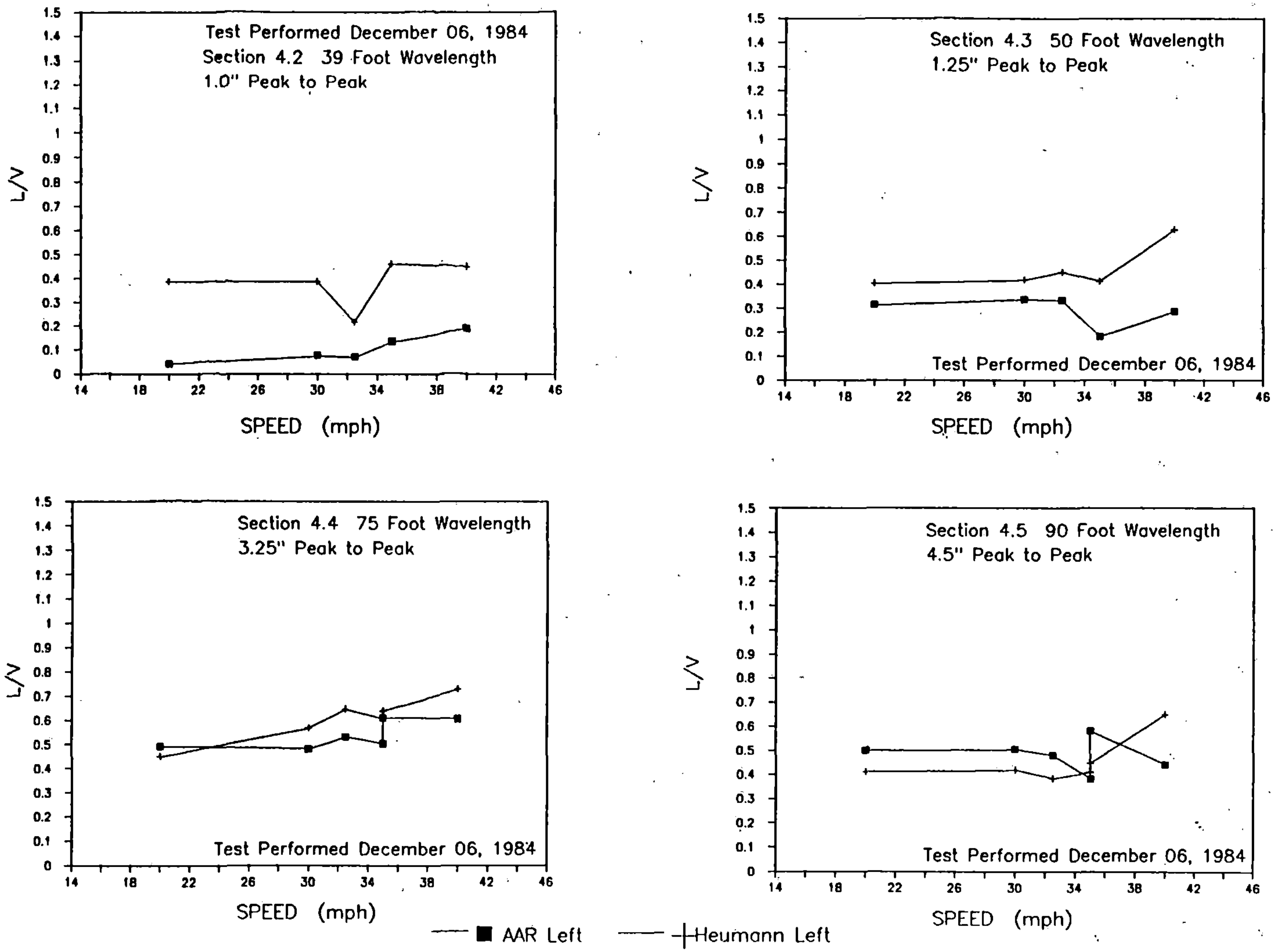


FIGURE 3.4-6 LOADED FLAT CAR - PEAK LATERAL TO VERTICAL WHEEL FORCE RATIOS AT HIGH SPEED TEST SECTION

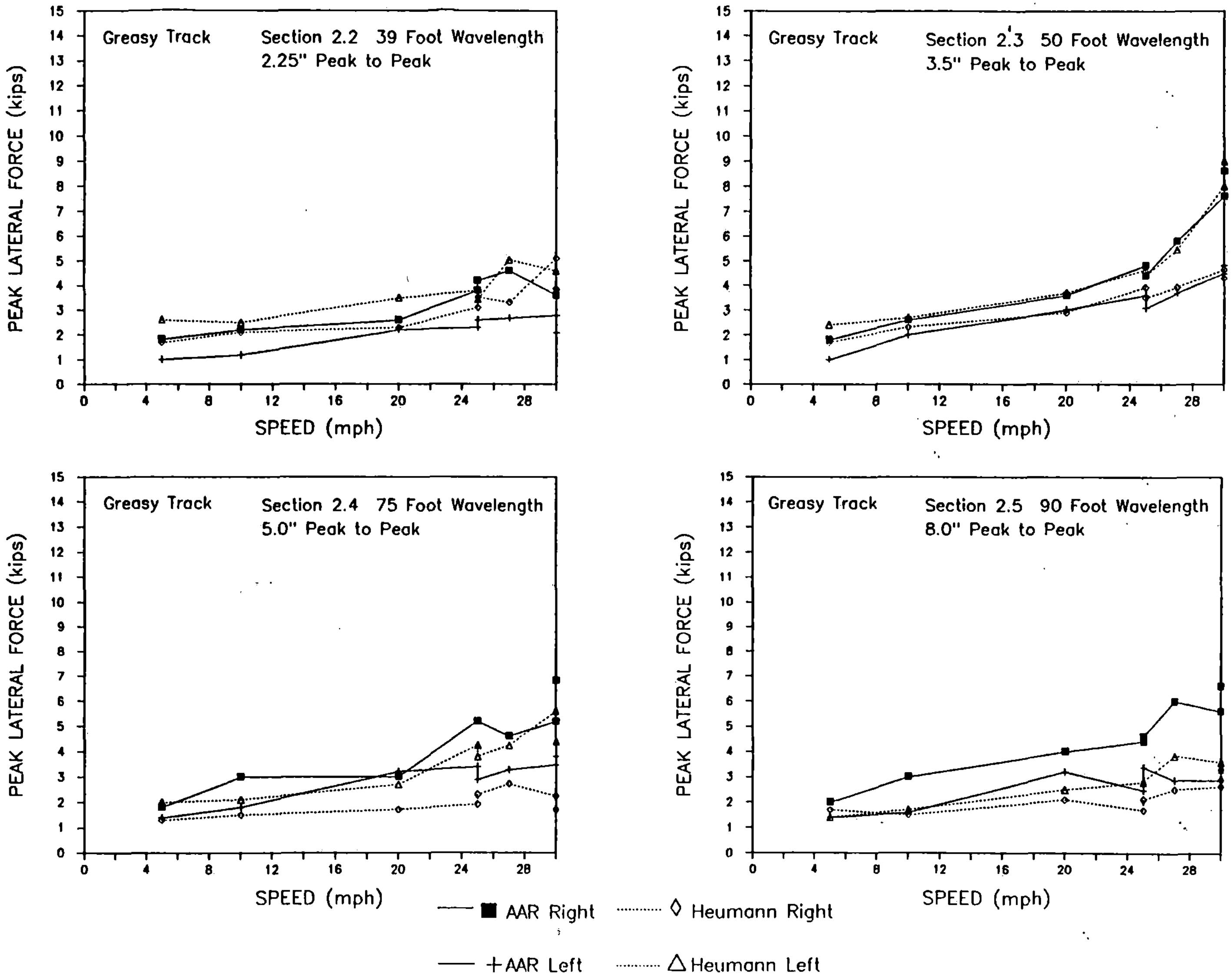


FIGURE 3.5-1 EMPTY HOPPER CAR - PEAK LATERAL WHEEL FORCES AT LOW SPEED TEST SECTION

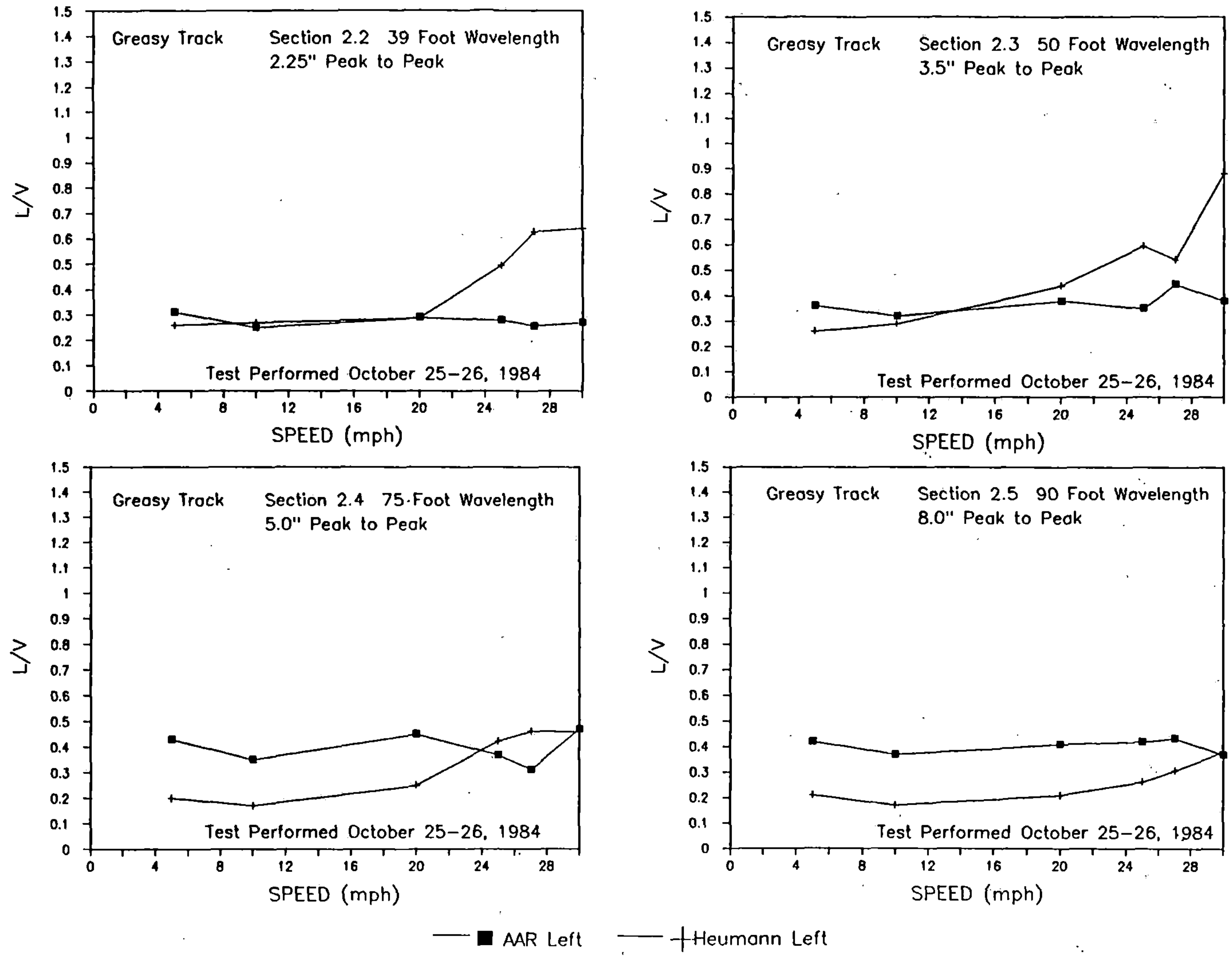


FIGURE 3.5-2 EMPTY HOPPER CAR - PEAK LATERAL TO VERTICAL WHEEL FORCE RATIOS AT LOW SPEED TEST SECTION

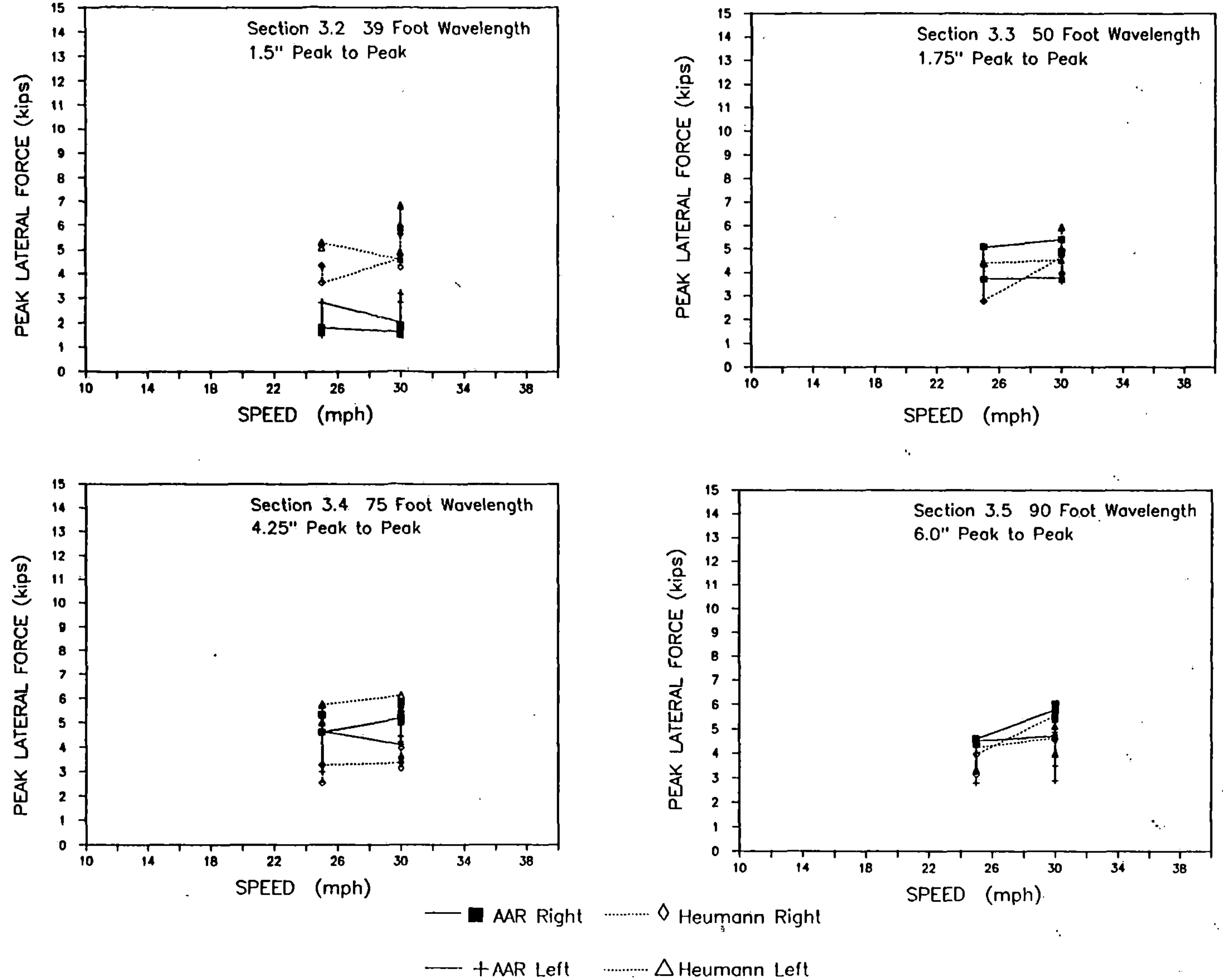


FIGURE 3.5-3 EMPTY HOPPER CAR - PEAK LATERAL WHEEL FORCES AT INTERMEDIATE SPEED TEST SECTION

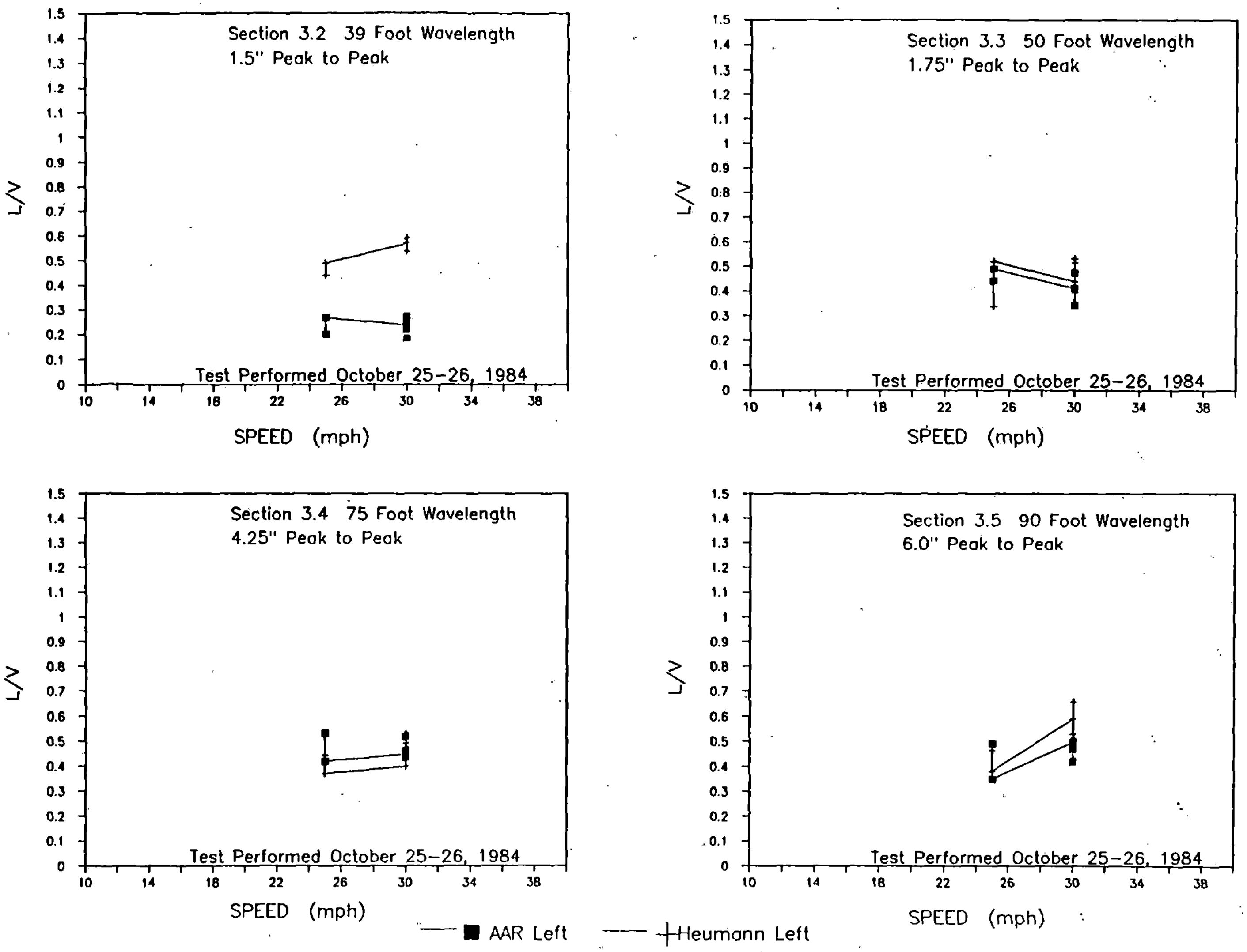


FIGURE 3.5-4 EMPTY HOPPER CAR - PEAK LATERAL TO VERTICAL WHEEL FORCE RATIOS AT INTERMEDIATE SPEED TEST SECTION

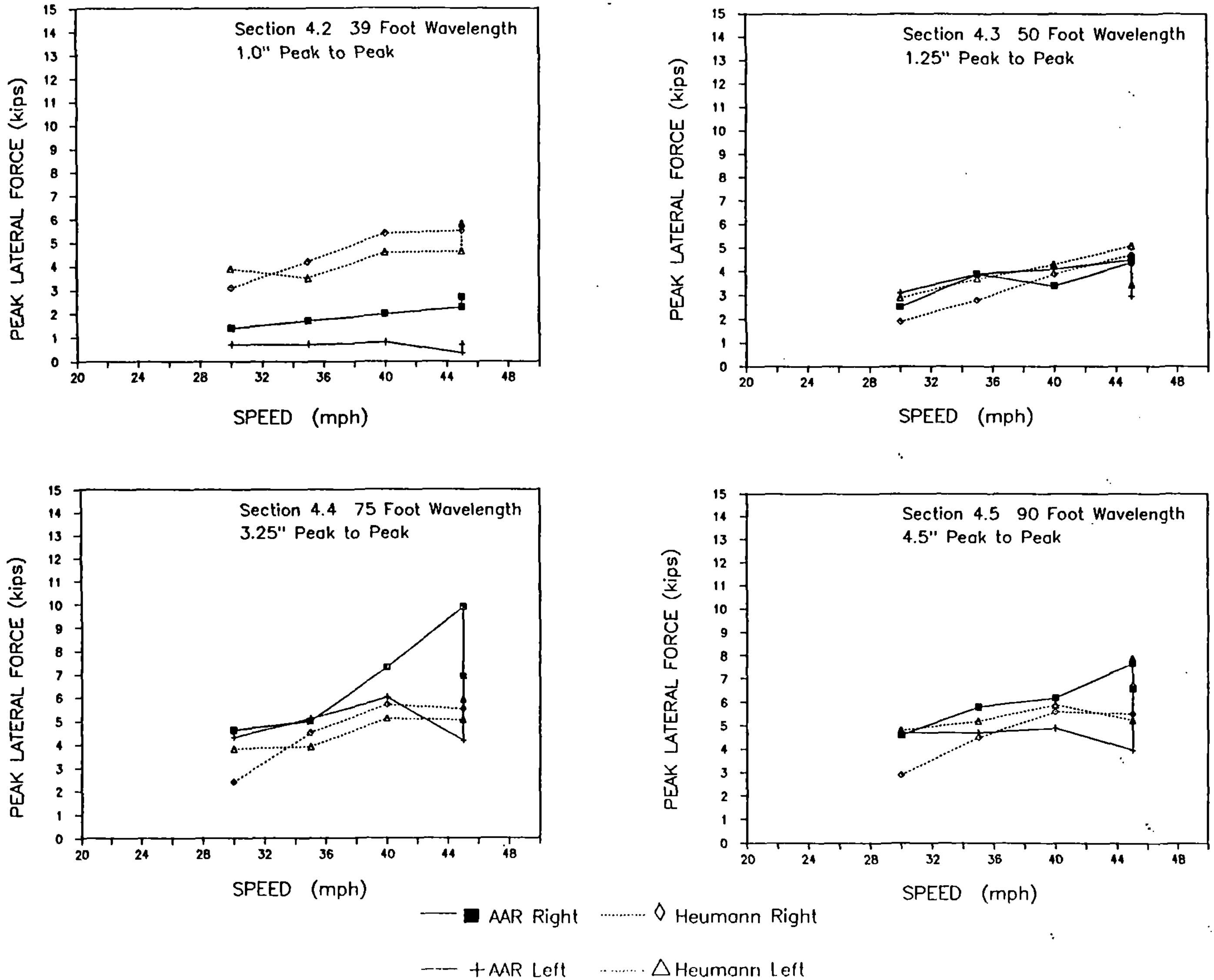


FIGURE 3.5-5 EMPTY HOPPER CAR - PEAK LATERAL WHEEL FORCES AT HIGH SPEED TEST SECTION

segment is the low lateral forces of 1 to 2 kips for the AAR profile wheels, while the forces for the Heumann profile wheels reach 3 to 6 kips. At the 50' wavelength segment, the lateral wheel forces for both wheel profiles are about the same, ranging from 2 to 3 kips at 30 mph, and increasing to 4 to 5 kips at 45 mph. For the 75' and 90' wavelength segments, the lateral forces on the Heumann profile wheels were at about the same level as was measured at the 50' wavelength. However, in the 75 foot wavelength segment, the AAR profile wheels exhibit an unusual behavior; the right wheel forces increase steeply from 5 kips at 35 mph to 8 kips or more at 45 mph, while the left wheel forces decrease slightly from 5 to 4 kips over the same speed range.

The peak L/V ratios for the two wheel profiles in the 50 foot, 75 foot, and 90 foot wavelength segments are about the same and range from 0.3 to 0.6 (Figure 3.5-6). At the 39' track wavelength, the peak L/V ratios for the AAR profile wheels remained constant with speed at a level of about 0.2, while the peak L/V ratios for the Heumann profile wheels increased from 0.45 at 30 mph to 0.7 at 45 mph.

3.5.4 SUMMARY OF EMPTY HOPPER CAR TEST RESULTS

The presence of lubrication on the track in the low speed test segments had the effect of reducing the gauge widening forces on the track and produced lower lateral forces and L/V ratios than anticipated. Surprisingly, the difference in behavior of the Heumann profile wheels and AAR profile wheels observed in the other tests at low speed was not observed in this test sequence. Both cars showed a strong sensitivity of peak lateral forces to speed in the 3.5 inch peak to peak, 50 foot wavelength segment. A rapid increase in peak lateral force was observed in both wheel profiles between 25 and 30 mph. The AAR profile wheels indicated a higher speed sensitivity than the Heumann profile wheels in the 75 foot and 90 foot wavelength segments.

With the exception of the lubricated track results, the level of forces that were measured in these tests are generally consistent with scaling the forces measured in the loaded tests by the ratio of the car weights on the rail (approximately 1/4).

3.6 EMPTY TANK CAR

The peak lateral forces measured in the unloaded tank car tests are shown in Figures 3.6-1 to 3.6-3. The peak force versus speed characteristics for each of the segments are similar to those obtained in the loaded tank car tests. The magnitude of the peak forces measured are consistent with those that would be estimated by scaling the lateral forces measured in the loaded car tests by the ratio of the weight of the unloaded vehicle to that of the loaded vehicle on the rail.

The peak lateral to vertical force ratios measured in the tests are shown in Figures 3.6-4 to 3.6-6. The behavior with speed is similar to that observed in the loaded tank car tests. However, the magnitude of the L/V ratios is slightly larger.

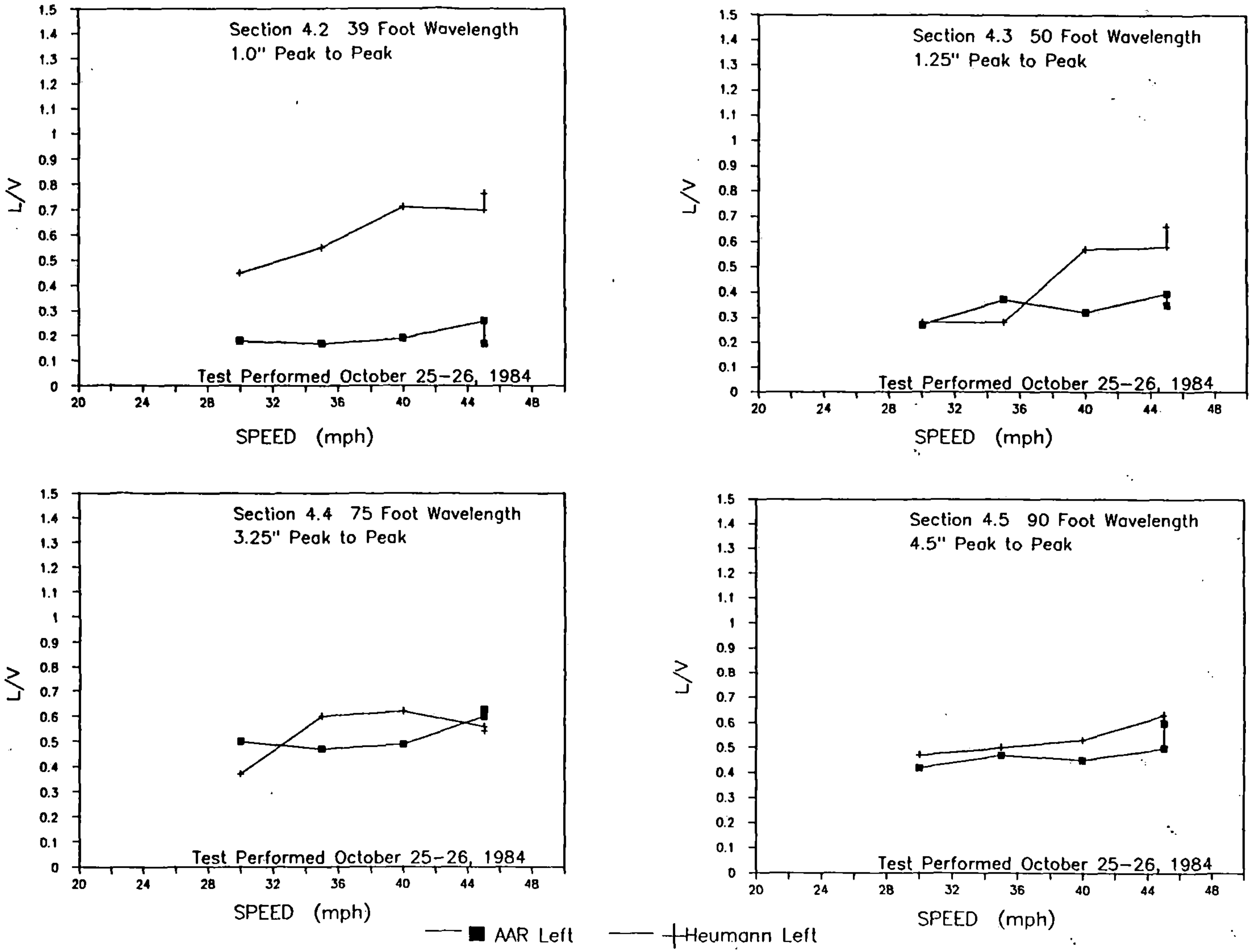


FIGURE 3.5-6 EMPTY HOPPER CAR - PEAK LATERAL TO VERTICAL WHEEL FORCE RATIOS AT HIGH SPEED TEST SECTION

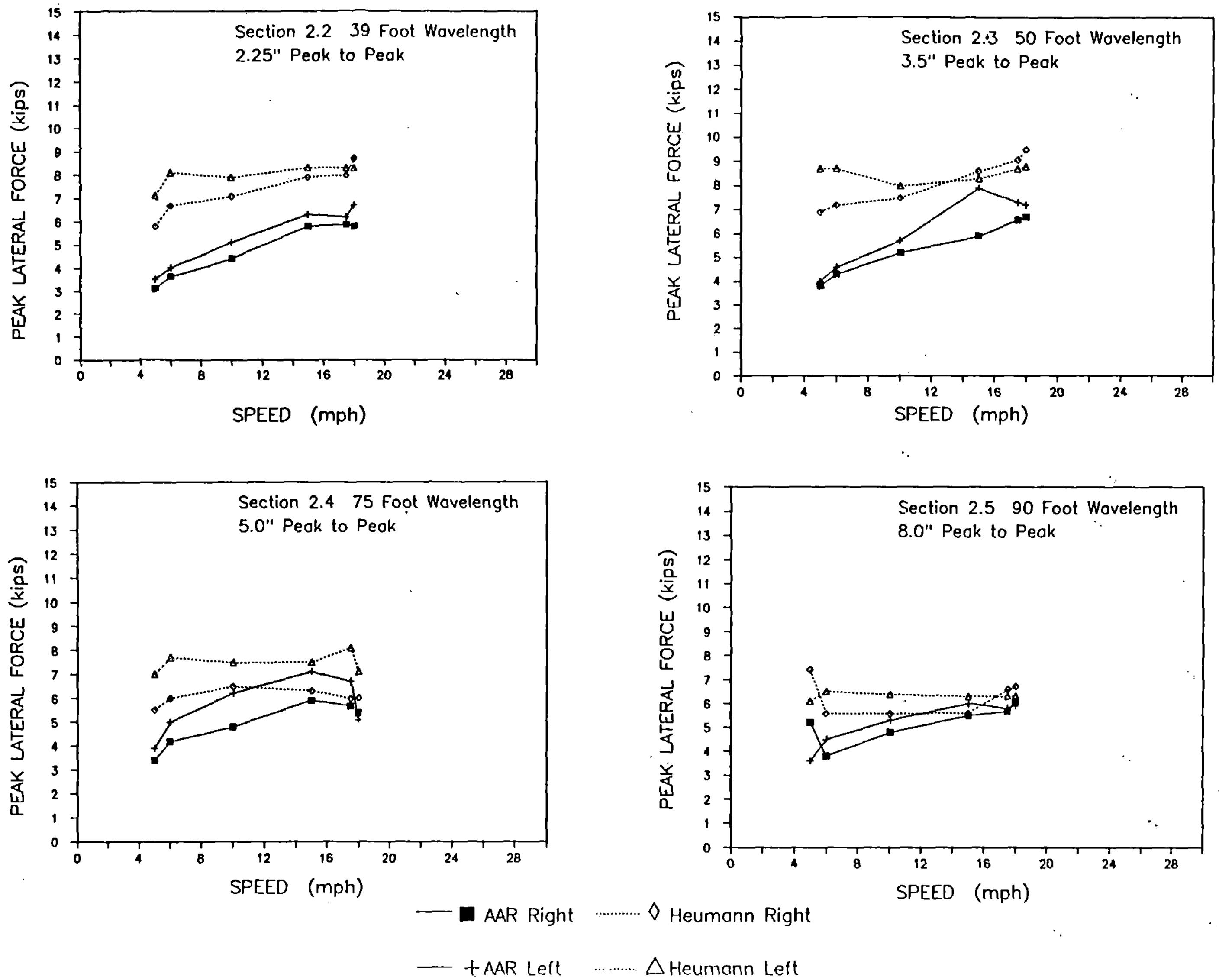


FIGURE 3.6-1 EMPTY TANK CAR - PEAK LATERAL WHEEL FORCES AT LOW SPEED TEST SECTION

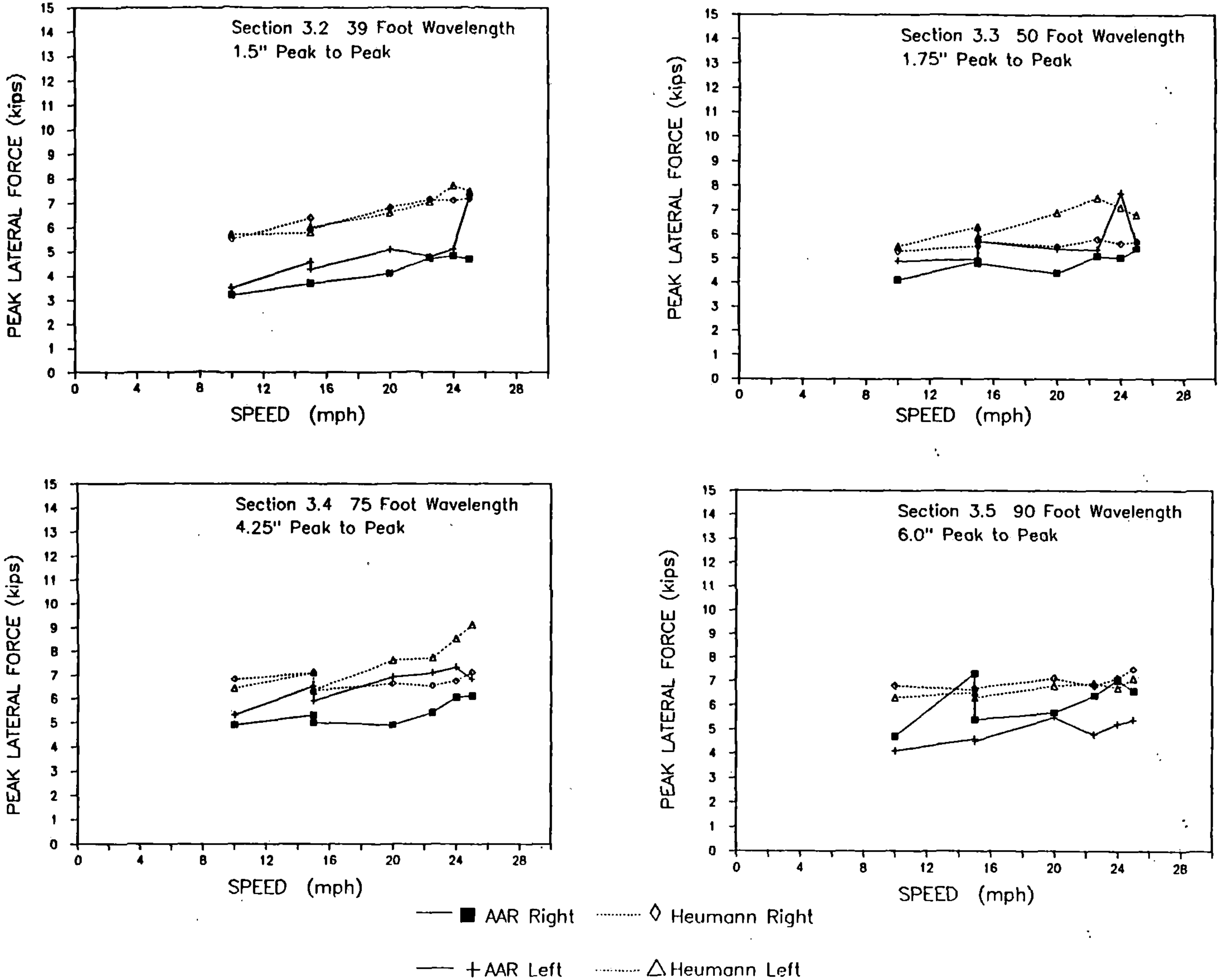


FIGURE 3.6-2 EMPTY TANK CAR - PEAK LATERAL WHEEL FORCES AT INTERMEDIATE SPEED TEST SECTION

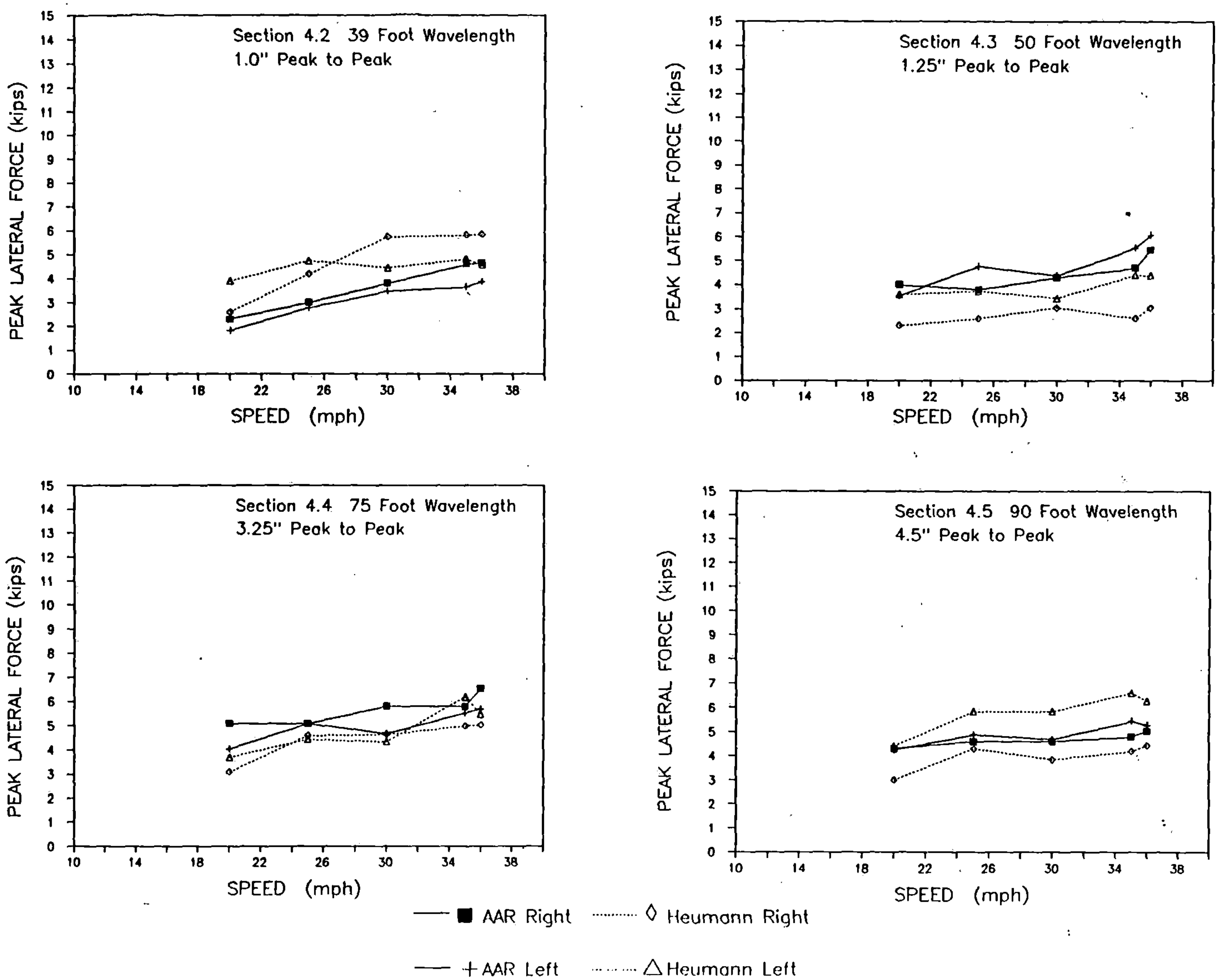


FIGURE 3.6-3 EMPTY TANK CAR - PEAK LATERAL WHEEL FORCES AT HIGH SPEED TEST SECTION

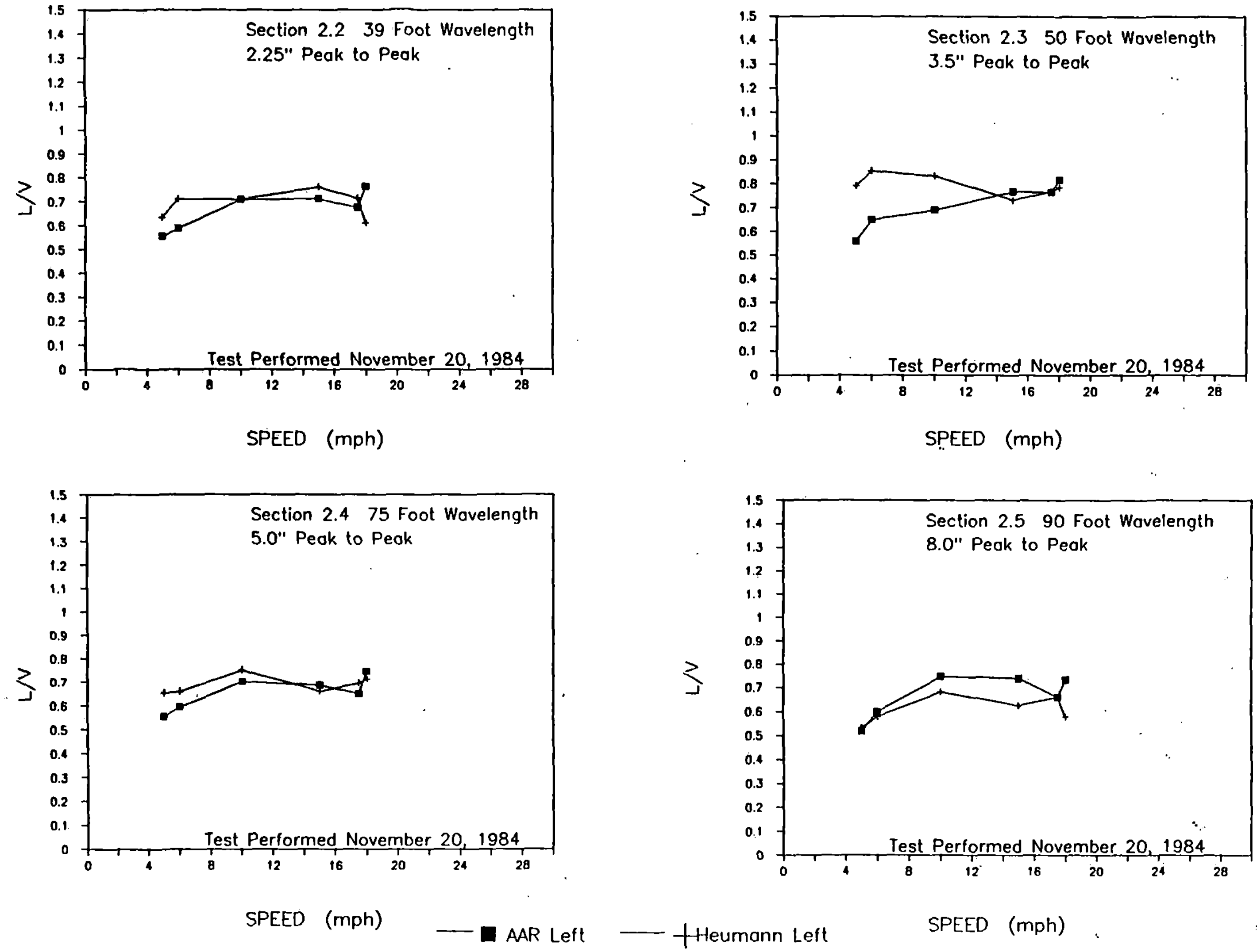


FIGURE 3.6-4 EMPTY TANK CAR - PEAK LATERAL TO VERTICAL WHEEL FORCE RATIOS AT LOW SPEED TEST SECTION

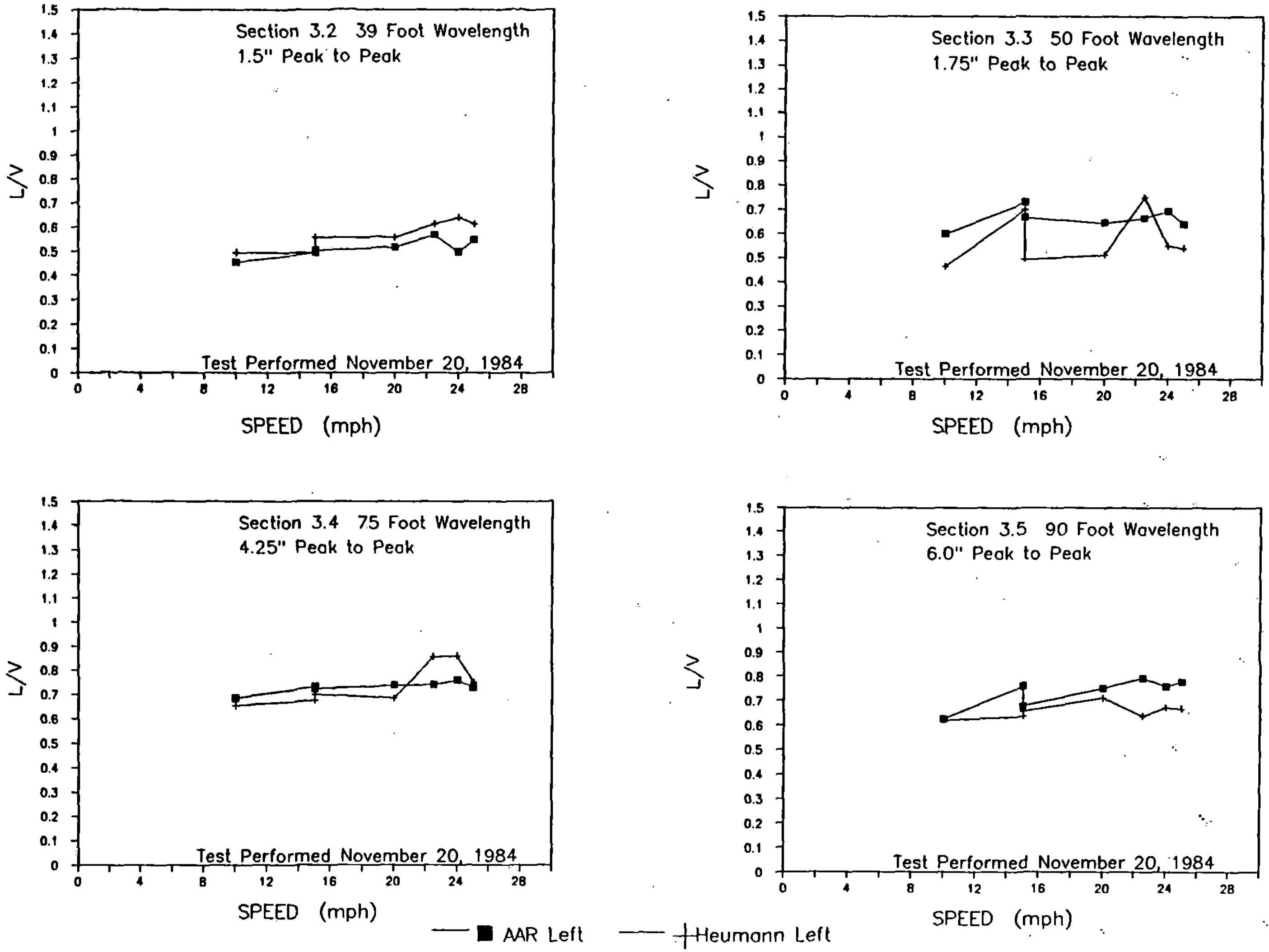


FIGURE 3.6-5 EMPTY TANK CAR - PEAK LATERAL TO VERTICAL WHEEL FORCE RATIOS AT INTERMEDIATE SPEED TEST SECTION

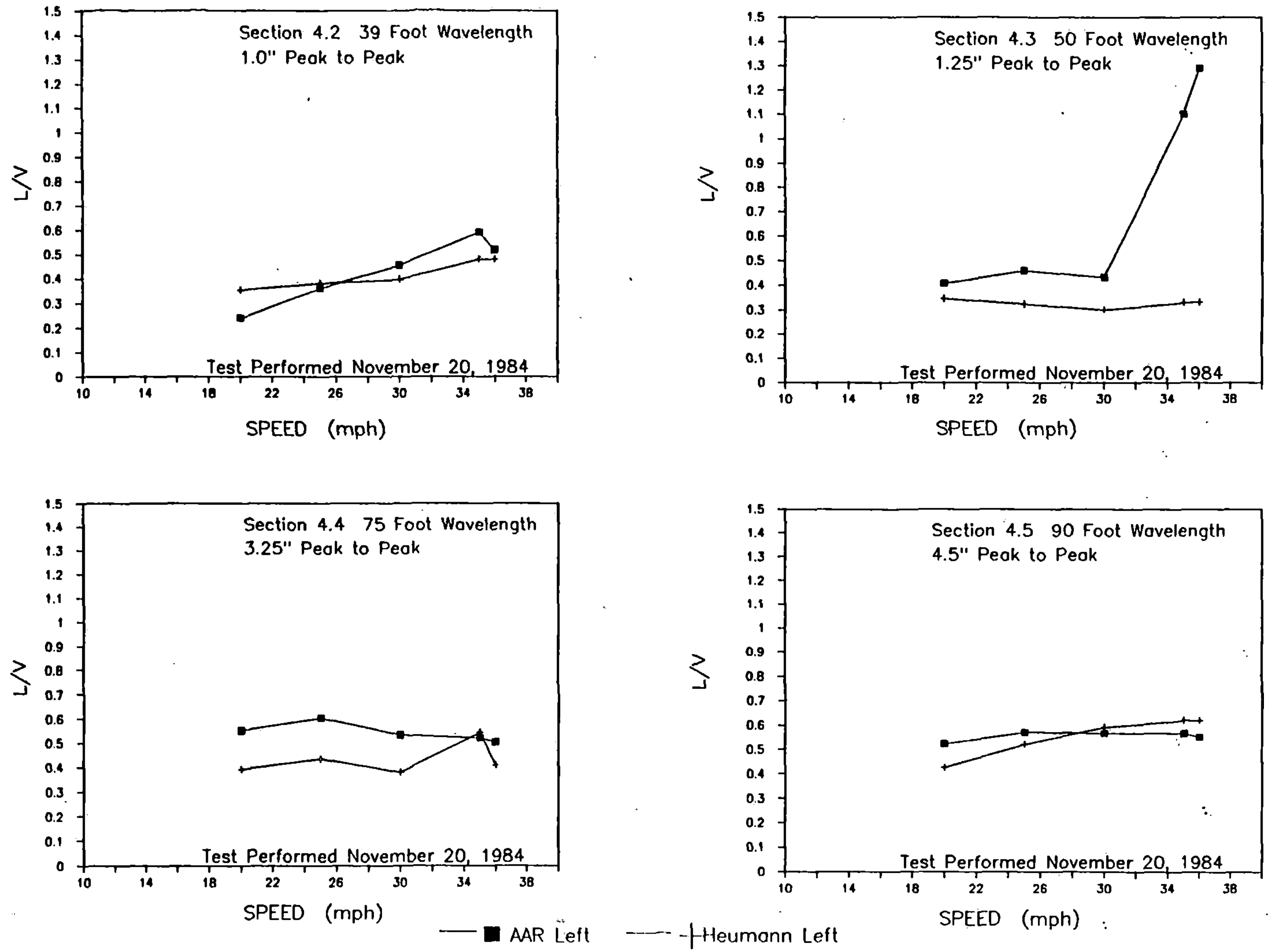


FIGURE 3.6-6 EMPTY TANK CAR - PEAK LATERAL TO VERTICAL WHEEL FORCE RATIOS AT HIGH SPEED TEST SECTION

3.7 EMPTY FLAT CAR

The peak lateral forces measured in the unloaded flat car tests are shown in Figures 3.7-1 to 3.7-3. The peak force versus speed characteristics for each of the segments are similar to those obtained in the loaded flat car tests. For each test segment, the peak forces are relatively constant with speed for the Heumann profile wheels. As in the loaded car tests, the wheelsets for the AAR profile indicate a lower level of forces at low speeds. The magnitude of the peak forces measured are consistent with those that would be estimated by scaling the lateral forces measured in the loaded car tests by the ratio of the weight of the unloaded vehicle to that of the loaded vehicle on the rail.

The peak lateral to vertical force ratios measured in the tests are shown in Figures 3.7-4 to 3.7-6. In each of the test segments, and at all speeds, the L/V ratios for the Heumann profile wheels were significantly larger than those measured for the AAR profile wheels. For the 39 foot wavelength segments, L/V ratios in excess of 0.8 are measured for the Heumann profile wheels at all speed ranges. In the 50 foot wavelength, low speed and intermediate speed segments, L/V ratios of 0.9 are measured for the Heumann profile. For the 75 foot wavelength, in the low speed and intermediate speed segments, and in the 90 foot intermediate speed segment, the Heumann profile L/V ratios are about 1.0. The L/V ratios measured for the unloaded flatcars were the largest observed during the tests of all of the cars.

3.8 SUMMARY OF RESULTS

The data from the AAR profile wheelset indicated forces at low speeds that were much lower than those obtained from the Heumann profile wheels. Although a review of the wheelset instrumentation did not indicate any clear instrumentation errors, the authors believe the low speed data for these wheelsets to be in error since it is not consistent with simulation studies and data obtained for the locomotive and the tests conducted in Bennington, New Hampshire, as discussed in Section 6.

MAXIMUM LATERAL FORCES

The largest wheel rail forces measured during the tests were produced by the locomotive in segment 4.4 (75 foot wavelength, 3.25 inch peak to peak) at a speed of 50 mph with a peak measured lateral force of about 42 kips. For the freight cars, the largest lateral wheel rail load was produced by the loaded tank car with a peak lateral force of about 24 kips as measured in segment 2.3 (50 foot wavelength, 3.5 inch peak to peak) at a speed of 20 mph.

MAXIMUM L/V RATIOS

For the locomotive, the maximum L/V ratio measured was 0.9 in segment 4.4 at a speed of 50 mph. For the freight cars tested, the largest L/V ratio measured was for the unloaded tank car with the AAR profile wheels. For the unloaded tank car with the AAR profile wheels, an L/V ratio of 1.3 was measured at 36 mph in segment 4.3 (50 ft wavelength, 1.25 inch peak to peak).

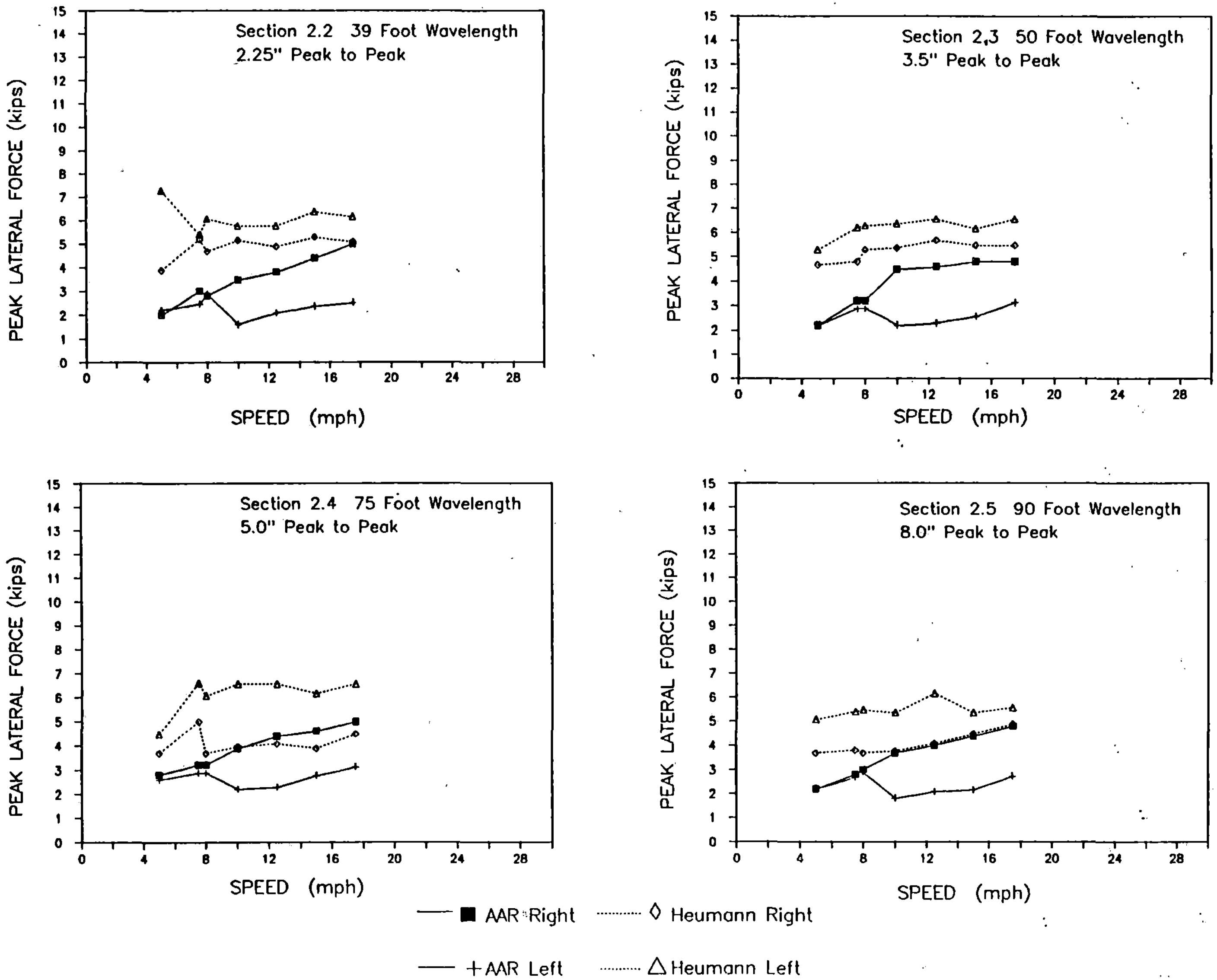


FIGURE 3.7-1 EMPTY FLAT CAR - PEAK LATERAL WHEEL FORCES AT LOW SPEED TEST SECTION

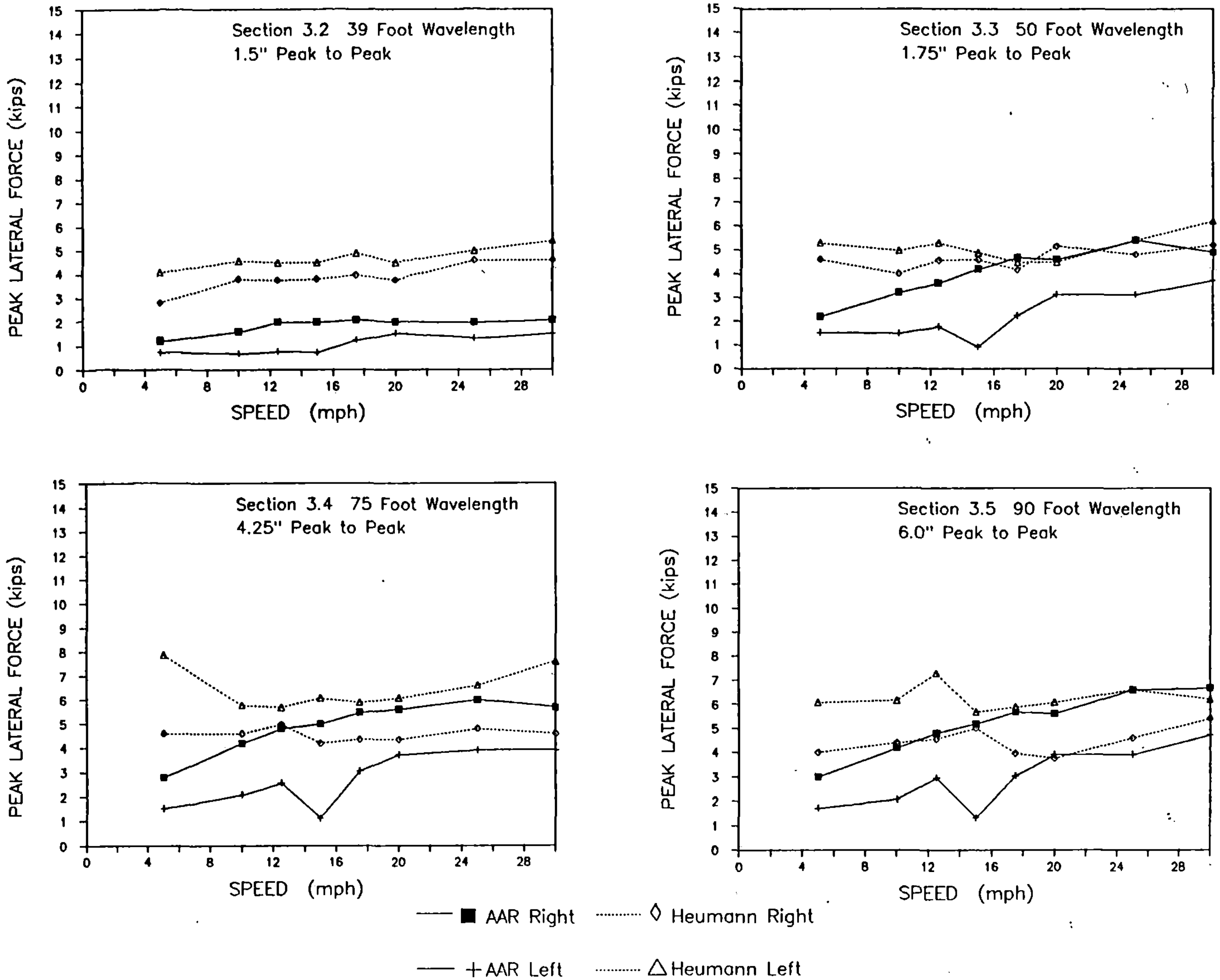


FIGURE 3.7-2 EMPTY FLAT CAR - PEAK LATERAL WHEEL FORCES AT INTERMEDIATE SPEED TEST SECTION

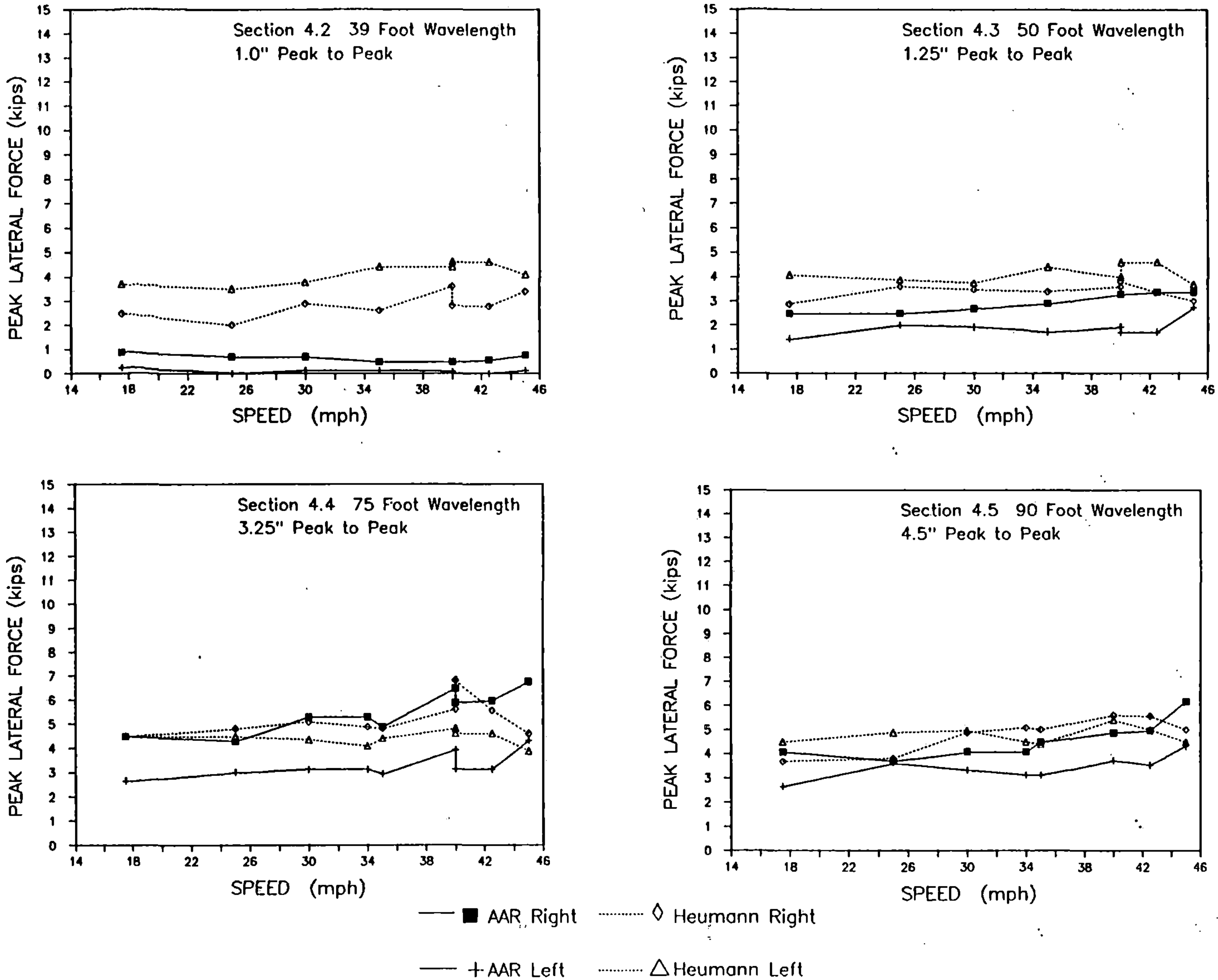


FIGURE 3.7-3 EMPTY FLAT CAR - PEAK LATERAL WHEEL FORCES AT HIGH SPEED TEST SECTION

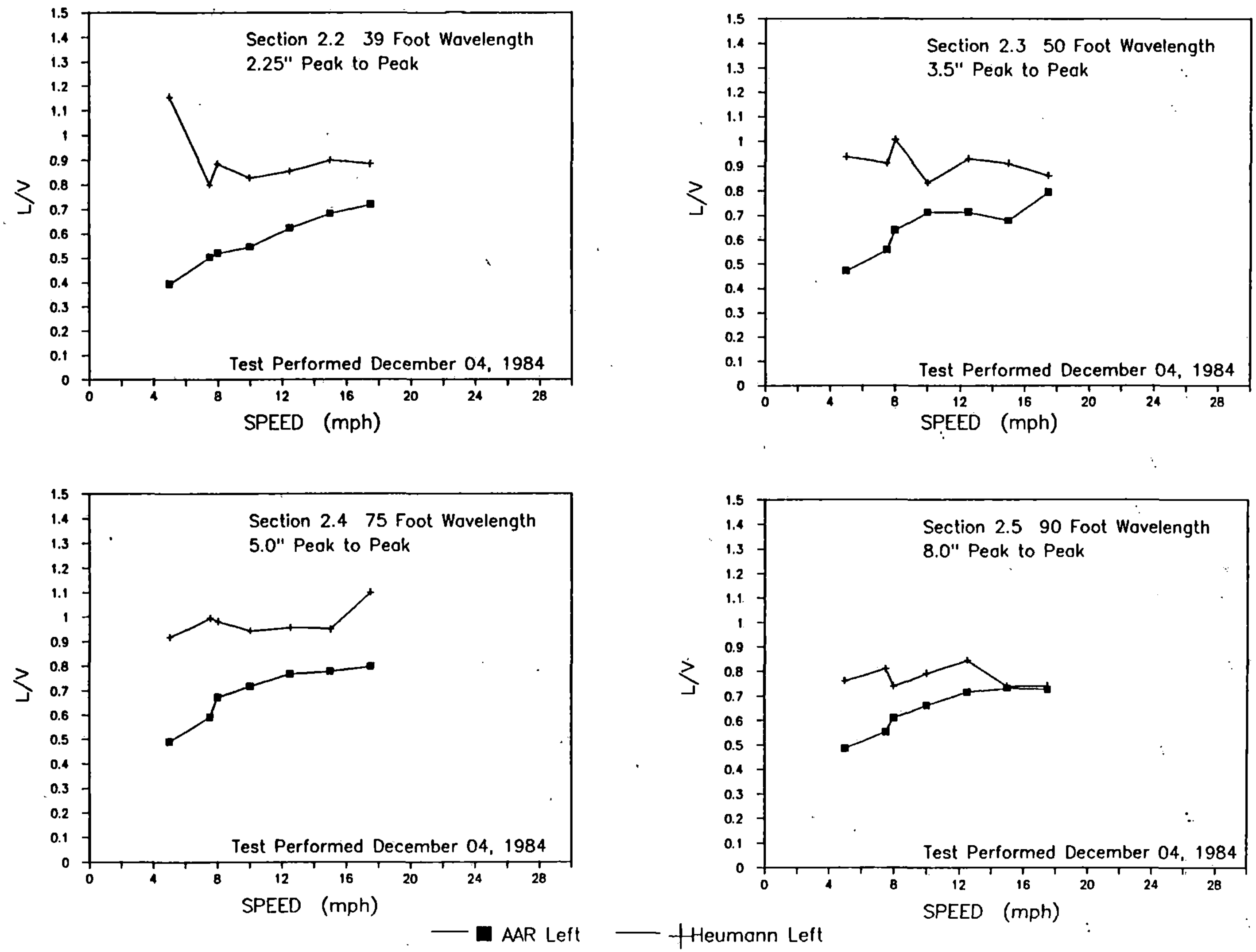


FIGURE 3.7-4 EMPTY FLAT CAR - PEAK LATERAL TO VERTICAL WHEEL FORCE RATIOS AT LOW SPEED TEST SECTION

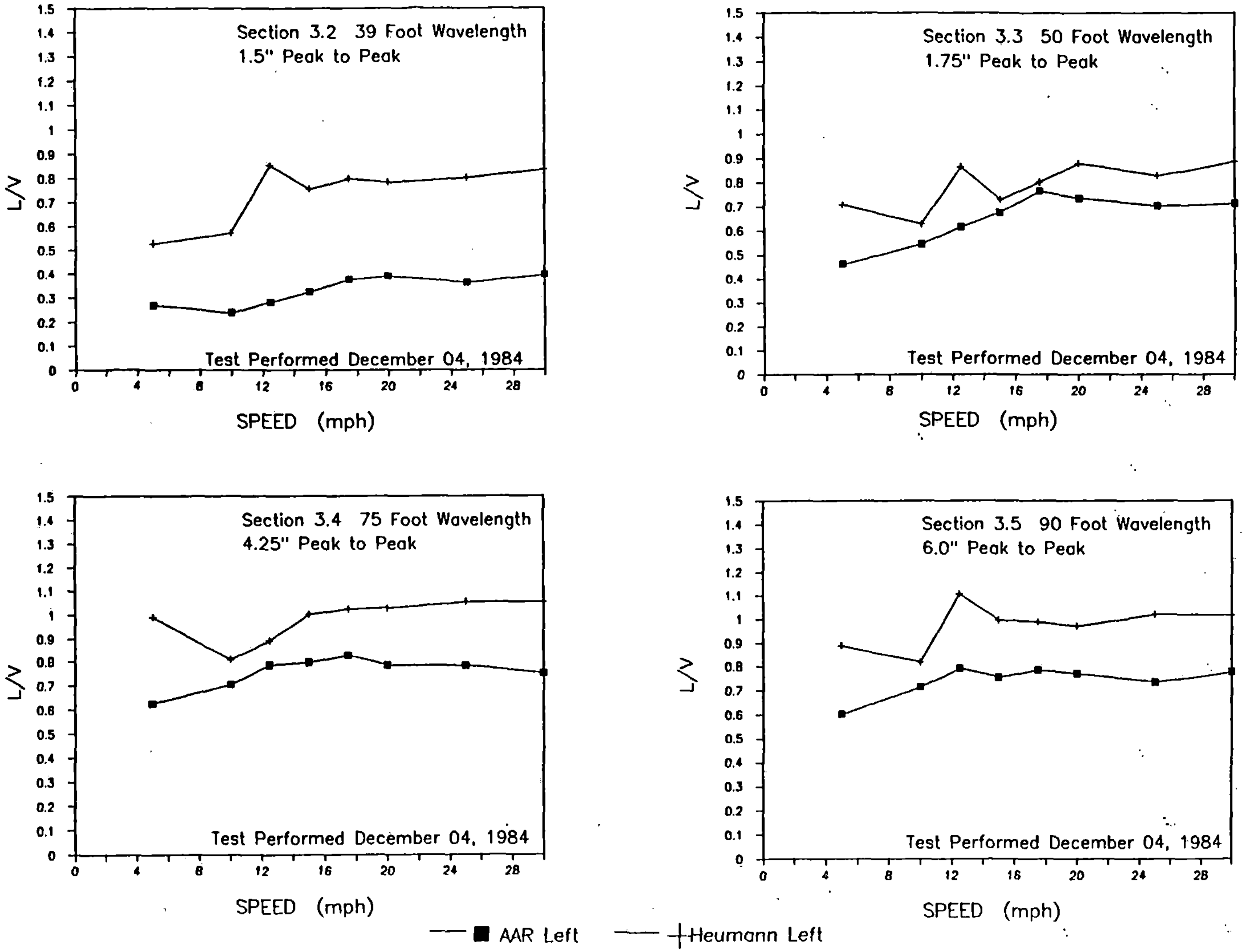


FIGURE 3.7-5 EMPTY FLAT CAR - PEAK LATERAL TO VERTICAL WHEEL FORCE RATIOS AT INTERMEDIATE SPEED TEST SECTION

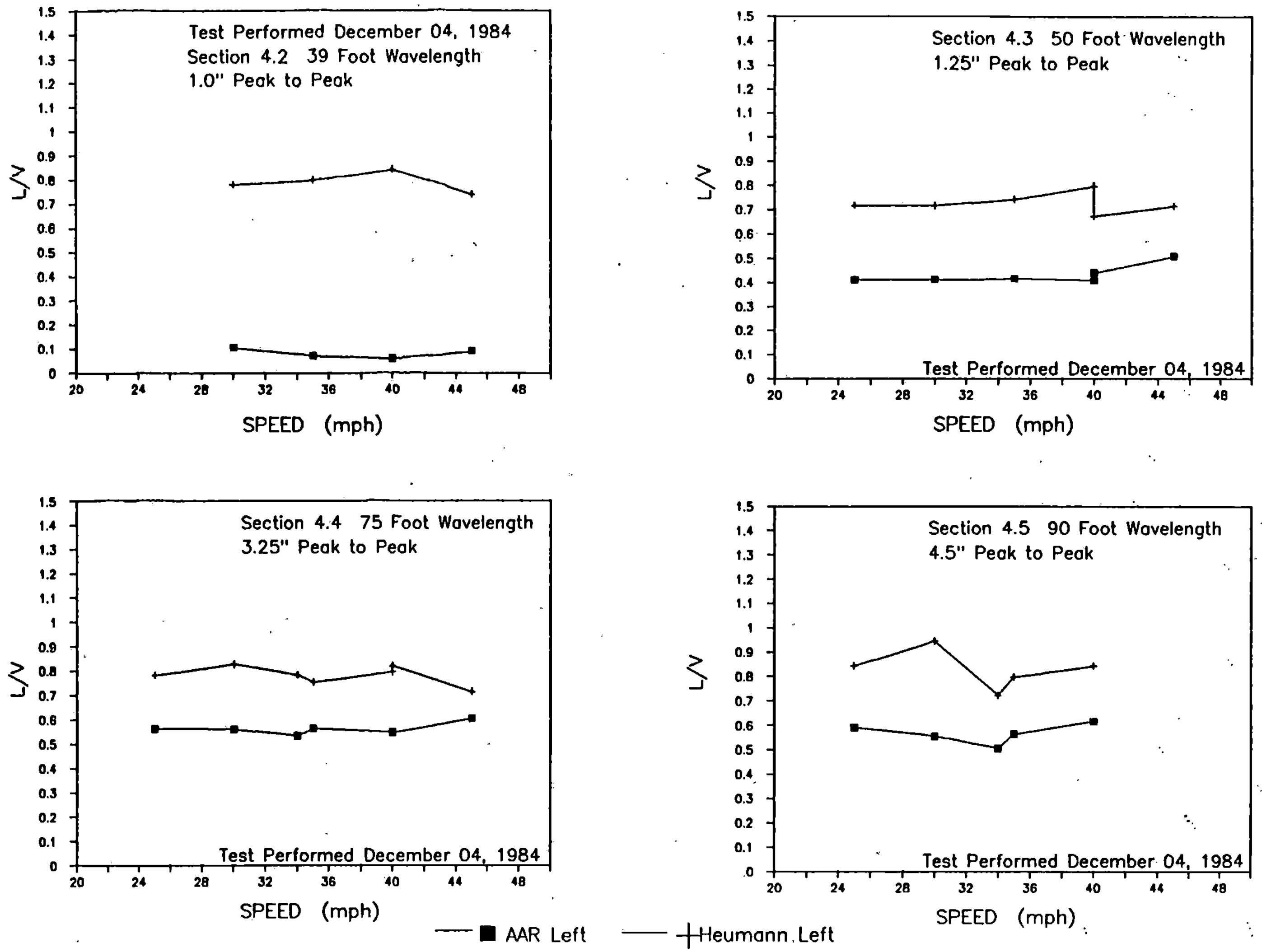


FIGURE 3.7-6 EMPTY FLAT CAR - PEAK LATERAL TO VERTICAL WHEEL FORCE RATIOS AT HIGH SPEED TEST SECTION

For the freight cars in the lower speed segments, the largest L/V ratios were experienced by the unloaded flatcar with Heumann profile wheels. For the 39 foot wavelength segments, L/V ratios in excess of 0.8 are measured for the Heumann profile wheels at all speed ranges. In the 50 foot wavelength, at the low speed and intermediate speed segments, L/V ratios of 0.9 are measured for the Heumann profile. For the 75 foot wavelength, in the low speed and intermediate speed segments, and in the 90 foot intermediate speed segment, the Heumann profile L/V ratios were about 1.0.

INFLUENCE OF WHEEL PROFILE

With the exception of the 39 foot wavelength segments and the unexpected results produced by the wheelset for the AAR profile at low speed, the lateral forces measured by the Heuman profile wheels and by the AAR profile wheels were generally of comparable magnitudes. In the 39 foot segments, the AAR profile wheels (including the locomotive) produced much smaller lateral forces than the Heumann profile wheels. It is believed that this results from a smaller effective flange clearance for the Heumann profile wheels than for the AAR profile wheels.

The behavior of the L/V ratios generated by the two wheel profiles appears to be strongly influenced by the car weight. For the loaded hopper car and the loaded tank car, the L/V ratios (with the exception of the intermediate and high speed 39 foot segments) measured for the AAR profile wheels were comparable or larger than those measured for the Heumann profile wheels. For the loaded flat car, the L/V ratios for the AAR profile wheels were comparable or larger than those for the Heumann profile at the 75 and 90 foot wavelengths. However, at the 39 foot and 50 foot wavelengths, the Heumann profile wheels generated larger L/V ratios than the AAR profile wheels for the loaded flatcar.

For the unloaded flatcar, the L/V ratios generated by the Heumann profile wheels are much larger than those generated by the AAR profile wheels. The L/V ratios generated by the Heumann profile wheels on the unloaded hopper cars also tend to be larger or comparable to those generated by the AAR profile wheels. For the empty tank car, the L/V ratios generated by the two wheel profiles are similar and small, except for the behavior observed in segment 4.3, a 50 foot wavelength segment, at speeds of 35 and 36 mph, where the AAR profile wheels generate L/V ratios of 1.1 and 1.3, while the Heumann profile L/V ratio remains at about 0.3.

INFLUENCE OF CAR WEIGHT

The magnitude of the peak lateral forces measured in the tests tended to be proportional to the weight of the car on the rail. Lightly loaded cars developed significantly higher wheel L/V ratios than fully loaded cars.

INFLUENCE OF WAVELENGTH AND SPEED

The peak lateral forces generated by the locomotive were relatively insensitive to speed, for speeds less than 35 mph, for the 39 foot, 75 foot, and 90 foot wavelengths. At the 3.5 inch peak to peak, 50 foot wavelength, the locomotive forces increased with speed from about 20 kips at 4 mph to about 30 kips at 28 mph. However, at the 1.75 inch peak to peak, 50 foot wavelength, there was almost no sensitivity to speed up to 30 mph, with the peak force remaining uniform at a level of about 19 kips. This result would indicate that the shape of the peak force-speed characteristic is dependent on the amplitude of the perturbation.

Above 35 mph, the peak locomotive wheel forces were relatively insensitive to speed for wavelengths of 39 and 50 feet. However, above 35 mph, the wheel rail forces generated by the locomotive in the 75 foot wavelength segment increase very rapidly with speed. For the 34 foot truck center spacing of the locomotive, the 75 foot wavelength produces a locomotive yaw mode input. The peak locomotive wheel forces in the 90 foot segment also increase with speed above 35 mph, but not as rapidly as in the 75 foot segment.

Ignoring the unexpected behavior of the instrumented AAR profile wheels, the freight cars tested did not show as strong a sensitivity of peak lateral wheel forces to speed variations as the locomotive. In the low speed test segments, independent of wavelength, the peak lateral wheel rail forces measured for the Heumann profile wheels were relatively independent of speed for speeds less than 25 mph. In the intermediate speed segments, the largest speed sensitivities were observed at wavelengths of 50 and 75 feet. The amplitude of the perturbation had a significant effect on the peak lateral force speed characteristics at a given wavelength. In much of the data, the differences observed between the left and right wheel forces obscure the trends in the data.

4. COMPARISONS WITH PREVIOUS DATA AND SIMULATION RESULTS

4.1 BENNINGTON TEST

The tests conducted at Bennington, N.H. (Reference 3) included sinusoidally varying alignment perturbations that are comparable to those in test segments 3.2, 3.3, and 3.4, and test segments 4.2, 4.3, and 4.4. At Bennington, the track included perturbations of 4-1/2 inch peak to peak at a wavelength of 90 feet, 1-1/4 inch peak to peak at a 50 foot wavelength, and 1-1/3 inch at a 39 foot wavelength. The instrumented wheelsets for the AAR profile wheels in the tests described in this report were the same as those used for the hopper car tested at Bennington.

The hopper car was a partially loaded open top coal car. The hopper car weight on the rail was approximately 200 kips (about 15% lighter than the hopper cars used in the tests at TTC). The locomotive used in the Bennington tests was a GP-9 with 2 ASEA instrumented wheelsets on the trailing truck.

Figure 4-1 shows the peak right wheel lateral force measured on the lead axle of the trailing truck of the locomotive in the Bennington tests for speeds ranging from 5 to 30 mph. Over comparable speed ranges (18 to 30 mph) the locomotive data obtained at Bennington is seen to be consistent with the results obtained in the tests discussed in this report at TTC.

Figure 4-2 shows the peak lateral wheel forces measured on the lead axle of the lead truck of the hopper car for each of the alignment perturbations for speeds of 5 to 30 mph. The Bennington test data show peak lateral forces that are consistent with those measured for the Heumann profile in the tests at TTC. The forces measured for the AAR profile wheels in the 39 foot wavelength segments 3.2 and 4.2 at TTC are much smaller than those measured in Bennington. This may be the result of remachining of the instrumented wheelset with the AAR profiles prior to the TTC tests resulting in a larger effective flange clearance. Although the peak lateral wheel forces in the Bennington tests show some dependence on speed, they do not exhibit the strong sensitivity to speed below 20 mph as seen in the data for the AAR profile wheelsets in the tests at TTC.

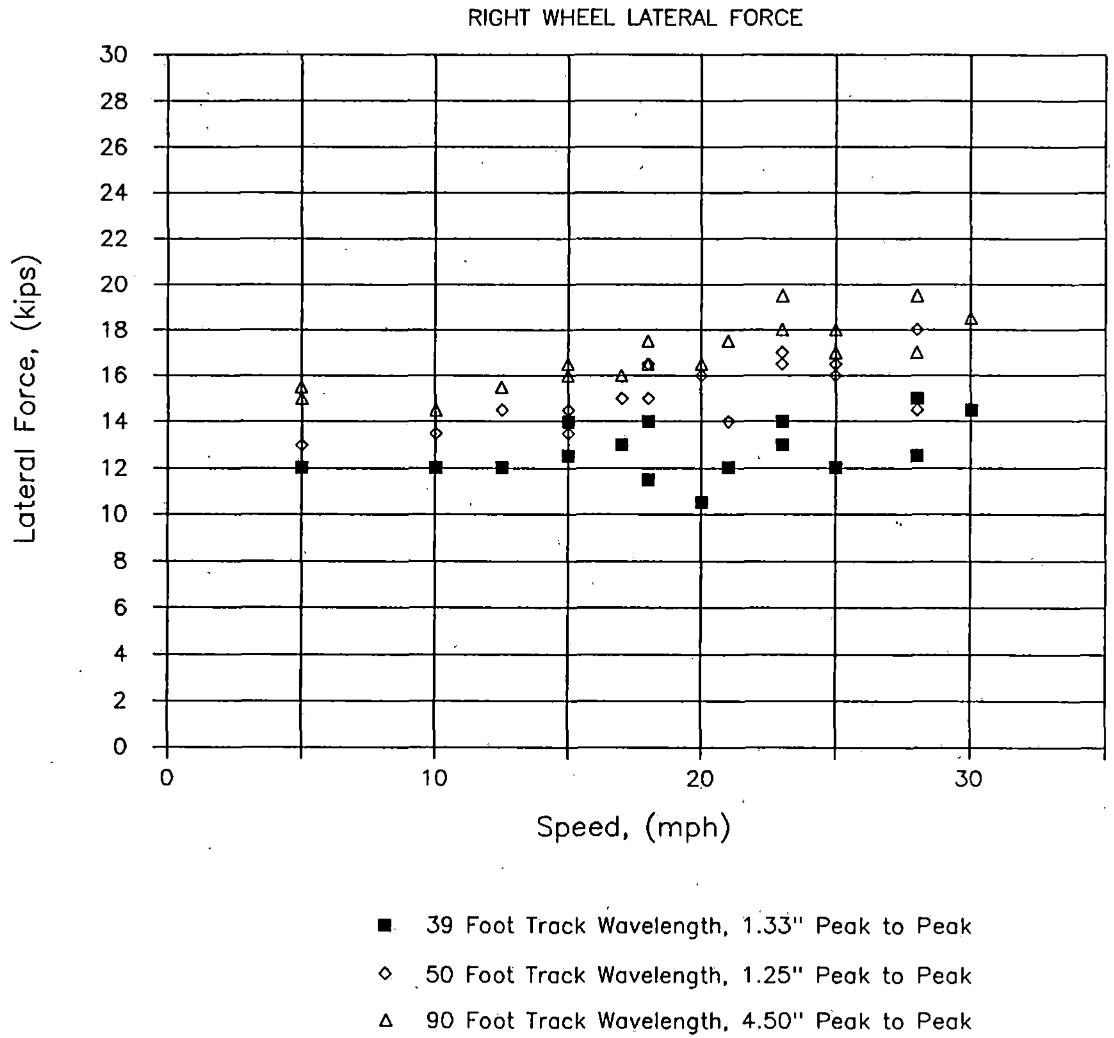


FIGURE 4-1 TEST AT BENNINGTON, NH - LOCOMOTIVE

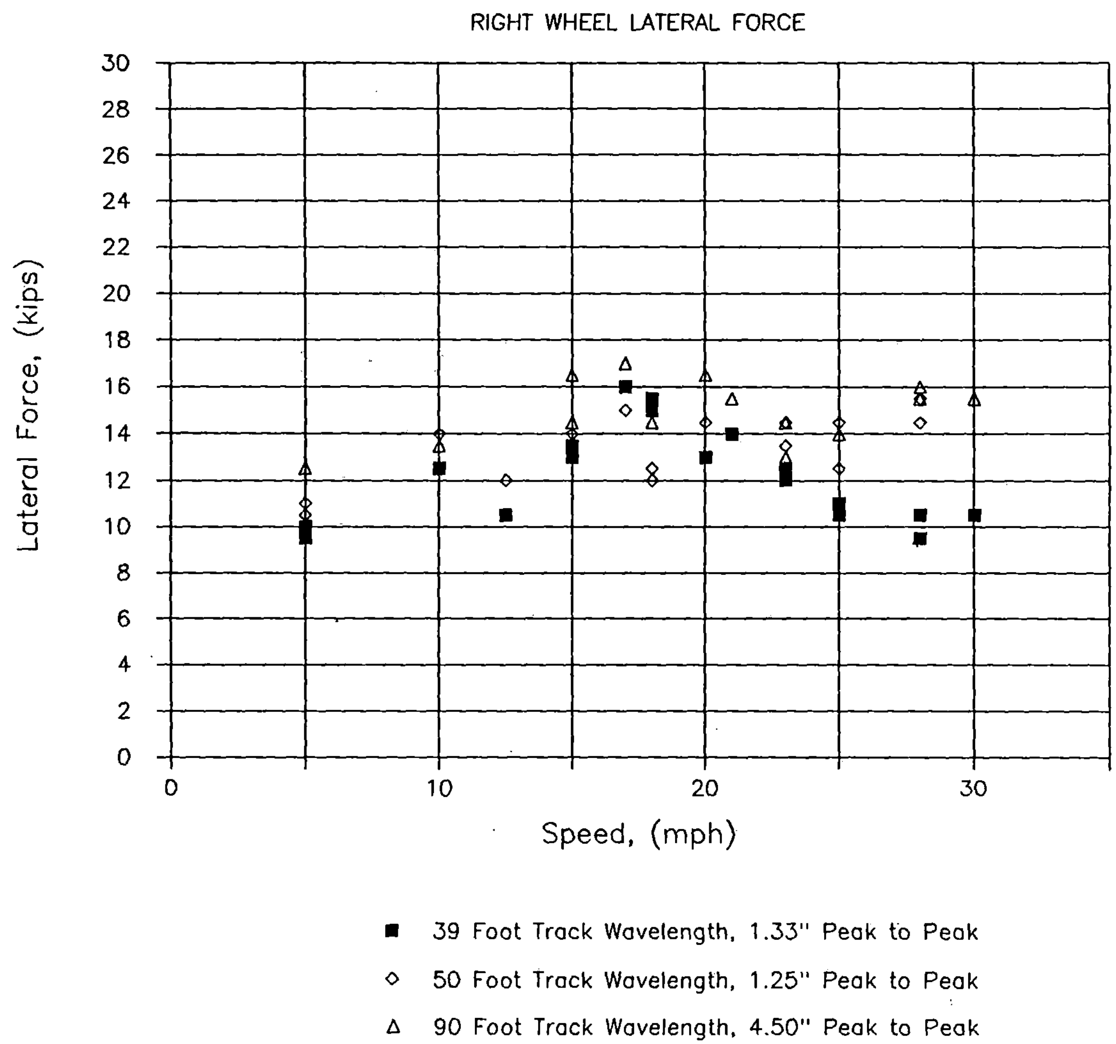


FIGURE 4-2 TEST AT BENNINGTON, NH - HOPPER CAR

4.2 SIMCAR COMPUTER SIMULATION

Calculations of the peak lateral wheel rail forces were made using the SIMCAR computer program for a loaded 100 ton hopper car traversing the track alignment variations that were used in the tests conducted at TTC. These simulation results are compared to those obtained in the tests in Figures 4-3 to 4-11. The wheel profile used in the simulation is an AAR 1/20 wheel. In those track segments where the test results indicate significant differences in behavior between the AAR profile wheels and the Heumann profile wheels, the results from the computer simulation compares much more closely to the test results from the Heumann profile. Differences between simulation results and experimental data are within the range of experimental uncertainty.

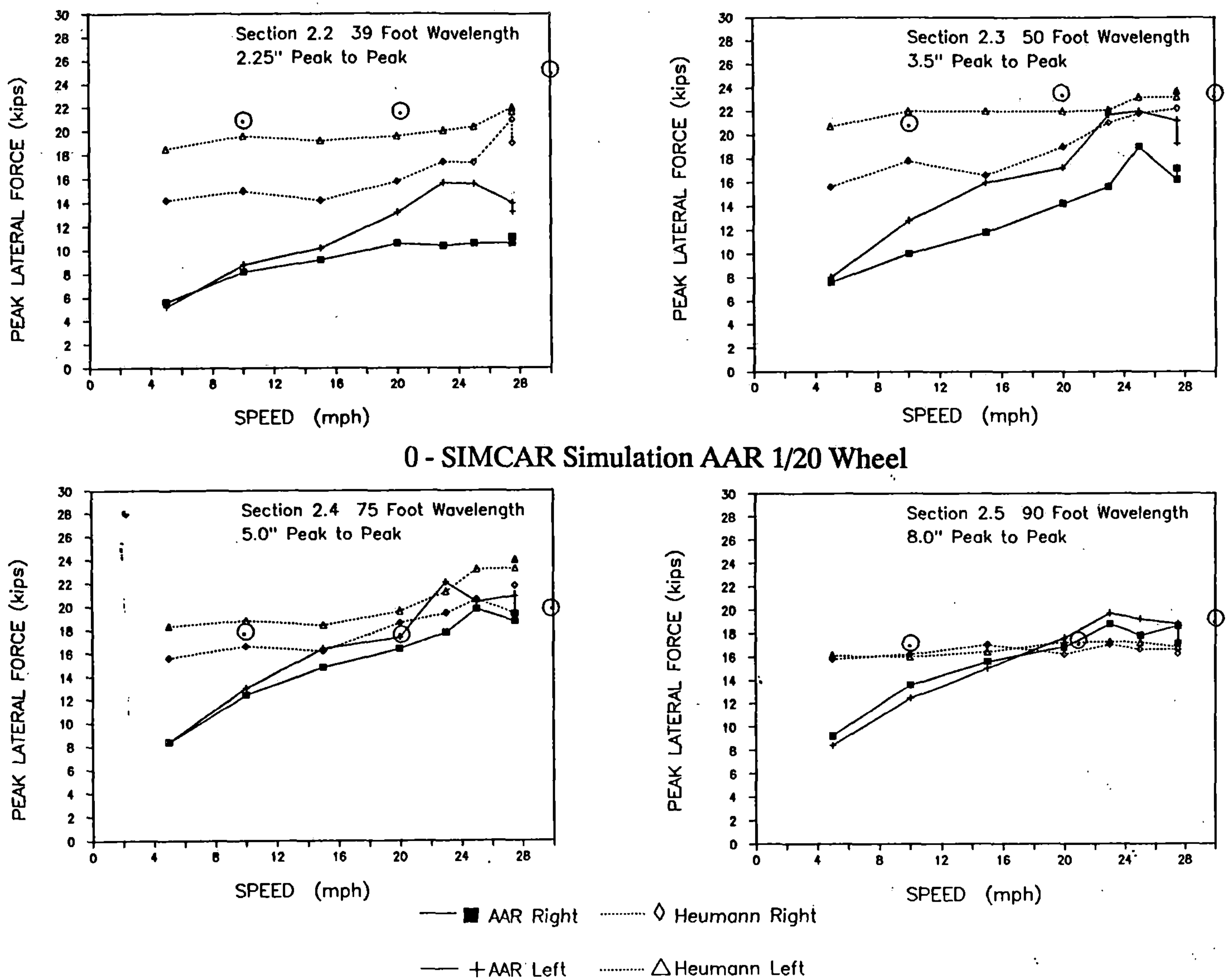


FIGURE 4-3 LOADED HOPPER CAR - COMPARISON OF TEST MEASUREMENTS WITH SIMCAR SIMULATION RESULTS - PEAK LATERAL WHEEL FORCES AT LOW SPEED TEST SECTION

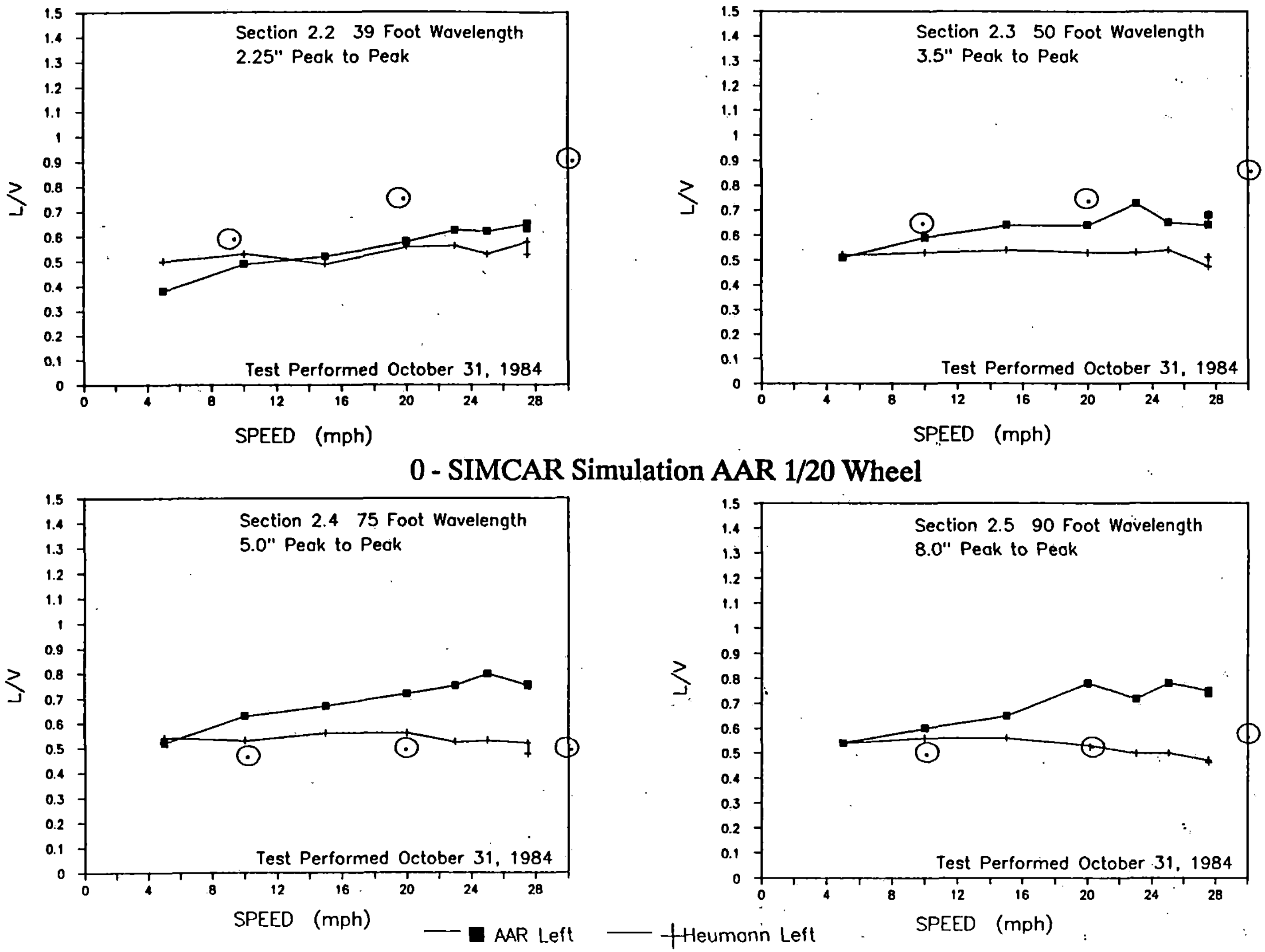


FIGURE 4-4 LOADED HOPPER CAR - COMPARISON OF TEST MEASUREMENTS WITH SIMCAR SIMULATION RESULTS - PEAK LATERAL TO VERTICAL WHEEL FORCE RATIOS AT LOW SPEED TEST SECTION

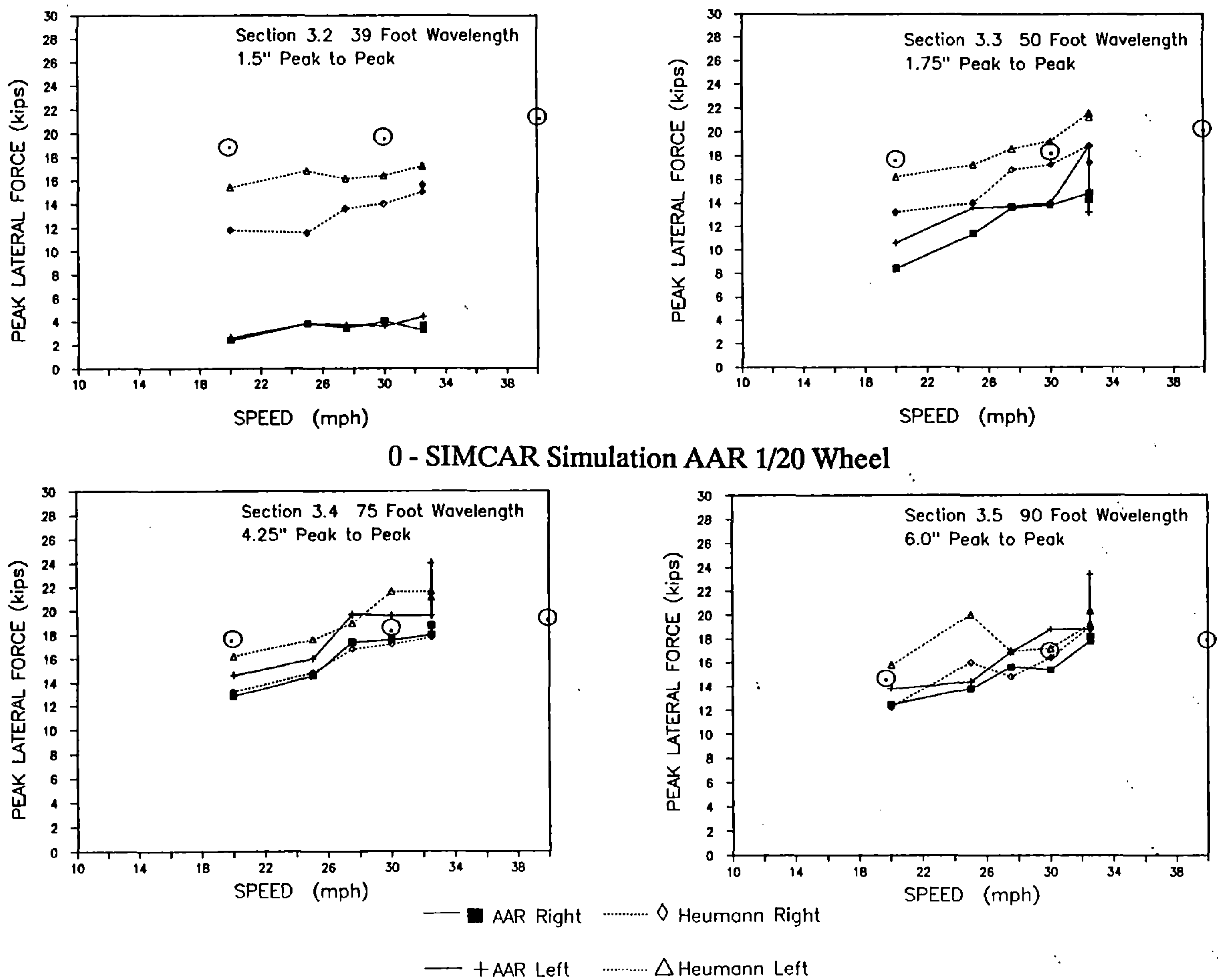


FIGURE 4-5 LOADED HOPPER CAR - COMPARISON OF TEST MEASUREMENTS WITH SIMCAR SIMULATION RESULTS - PEAK LATERAL WHEEL FORCES AT INTERMEDIATE SPEED TEST SECTION

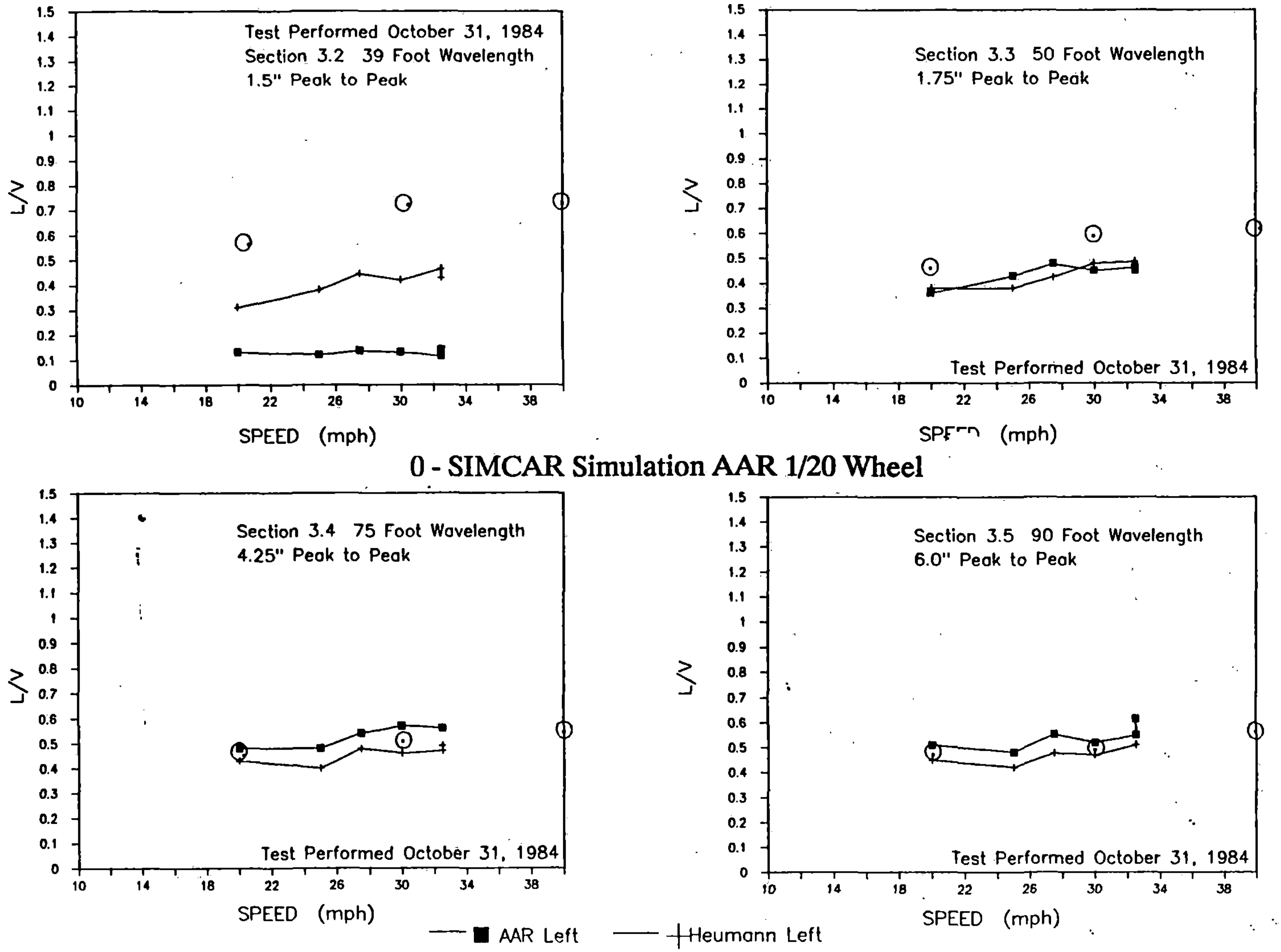


FIGURE 4-6 LOADED HOPPER CAR - COMPARISON OF TEST MEASUREMENTS WITH SIMCAR SIMULATION RESULTS - PEAK LATERAL TO VERTICAL WHEEL FORCES AT INTERMEDIATE SPEED TEST SECTION

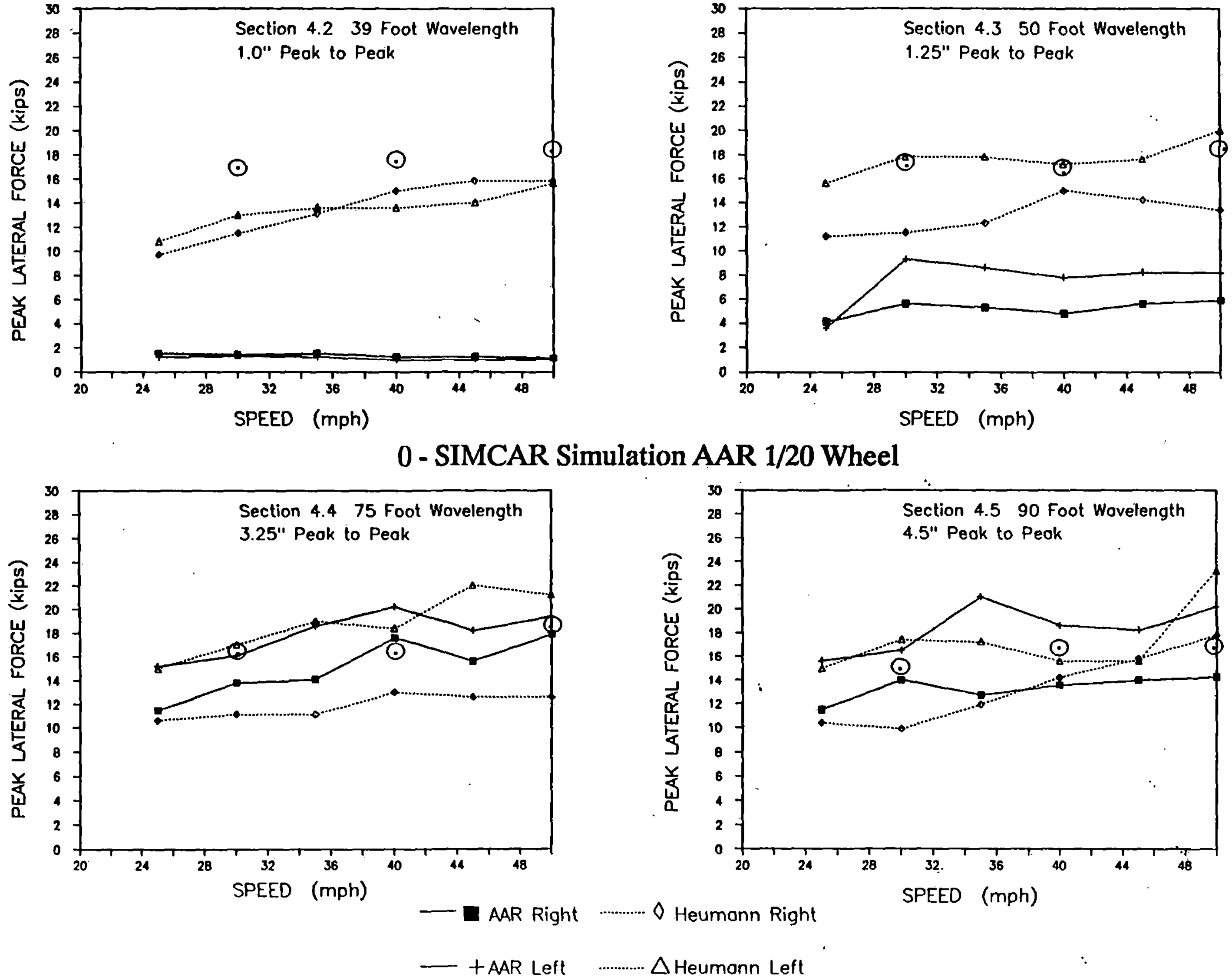


FIGURE 4-7 LOADED HOPPER CAR - COMPARISON OF TEST MEASUREMENTS WITH SIMCAR SIMULATION RESULTS - PEAK LATERAL WHEEL FORCES AT HIGH SPEED TEST SECTION

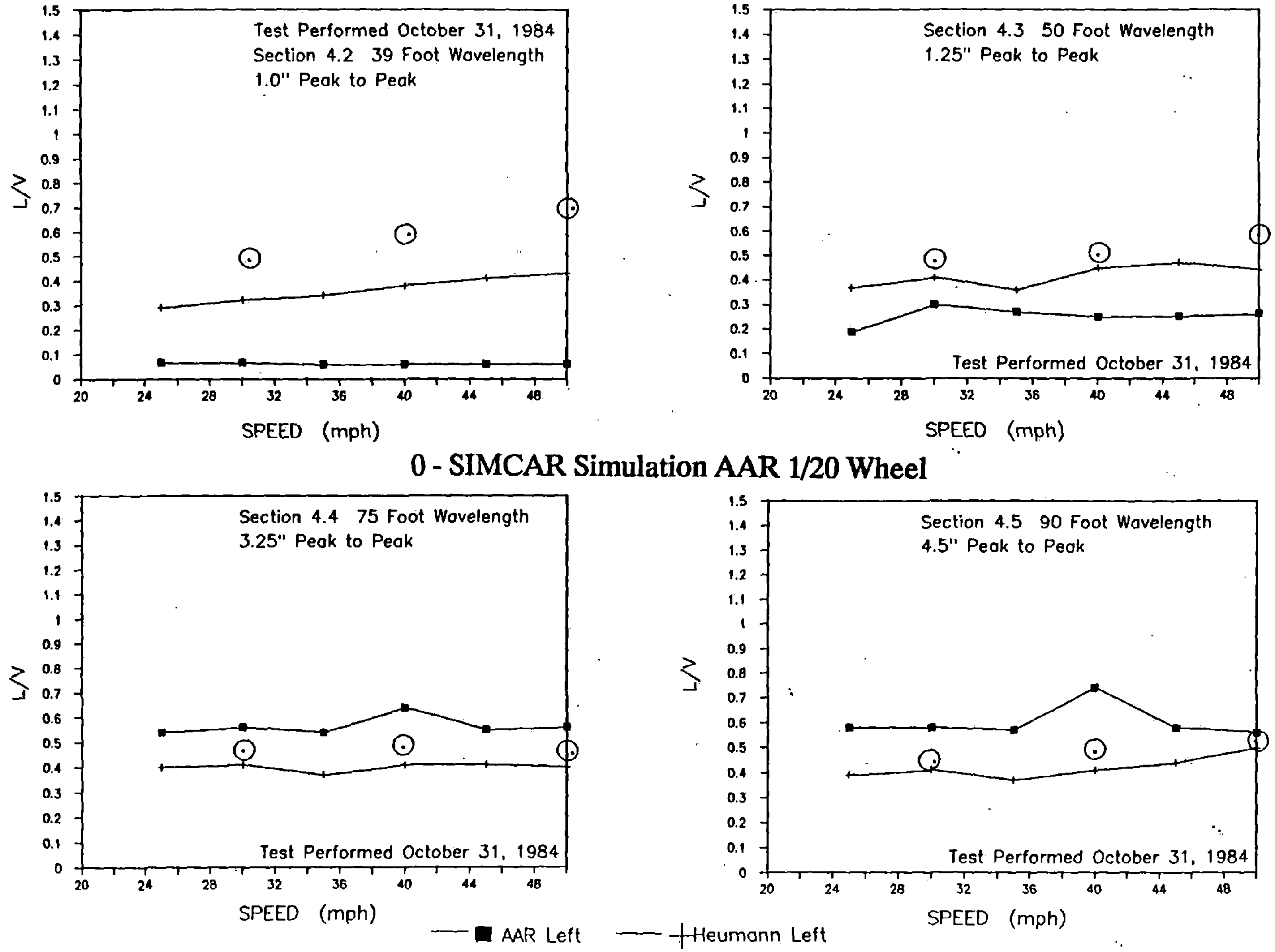


FIGURE 4-8 LOADED HOPPER CAR - COMPARISON OF TEST MEASUREMENTS WITH SIMCAR SIMULATION RESULTS - PEAK LATERAL TO VERTICAL WHEEL FORCE RATIOS AT HIGH SPEED TEST SECTION

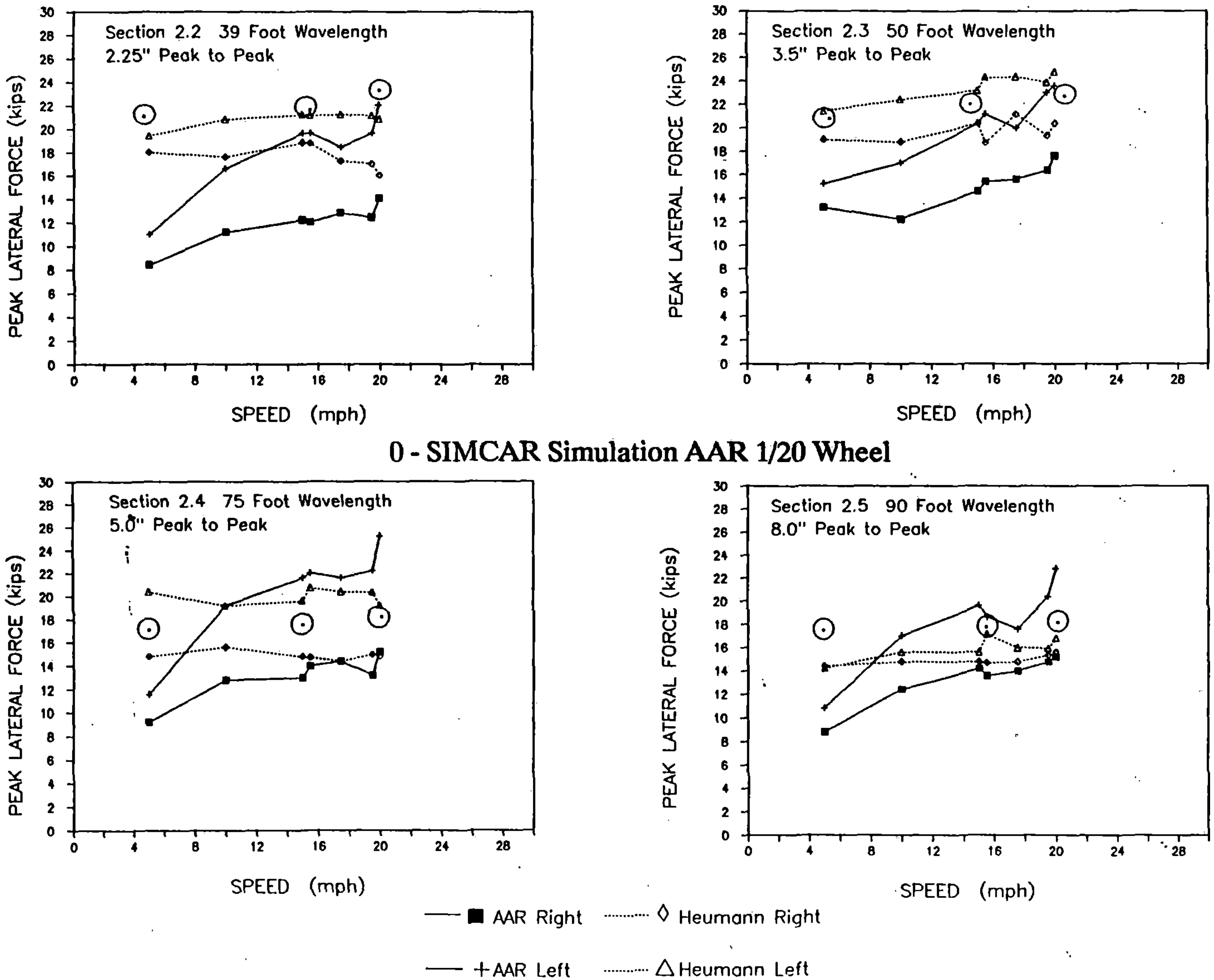


FIGURE 4-9 LOADED HOPPER CAR - COMPARISON OF TEST MEASUREMENTS WITH SIMCAR SIMULATION RESULTS - PEAK LATERAL WHEEL FORCES RATIOS AT LOW SPEED TEST SECTION

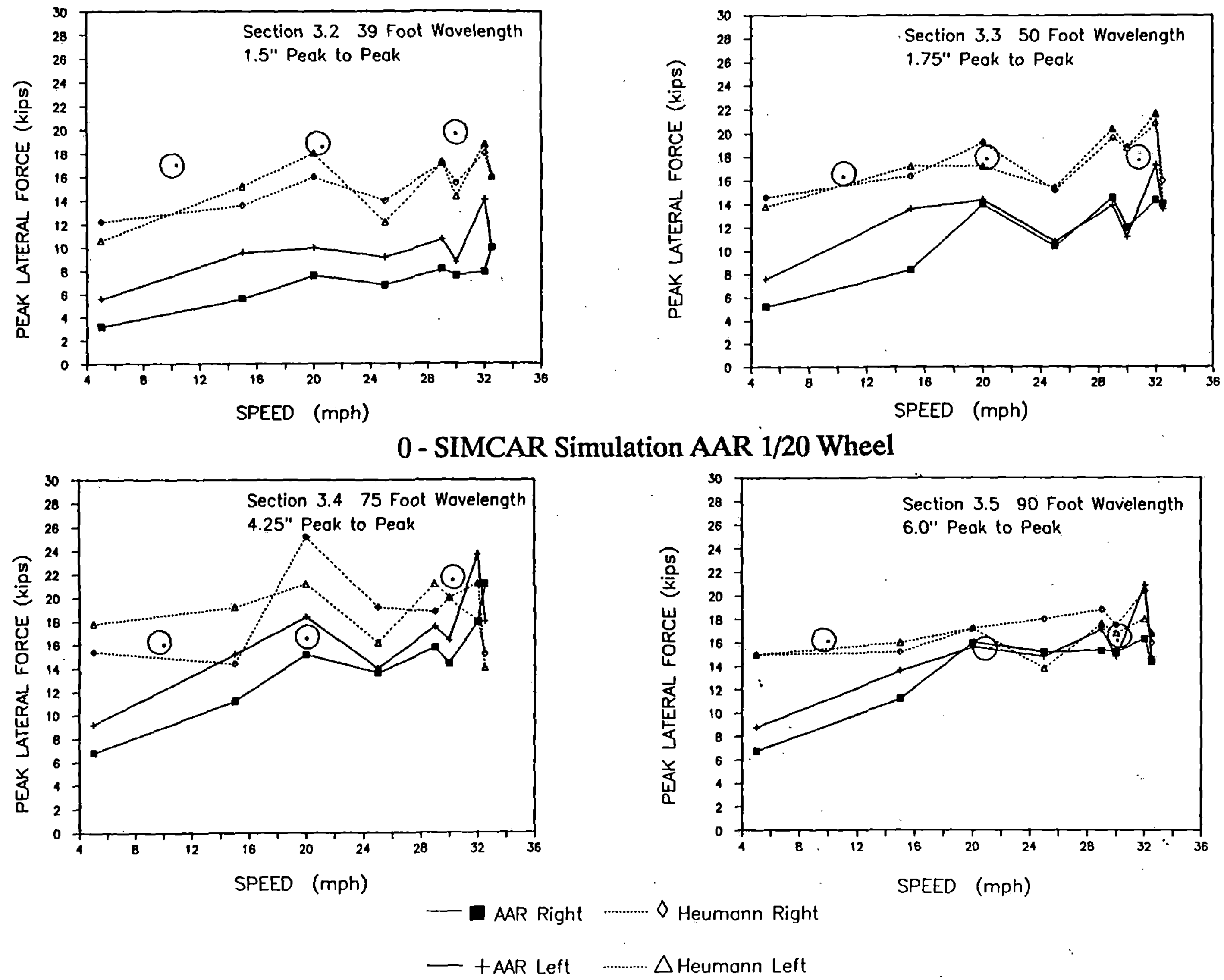


FIGURE 4-10 LOADED HOPPER CAR - COMPARISON OF TEST MEASUREMENTS WITH SIMCAR SIMULATION RESULTS - PEAK LATERAL WHEEL FORCES AT INTERMEDIATE SPEED TEST SECTION

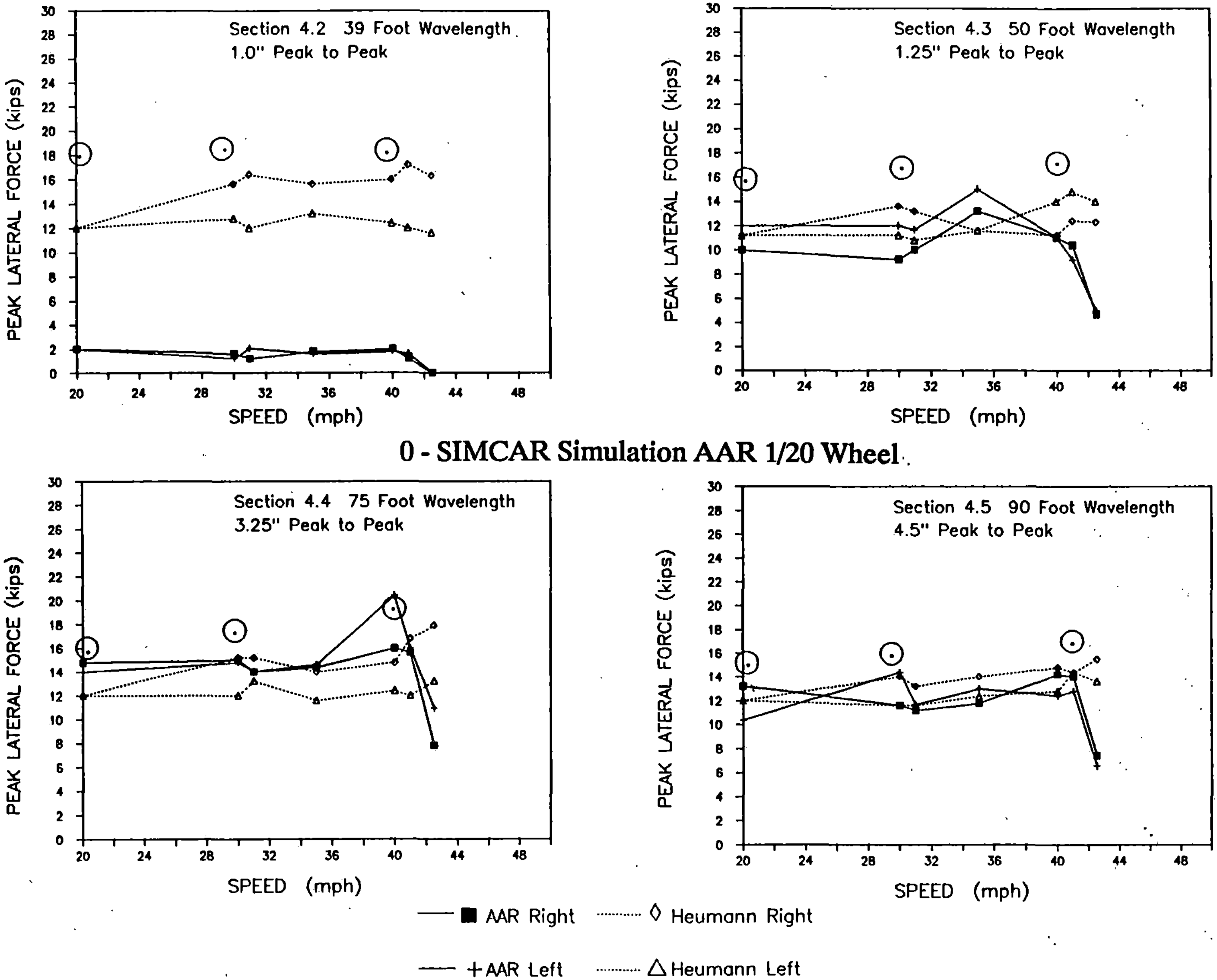


FIGURE 4-11 LOADED HOPPER CAR - COMPARISON OF TEST MEASUREMENTS WITH SIMCAR SIMULATION RESULTS - PEAK LATERAL WHEEL FORCES AT HIGH SPEED TEST SECTION

5. CONCLUSIONS AND RECOMMENDATIONS

A series of tests have been conducted for loaded and unloaded hopper cars, tank cars, and TOFC flat cars over a range of severe track alignment variations. This data base can be applied to partially test the validity of analytical models for predicting rail vehicle performance and wheel rail forces.

The range of speeds covered in these tests was limited by the capabilities of the GP-9 locomotive used in the test consist. The locomotive generated wheel rail forces and L/V ratios under these test conditions that approached the safe limits prescribed for the tests. Studies directed towards defining maximum loads on track structures should include consideration of locomotive dynamic behavior as well as freight car behavior.

The interpretation of the data was confused by the low speed filters applied to the signals from the instrumented AAR profile freight car wheelsets and sensitivites of the signals to the lateral position of the wheelsets. Future testing should include a more detailed calibration of the wheelsets and design to minimize the sensitivities to position of the wheel rail contact under large variation conditions.

The use of Heumann profiles on conventional truck designs did not result in a reduction of wheel rail forces in traversing large alignment irregularities. For unloaded cars, the Heumann profile wheels produced significantly larger L/V ratios than the AAR profile wheels. More conclusive data is needed to establish the relative safety of different wheel profiles for conventional truck designs.

Changes in amplitude of sinusoidal alignment perturbations result in very significant changes in the peak force versus speed characteristic of rail cars. Extrapolations of test results must therefore be made with extreme caution. Tests and analyses to establish safe limits must be conducted at the extreme limits.

For the alignment variations tested, the ride vibration levels generated in the locomotive and instrumentation car were a much more severe limitation on maximum test speed than the likelihood of derailment due to rail climb of the freight cars tested. In the specification of allowable alignment deviations, it would be desirable to include control of ride vibration experienced by train operating personnel as a criterion.

The wheel rail forces generated by the freight cars were consistent with predictions made using the SIMCAR program. It is therefore concluded that SIMCAR is a reasonable valid tool for estimating wheel rail forces generated by alignment variations over speeds up to 50 mph. Further testing will be required to establish a sufficient data base for analysis tools capable of predicting rail car response at higher speed.

APPENDIX A
TRACK GEOMETRY MEASUREMENTS

Two track geometry surveys were run in connection with this test; one prior to it, and one following it. The purpose of the initial survey, conducted in September 1984, was to verify that the perturbations had been installed per design, and to collect actual geometry data for use in evaluating the results of the test. The posttest track geometry survey was conducted in January 1985, to determine whether the geometry of the track changed during the test due to the high forces involved.

The T-6 track geometry measurement vehicle was used to make the geometry measurements. The track geometry parameters measured included gage, crosslevel, and alignment. In the remainder of this section, the initial geometry survey results are presented in tabular form and discussed with respect to accuracy for each of the parameters considered (gage, crosslevel and alignment). These results are then compared to those of the posttest geometry survey. Finally, remarks on geometry measurement accuracy and track movements are summarized.

A.1 PRETEST TRACK GEOMETRY MEASUREMENTS

All test zones were designed with a nominal gage of 4' 8-5/8". The actual installation is believed accurate to within 1/8". Table A-1 shows the nominal and maximum measured gage values for each test zone.

TABLE A-1. MEASURED GAGE

Test Segment	Installed Gage (inch)	Measured Gage (inch)	
		Nominal	Maximum
1.1	56.625 + .125	56.6	57.0
2.2	56.625 + .125	56.8	56.9
2.3	56.625 + .125	56.8	56.9
2.4	56.625 + .125	56.8	57.0
2.5	56.625 + .125	56.8	56.9
2.6	56.625 + .125	56.8	57.0
3.2	56.625 + .125	56.8	56.9
3.3	56.625 + .125	56.8	56.9
3.4	56.625 + .125	56.8	57.0
3.5	56.625 + .125	56.8	56.9
3.6	56.625 + .125	56.8	56.9
4.2	56.625 + .125	56.6	56.8
4.3	56.625 + .125	56.7	56.9
4.4	56.625 + .125	56.6	56.9
4.5	56.625 + .125	56.6	56.9

A.1.1. GAGE MEASUREMENTS

Gage measurement was accomplished on T-6 by servo-magnetic sensors which maintain a proximity to the gage side of each rail as the car moves along the track. Based upon the repeatability test results of 1977, the maximum variation in mean gage measurements is no more than 0.037 inches for speeds ranging from 15 to 55 mph.

Table A-1 shows that the nominal gage varies from that installed by no more than .05 inches for all test segments. At those locations where the measured gage varies from the installed gage, it is higher. This suggests that gage spreading occurred under the weight of the measurement vehicle when it negotiated the severe perturbations. Thus, considering the accuracy of the measurements, gage spreading was in the range of 0.13 to 0.263 inches.

A.1.2 CROSSLEVEL

Crosslevel perturbations were installed in 3 of the 15 test segments, but crosslevel variations as measured by T-6 were indicated for 9 of the segments, as shown in Table A-2. For the three segments which actually contained crosslevel (segments 1.1, 2.6 and 3.6), the corresponding T-6 measurements were in agreement. However, the measurements shown for segments 2.4, 2.5, 3.4, 4.4 and 4.5 are in error as much as 1.2 inches.

TABLE A-2. MEASURED CROSSLEVEL

Segment	Speed (mph)	Measured Amplitude (inch)	Designed Amplitude (inch)	Amplitude Of Alignment Perturbation (inch)
1.1	20	6.0	6.0	0.00
2.2	25	Negligible	0.0	2.25
2.3	25	Negligible	0.0	3.50
2.4	25	1.0	0.0	5.00
2.5	25	1.2	0.0	8.00
2.6	25	1.2	2.0	3.50
3.2	30	Negligible	0.0	1.50
3.3	30	Negligible	0.0	1.75
3.4	30	0.6	0.0	4.25
3.5	30	0.8	0.0	6.00
3.6	30	1.0	1.0	1.75
4.2	40	Negligible	0.0	1.00
4.3	40	Negligible	0.0	1.25
4.4	40	0.6	0.0	3.25
4.5	40	0.9	0.0	4.50

Abnormally large alignment perturbations are suspected as the cause of the erroneous crosslevel measurements of the six segments (2.4, 2.5, 3.4, 4.4 and 4.5). This is because T-6 was designed to handle situations within the FRA track classes (typical American railroad track). In comparing the alignment amplitudes of Table 2-1 with the FRA Standards, it can be seen that the alignment perturbations in this test are of magnitudes which are up to four times that of typical for the various track classes (e.g, for Track Class 4, alignment standard is 1.5 inches).

In particular, the following factors influenced crosslevel measurement for the six erroneous segments.

1) The crosslevel measurement subsystem of T-6 consists of a vertical reference sensor and tow displacement transducers. The displacement transducers measure the angular displacement between the carbody and truck. These are also used in the alignment system. Crosstalk between the alignment and crosslevel systems is apparent because the two are related such that alignment feeds crosslevel via the displacement transducers. A yaw rate gyro, two velocity transducers, and a tachometer are used to compensate the contribution to crosslevel of lateral accelerations caused by alignment. First-order cross-sensitivities between these are filtered out, leaving a small component of crosslevel which results from carbody roll in large amplitude alignment perturbations. two?

2) A real component of crosslevel is introduced by the wheel conicity and lateral variance of wheel contact point. Assuming a 1.5 inch lateral excursion and a 1:20 wheel profile, this yields a possible contribution to crosslevel from wheel conicity effects of 0.15 inch.

3) If flange climbing occurs, this contribution increases, which may have been the case in some of the runs (depending on speed and alignment amplitudes and wavelengths).

Thus, the values shown in Table A-2 indicate that the crosslevel measurements are very accurate when measuring only crosslevel perturbations. They also show that the magnitude of erroneous measurements shown for unperturbed segments is related to lateral force. As lateral forces at the wheel/rail interfaces increase, larger values for crosslevel are indicated. The lateral force generated is a function of alignment wavelength and amplitude and the speed at which the alignment is traversed. In these six cases of error, three similar trends can be seen where the error increases for two consecutive segments of identical speed and increasing amplitude.

A.1.3 ALIGNMENT

Alignment perturbations were installed in 14 of the 15 test zones, with the designed peak to peak amplitudes ranging from 1 to 8 inches. Installation was believed to be accurate within plus or minus 1/8" for each rail.

Of the measurements made by T-6, alignment was expected to be the least accurate for this application. One reason is that the system uses an inertial reference which is not suitable for measuring at low speeds. In the T-6 acceptance tests, alignment was not recorded below 30 miles per hour. The mean variance of alignment measurements approaches 0.1 inch at 45 mph. In the VTI test, the severe perturbations required that speeds be below or near the 30 mph threshold. T-6 is actually capable of measuring alignment at speeds as low as 25 miles per hour, with a variance in mean of 0.018 inches, provided that the alignment deviations are within the bounds of what is classified as typical for the various track classes. As pointed out in Section 6.1.2, the perturbations used in this test were as large as four times that of typical track.

In addition to the error sources described above, the reported alignment measurements are affected by the filtering in off-line data processing. T-6 was designed to measure the geometry of typical track in terms of 62-foot mid-chord offsets, which is a standard method in the industry. Therefore, the filter corner is set such that wavelengths longer than approximately 80 feet are excluded. For this reason, the amplitudes reported for alignment wavelengths of 75 and 90 feet are particularly suspect.

In general, the data presented in Table A-3 support the preceding discussion. In summary, the alignment measurements may be confounded for the following reasons:

1) Low speed (below 30 mph)

2) Amplitude of perturbations which are larger than FRA Standards for each track class

3) Long wavelengths (particularly those longer than filter length)

Based on the verification of other parameters and transit survey measurements taken prior to the test, it is believed that the alignment perturbations were installed within acceptable tolerances.

TABLE A-3. MEASURED ALIGNMENT

Test Segment	Speed (mph)	Measured Amplitude (inch)	Verification By Transit (inch)	Design Amplitude (inch)	Change In Amplitude (inch)	Wave-Length (foot)
1.1	10,20	10.8,3.7		0.00	0.00	
2.2	25	2.0		2.25	-0.25	39
2.3	25	3.4		3.50	-0.10	50
2.4	25	6.0		5.00	+1.00	75
2.5	25	10.4	8.0	8.00	+2.40	90
2.6	25	3.5		3.50	0.00	50
3.2	30	1.1		1.50	-0.40	39
3.3	30	2.0		1.75	+0.25	50
3.4	30	4.6		4.25	+0.35	75
3.5	30	8.0	6.0	6.00	+2.00	90
3.6	30	2.0		1.75	+0.25	50
4.2	40	0.8		1.00	-0.20	39
4.3	40	1.6		1.25	+0.35	50
4.4	40	3.6		3.25	+0.35	75
4.5	40	5.2	4.5	4.50	+0.70	90

A.2 POST TEST TRACK GEOMETRY MEASUREMENT

A.2.1 GAGE

Results of the posttest geometry survey are compared to those of the initial survey for gage in Table A-4. It is seen from the table that there was no significant change in gage throughout the test program. This also indicates that the gage measurements are repeatable, which further supports that the measurements are independent of speed, amplitude, and wavelength in this application.

TABLE A-4. COMPARISON OF GAUGE BEFORE AND AFTER TESTS

Test Segment	Nominal Gage (inch)		Change In Gage (inch)
	Pretest	Post Test	
1.1	56.6	56.7	0.1
2.2	56.8	56.8	0.0
2.3	56.8	56.8	0.0
2.4	56.8	56.8	0.0
2.5	56.8	56.8	0.0
2.6	56.8	56.8	0.0
3.2	56.8	56.7	-0.1
3.3	56.8	56.7	-0.1
3.4	56.8	56.8	0.0
3.5	56.8	56.7	-0.1
3.6	56.8	56.8	0.0
4.2	56.6	56.7	-0.1
4.3	56.7	56.7	0.0
4.4	56.6	56.7	0.1
4.5	56.6	56.7	0.1

A.2.2 CROSSLEVEL

Table A-5 presents the crosslevel data for the two track geometry surveys. Changes in track crosslevel are indicated for only two test segments (segments 2.5 and 3.4). These measurements are small, and they are considered insignificant. A change in crosslevel of this magnitude is expected due to ballast/subgrade settlement after a number of test runs. Thus, the track geometry may be considered as remaining stable throughout the test.

TABLE A-5. PRETEST AND POSTTEST CROSSLEVEL

Test Segment	Crosslevel (inch)		Crosslevel (inch)
	Pretest	Post Test	
1.1	6.0	6.0	0.0
2.2	Neg	Neg	0.0
2.3	Neg	Neg	0.0
2.4	1.0	1.0	0.0
2.5	1.2	1.3	0.1
2.6	2.0	2.0	0.0
3.2	Neg	Neg	0.0
3.3	Neg	Neg	0.0
3.4	0.7	0.9	0.2
3.5	0.8	0.8	0.0
3.6	1.0	1.0	0.0
4.2	Neg	Neg	0.0
4.3	Neg	Neg	0.0
4.4	.6	.6	0.0
4.5	.9	.9	0.0

A.2.3. ALIGNMENT

Posttest and initial alignment measurements are reported in Table A-6. For the track conditions under which the surveys were performed, and with respect to measurement system capability, an accuracy of +0.25 inch is considered appropriate. This also considers the decreased accuracy of the alignment system at low speeds, and that the survey runs were performed at various speeds. With this criteria, significant track movement is indicated for only one of the test segments (segment 2.5). It is believed that segment 2.5 shows significantly larger movement than the others segment because the amplitude of the alignments in segment 2.5 was much larger than the other segments (8 inches for segment 2.5 as opposed to 1 to 6 inches for the other segments as shown in Table A-3). However, considering test conditions and the system capability, all test segments remained in relatively stable condition.

TABLE A-6. PRETEST AND POSTTEST ALIGNMENT

Test Segment	Pretest		Post Test		Change In Alignment (inch)
	Alignment Amplitude (inch)	Measurement Speed (mph)	Alignment Amplitude (inch)	Measurement Speed (mph)	
1.1	3.7	20	4.00	20	+0.3
2.2	2.0	25	2.00	25	0.0
2.3	3.4	25	3.20	25	-0.2
2.4	6.0	25	5.70	25	-0.3
2.5	10.4	25	11.20	25	+0.8
2.6	3.5	25	3.20	25	-0.3
3.2	1.1	30	1.10	25	0.0
3.3	2.0	30	1.75	25	-0.25
3.4	4.6	30	4.80	25	+0.2
3.5	8.0	30	8.10	25	+0.1
3.6	2.0	30	2.00	25	0.0
4.2	0.8	40	0.80	25	0.0
4.3	1.3	40	1.30	25	0.0
4.4	3.6	40	3.60	25	0.0
4.5	5.2	40	5.60	25	+0.4

A.3 SUMMARY

In summarizing the major observations of this section, the following remarks are presented:

1) Track geometry remained stable throughout the test, with the exception of one alignment segment. It is likely, as pointed out by the data, that some track movement occurred where high lateral forces were induced. The lateral forces are dependent upon alignment wavelength and amplitude, and vehicle speed.

2) The track geometry measurements are, in general, admissible for this test. The inconsistencies noted above are presumed to be due to the conditions which were explained. Although the measurement vehicle was operated in some cases beyond its intended capability, it is felt that it demonstrated good reliability in measuring this geometry.

3) Temperature effects were a minimal factor in the comparison of the two geometry surveys of September 1984 and January 1985. The colder temperature during January survey would probably cause decreases in the amplitude of perturbations due to contraction of the rail.

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2. H. Weinstock and D. Tyrell, "A Study of Rail Vehicle Unloading Due to Track Twist," Applied Mechanics Rail Transportation Symposium-1988, AMD-Vol. 96/RTD-Vol. 2: 181-189.

3. M. Coltman and H. Weinstock, "Vehicle/Track Interaction Test at Bennington, NH - Revision 1.0" U.S. Department of Transportation Federal Railroad Administration, Washington, DC, April 1988, DOT/FRA/ORD-87/1, 100 p.

U.S. Department of Transportation

Research and Special Programs Administration

Memorandum

Date: 6/7/90

Reply to Attn. of: DTS-930

Subject: Review and approval of TSC technical reports resulting from FRA PPA's

From: TSC, Center for Transportation Information, DTS-32

To: William Paxton, RRS-31
Federal Railroad Administration
400 7th Street, S.W.
Washington, DC 20590

DOT-TSC-FRA-89-5

Attached for your review and approval in accordance with the memorandum of understanding are (1) copie(s) of the report entitled:

Wheel Rail Forces Measured under Severe Track Geometry Alignment Variations

☐ Document approved for publication without recommendations.

☐ Document approved for publication with the enclosed recommendations.

☐ Document not approved for publication. See enclosed remarks.

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Wheel Rail Forces Measured Under Severe Track Geometry Alignment Variations, 1984, M. Coltman, H. Lee, H. Weinstock, US DOT, FRA, 01-Track & Structures