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The Effects of Rail Profile Variation

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RPI Railway Progress Institute

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16. Abstract

Railroads in various countries including the United States have found that benefits may be obtained by grinding rails to an "asymmetric" profile rather than to the original "new" rail profile. To investigate these findings further, the Federal Railroad Administration (FRA) and the Association of American Railroads (AAR) sponsored and conducted a Rail Profile Variation test at the Transportation Test Center (TTC) in Pueblo, Colorado.

The first objective of the test was to select, from among four prospective designs, the one specific rail profile with the best computer-predicted performance after mating that profile with a modified Heumann wheel profile. The selected profile then served as the design base for tests of three specially ground rail profile designs and an unground control rail (standard 136-lb RE). The four profile designs were then tested, in track, by designating one zone for the unground control rail and grinding three other zones to the specifications of the profile designs. Five separate curves in the TTC track layout, of 1.5, 3.0, 4.0, 5.0, and 7.5-deg of curvature, were prepared with the four-zone test segments. In-track testing was conducted with a "mini-consist" of locomotive, two buffer hopper cars, a loaded hopper car with instrumented wheelset, and an instrumentation car.

Results showed that profile grinding can effectively reduce lateral and longitudinal forces and decrease the rate of rail wear on unlubricated track. Severe grinding proved more practical for curves of less than 4 deg, while moderate grinding proved effective for curves of more than 4 deg.

During the 20-MGT test, the ground rails did not suffer from rail corrugations. After 20 MGT, when all rails had acquired a normal "worn" profile, some corrugation development was noted.

Static long-term wear measurements, using profilometer, snap gauge, and Brinell and Shore hardness testers, were taken during the test.

Based on total head-area loss for the 4-deg curve, these measurements showed lower wear rates for both the inside and outside ground rails than for the unground control rail. Head-height-loss wear rates were essentially the same for all profiles tested, with inside rails wearing more than outside rails. Hardness of the field side of the inside rail head increased slightly because of the profile grinding. Some metal flow occurred on the field side of the inside rail head for the ground profiles and on the gauge-face side of the unground control rail.

Recommendations based on the results of this test include upgrading grinding equipment (for greater profile flexibility), rolling pre-profiled rails (including the use of wear-resistant metallurgies), and long-term testing in lubricated environments to obtain more comprehensive data on defect occurrences.

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RAIL PROFILE VARIATION EXPERIMENT

TABLE OF CONTENTS

	Page
Executive Summary	ix
1.0 Introduction	1
2.0 Background	1
3.0 Objective	2
4.0 Computer Modeling	2
5.0 Test Curve/Instrumentation Description	18
6.0 Curving Tests	21
7.0 Wear Tests	41
8.0 Conclusions	69
9.0 Recommendations	69
10.0 Acknowledgements	70
11.0 References	70

LIST OF FIGURES

Figure	Title	Page
1a	Design No. 1	3
1b	Design No. 2	3
1c	Design No. 3	3
1d	Design No. 4	3
2	Modified Heumann Wheel Profile	5
3	Math Model Lateral Wheel Forces - 1.5° Curve	6
4	Math Model Lateral Wheel Forces - 3.0° Curve	7
5	Math Model Lateral Wheel Forces - 4.0° Curve	8
6	Math Model Lateral Wheel Forces - 5.0° Curve	9
7	Math Model Lateral Wheel Forces - 7.5° Curve	10
8	Wheel/Rail Contact Position	11
9	General Experimental Test Profiles	12
10	NLC/BR Wheel Forces - 1.5° Curve	13
11	NLC/BR Wheel Forces - 3.0° Curve	14
12	NLC/BR Wheel Forces - 4.0° Curve	15
13	NLC/BR Wheel Forces - 5.0° Curve	16
14	NLC/BR Wheel Forces - 7.5° Curve	17
15	TTC Fairmont Grinder	19
16	Rail Contour Gauge	19
17	Rail Profile Experiment Test Tracks	20
18	Instrumented Wheelset	22
19	Measurement Location - 1.5° Curve	23
20a	Profile 1 - 1.5° Curve	24
20b	Profile 2 - 1.5° Curve	24
20c	Profile 3 - 1.5° Curve	24
20d	Profile 4 - 1.5° Curve	24
21	Lateral Wheel Forces - 1.5° Curve	25
22	Longitudinal Wheel Forces - 1.5° Curve	26
23	Measurement Location - 3.0° Curve	27
24a	Profile 1 - 3.0° Curve	28
24b	Profile 2 - 3.0° Curve	28
24c	Profile 3 - 3.0° Curve	28
24d	Profile 4 - 3.0° Curve	28
25	Lateral Wheel Forces - 3.0° Curve	30
26	Longitudinal Wheel Forces - 3.0° Curve	31
27	Measurement Location - 4.0° Curve	32
28a	Profile 1 - 4.0° Curve	33
28b	Profile 2 - 4.0° Curve	33
28c	Profile 3 - 4.0° Curve	33
28d	Profile 4 - 4.0° Curve	33
29	Lateral Wheel Forces - 4.0° Curve	34
30	Longitudinal Wheel Forces - 4.0° Curve	35
31	Measurement Location - 5.0° Curve	36
32a	Profile 1 - 5.0° Curve	37
32b	Profile 2 - 5.0° Curve	37
32c	Profile 3 - 5.0° Curve	37
32d	Profile 4 - 5.0° Curve	37

LIST OF FIGURES (CONTINUED)

Figure	Title	Page
33	Lateral Wheel Forces - 5.0° Curve	38
34	Longitudinal Wheel Forces - 5.0° Curve	39
35	Measurement Location - 7.5° Curve	40
36a	Profile 1 - 7.5° Curve	42
36b	Profile 2 - 7.5° Curve	42
36c	Profile 3 - 7.5° Curve	42
36d	Profile 4 - 7.5° Curve	42
37	Lateral Wheel Forces - 7.5° Curve	43
38	Longitudinal Wheel Forces - 7.5° Curve	44
39	Summary of Lateral Forces	45
40	Summary of Longitudinal Forces	46
41	Yoshida Rail Profilometer	48
42	Brinell Hardness Tester	49
43	Shore Hardness Tester	50
44	Snap Gauge - Head Height Loss	51
45	Snap Gauge - Gage Face Wear	52
46	Snap Gauge - Metal Flow	53
47a	Rail Profile - 4.0° - Profile 1	55
47b	Rail Profile - 4.0° - Profile 2	55
47c	Rail Profile - 4.0° - Profile 3	55
47d	Rail Profile - 4.0° - Control Rail	55
48	Rail Head Area Loss - 4.0° - 2-10 MGT	56
49	Rail Head Area Loss - 4.0° - 2-20 MGT	57
50	Outside Rail Gage Face Wear - 12 MGT	58
51	Outside Rail Gage Face Wear - 20 MGT	59
52	Head Height Loss - 12 MGT	60
53	Head Height Loss - 20 MGT	61
54	Outside Rail Hardness (Rail Head Centerline)	62
55	Inside Rail Hardness (Rail Head Centerline)	63
56	Outside Rail Hardness (Rail Head Gage Side)	64
57	Inside Rail Hardness (Rail Head Field Side)	65
58	Instrumented Wheelset Data - 4.0° - 0 MGT	66
59	Instrumented Wheelset Data - 4.0° - 10 MGT	67
60	Instrumented Wheelset Data - 4.0° - 20 MGT	68

EXECUTIVE SUMMARY

The philosophy of rail grinding to maintain desired rail profiles has evolved from the long-standing practice of restoring original profiles to a newer approach based on advanced understanding of wheel-rail dynamics. In various countries including the United States, railroads have been experimenting with "assymetric" profiles that provide an off-center contact area on the railhead to effect a more desirable wheel-rail interaction. As a result of this continuing exploration of various rail-grinding possibilities, beneficial and very promising results have been obtained.

In conjunction with the above efforts, a Rail Profile Variation experiment was conducted. This three-phase experiment was conducted from June, 1984, through April, 1985, by the Association of American Railroads (AAR) at the Transportation Test Center (TTC) in Pueblo, Colorado, as a part of the Facility for Accelerated Service Testing (FAST) program, which is sponsored jointly by the Federal Railroad Administration (FRA), the AAR, and the Railway Progress Institute (RPI).

The experiment included (1) evaluation of four prospective rail profile designs, from which one was selected as having the best predicted performance for the tests to be conducted, (2) on-track testing of four distinct rail profiles (three specially ground and one not ground) for comparison of instrumented wheelset performance data with computer-predicted results, and (3) assessment of the track-tested profiles in terms of long-term wear under conditions of heavy tonnage and dry (unlubricated) running.

Four prospective rail profile patterns, based on (and including) a standard AREA 136-lb RE rail profile, were input to a computer program (steady-state curving model). These rail patterns were combined with (modified Heumann) wheel profile data from the instrumented truck that was to be used for the on-track testing. A computer was used to predict the rail forces to be encountered by each of the four rail profile designs when mated with the modified Heumann wheel profile. On this basis, a final rail profile design was selected which promised the best reduction of wheel-rail force.

The features of the design chosen included a heavy grind pattern on the field side of the high rail head and a heavy grind on the gauge side of the low rail head, which produces a difference in rolling radius between the two wheels sufficient to cause the axle to steer to a position that reduces the angle of attack. Three of the tested profiles (including the unground 136-pound RE control profile) resembled this general profile closely, varying only with depth of grind. The other profile tested was distinguished by additional grinding on the field and gauge face of each rail.

On-track testing of the four profiles was accomplished on curves of 1.5, 3.0, 4.0, 5.0, and 7.5-deg of curvature, each having four zones (one zone for each of the four profiles, including the unground control rail). A mini-consist containing locomotive power, two buffer hopper cars, a loaded hopper car with instrumented wheelset, and an instrumentation car, was run through test zones in each curved section at speeds representing underbalance, balance and overbalance curving conditions.

Data provided by the instrumented wheelset show that the ground profiles produced lower longitudinal and lateral forces at particular speeds and curvatures than were measured in the unground control zones. A profile (No. 2) having roughly equal grinding on the field side of the outside railhead and the gauge side of the inside railhead provided the over-all reduction of lateral wheel forces for curves greater than 4-deg. One profile (No. 3), with additional field and gauge-face grinding, performed better than did profile No. 2 for curves of less than 4 deg. curvature.

Long-term wear evaluation was accomplished by static measurements taken with rail profilometers, hardness testers, and snap gauges. Measurements were taken during 20 MGT of dry (unlubricated) running.

The 20-MGT profilometer results from the 4.0-deg curve show (based on total railhead area loss) that the wear rate for both the inside and outside rails was less for the ground profiles than for the unground control profile. Between 10 and 20 MGT, the rails had worn to a common profile, the outside rails showing comparatively more total area loss than the inside rails.

Brinell hardness tests for the centerline of the railhead and Shore tests for the field and gauge sides of the railhead revealed that the hardness on the field side of the head (inside rail) on the ground profiles increased slightly until all the profiles had reverted to the normal worn profile. Other hardness measurements, though they varied slightly during break-in of the (new) standard rail in this curve, remained consistent during the entire 20 MGT covered by the test.

Results of the Rail Profile Variation experiment showed that selected rail profile grinding can reduce lateral wheel-rail forces in unlubricated curves of 1.5, 3.0, 4.0, 5.0 and 7.5 deg and that truck lead axle longitudinal forces can also be reduced, though to a lesser extent, in curves of moderate degree. Severe grinding (profile No. 3) offered better performance with curvatures below 4.0 deg, while lesser grinding (profile No. 2) had better performance with curvatures above 4.0 deg.

None of the profile test zones experienced corrugations during the 20-MGT period. It was not until after the 20-MGT test period (when all the rails had attained a worn rail profile) that any corrugation was noted on the low rail in the 4.0-deg curve.

Based on total railhead area loss, profile grinding reduced wear of the inside rail slightly in the 4.0-deg curve. Likewise, gauge-face wear on the outside rail of this curve was also reduced. Hardness of the field side of the inside railhead increased slightly because of the profile grinding.

Some metal flow was evident on the field side of the inside railhead for the profile grinds, and the unground control railhead showed evidence of metal flow on its gauge-face side.

RAIL PROFILE VARIATION EXPERIMENT

1.0 INTRODUCTION

The symmetrical grinding of rail to correct surface defects and irregularities has been a practice on railroads for many years. In recent years the process of grinding rails to change the contour or profile of the rail head has become very popular in the belief that it would retard the development of surface defects and that the wear characteristics could be changed to increase the serviceable life of the rails. In early practice the grinding was directed toward reestablishing the original shape of the rail head after severe service wear. The recent asymmetrical grinding approach, especially with high wheel loading, is to grind the rail head to obtain optimum wheel/rail contact and reduce local high stress conditions that contribute to defect and rail wear. A new rail profile is symmetrically designed to provide wheel contact near the centerline of the rail head. An asymmetrical profile is designed to position the wheel contact patch either side of the rail centerline as desired.

The Rail Profile Variation Experiment at the Transportation Test Center (TTC) in Pueblo, Colorado, was sponsored by the Federal Railroad Administration (FRA) as a part of the ongoing Facility for Accelerated Service Testing (FAST) Program. This experiment, Wheel/Rail Profile Variation, is documented in this report and is also combined with documentation of two other experiments, Wheel/Rail Wear Index and Truck Tolerance, in Ref. (1).

The Rail Profile Variation experiment was conducted in three phases; 1) determination of test profiles utilizing computer modeling techniques to predict the non-linear curving characteristics of specific mathematically designed rail profiles; 2) testing of profiles in curves from 1.5° to 7.5° of curvature to provide comparison with computer modeling predictions and actual dynamic performance parameters measured by an instrumented wheelset; and 3) long term rail wear evaluation of the ground profiles using long, heavy train traffic for approximately 20 million gross tons (MGT) of dry rail running.

2.0 BACKGROUND

Over the past few years, encouraging results have been reported by several railroads, in the United States, Canada, and Australia, who have tried asymetrical profile rail grinding.

<u>Australia</u>. The Mount Newman Mining Railway reduced its rail corrugation problems with selected profile grinding. The Hamersley Iron Railway has improved the gage face wear rate of its rail in curves with profile grinding.

<u>Canada</u>. The Canadian National and the Canadian Pacific Railroads have reported successful rail profile grinding programs.

<u>United States</u>. Several U.S. railroads, as well as the Association of American Railroads at the TTC, have been working with rail profile grinding.

3.0 OBJECTIVE

The objective of this experiment was to design, utilizing computer modeling techniques, rail profiles that would reduce wheel/rail forces in curves and reduce rail wear.

4.0 COMPUTER MODELING

Through the years, considerable work has been done in developing a mathematical curving theory for railway vehicles to predict the forces on each wheel resulting from a truck negotiating a curve. A computer program based upon a study in 1977 by Elkins and Gostling "A General Quasi-Static Curving Theory for Railway Vehicles", Ref. (2), has been developed at the Transportation Test Center, and is implemented on the VAX 11/780 site computer. This program, including improvements to the theory described in Ref. (3), was used in evaluating mathematically-derived rail profiles and, later, was used to evaluate data from actual profiles ground into test rails. The version of the computer program compiled on September 9, 1983, was used for this experiment.

4.1 RAIL PROFILE DESIGN

Several potential rail profiles were initially constructed mathematically, starting with a standard 136#/yd rail profile. Each rail profile was mated with a modified Heumann wheel profile. The actual wheel profile for the instrumented wheelset was used to allow direct comparison with the dynamic data to be collected later. The math model rail profiles are as follows:

4.1.1 Rail Design No. 1

This design used AREA Standard dimensions for a 136 RE rail profile. This profile is presented in Figure 1a.

4.1.2 Rail Design No. 2

This profile provides grinding of both the field and gage side of the rail head to insure a wide load bearing pattern mainly over the web portion of the rail, resulting in less stress and less rollover. Both the high and low rails use similar profiles. The profile is presented in Figure 1b.

4.1.3 Rail Design No. 3

This profile is designed for asymmetrical grinding with different profiles for both the high and low rail. The high rail provides a ground profile on the top and gage corner of the rail head. The low rail provides a ground profile on both the gage and field corners of the rail. This profile is presented as Figure 1c.

4.1.4 Rail Design No. 4

Asymmetrical grinding is used for this rail profile, with slightly different profiles for the low and high rail. In general, the grinding is done on the gage top and corner of the low rail and the field top and corner of the high rail. This profile is presented as Figure 1d.

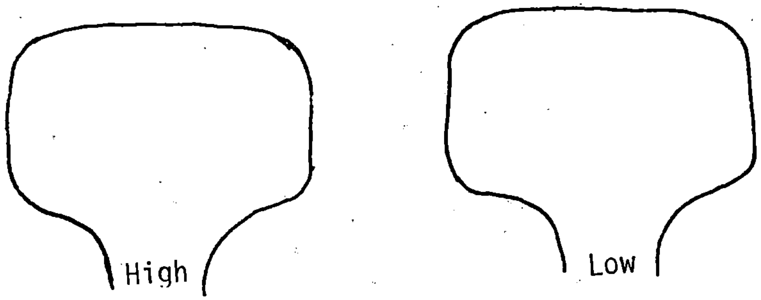


FIGURE 1a. DESIGN NO. 1.

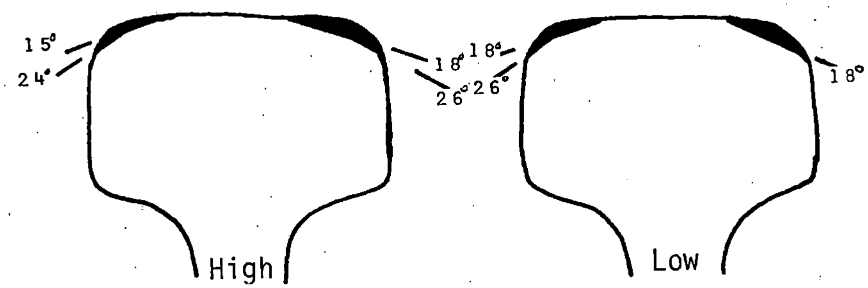


FIGURE 1b. DESIGN NO. 2.

<u>Rail Design Profiles</u>
<u>136# RE Rail</u>

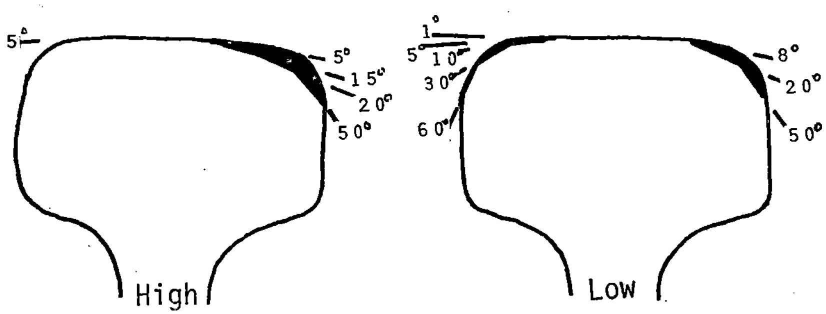


FIGURE 1c. DESIGN NO. 3.

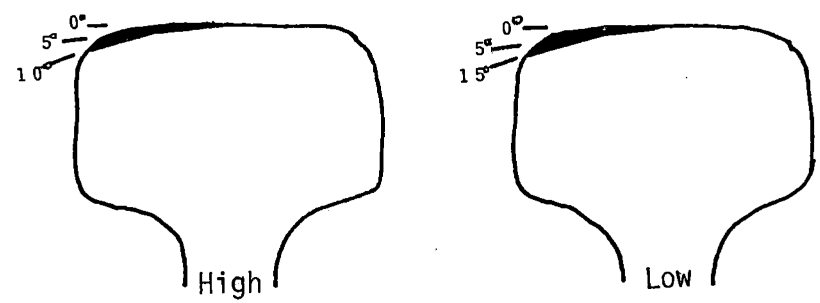


FIGURE 1d. DESIGN NO. 4.

4.1.5 Model Results

Each of the theoretical math rail profiles was mated to a measured wheel profile of the instrumented wheelset. This profile is a Canadian National modified Heumann design. The wheel profile is shown in Figure 2.

The curving model computer program required input data on the degree of curvature, cant deficiency (to simulate various speeds), wheel/rail geometry, and truck parameters. The input parameters used for the computer modeling are presented in Appendix A.

Lateral Wheel Forces. For the 1.5° to 7.5° curves tested, the theoretical computed wheel forces for the left wheel of the leading axle (the wheel in contact with the high rail in a clockwise curve negotiation) were almost always less for rail design No. 4 than for the other profiles tested. A positive lateral force for this wheel is toward the outside of the curve, with tendency to give flange contact. Rail profile No. 4 was chosen as a basic design for grinding the test rails. The lateral wheel forces for the computer designs are presented in Figures 3 through 7.

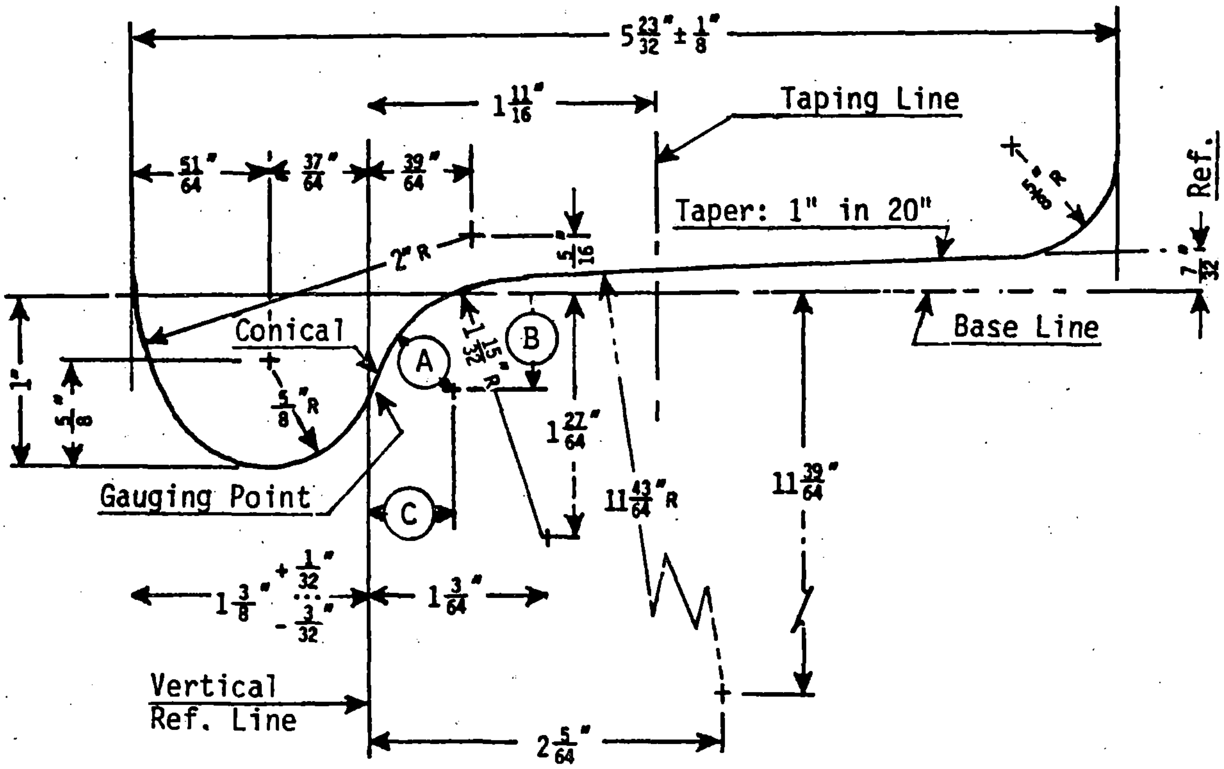
4.2 GROUND RAIL PROFILES

A general rail profile to be ground into the test rails was established from the low and high rail model results discussed in Section 4.1. This general rail profile, based upon computer Rail Design No. 4, uses asymmetrical grinding techniques; i.e., it provides an off-center wheel contact area on the rail head. The high rail in the curves has a heavy grind pattern on the field side of the rail head, which moves the wheel contact area to the gage side of the rail head. The low rail has a heavy grind pattern on the gage side of the rail head, which moves the wheel contact area to the field side. The pattern on the high rail contacts in the flange root, on a relatively large rolling radius of the wheel. The pattern on the low rail contacts towards the outer edge of the tread, on a relatively smaller rolling radius. This provides an increased rolling radius differential between the two wheels and provides improved curving characteristics for the axle, which tends to steer to a position that reduces the angle of attack and the tendency to flange on the high rail. The wheel/rail contact positions for a typical ground profile are shown in Figure 8.

The general profiles to be ground into each test curve rail, including a standard unground 136# RE control profile, are presented as Figure 9. With the exception of Profile 3, which has grinding on the field and gage corners of each rail, the ground profiles based upon rail design No. 4 are similar to each other, with more or less depth of grind. Four zones were established in each test curve. Each curve had three ground profiles, plus the unground control zone. The actual ground profiles in each curve were mated with the instrumented wheelset wheel profile (Figure 2) in the model to predict wheel/rail geometry characteristics. A rail profilometer developed by British Rail was used to obtain profile data from the rails. The computer-predicted wheel/rail forces for the various ground profiles, are presented in Figures 10 through 14. The negative lateral force indicates that the outside rail wheel is not likely to be in flange contact.

JOINT CANADIAN NATIONAL - CANADIAN PACIFIC
HEUMANN WHEEL TREAD AND FLANGE CONTOUR *

	A	B	C
Standard Heumann	7/16" R	9/16"	31/64"
Modified Heumann	11/16" R	47/64"	11/16"



* Source: G.M. McGee, "Survey of Railroad Rail and Wheel Contour Studies," Paper No. 82-HH-57; Proceedings: 2nd International Heavy Haul Conference, Colorado Springs, Colorado, Sept. 1982.

FIGURE 2. MODIFIED HEUMANN WHEEL PROFILE.

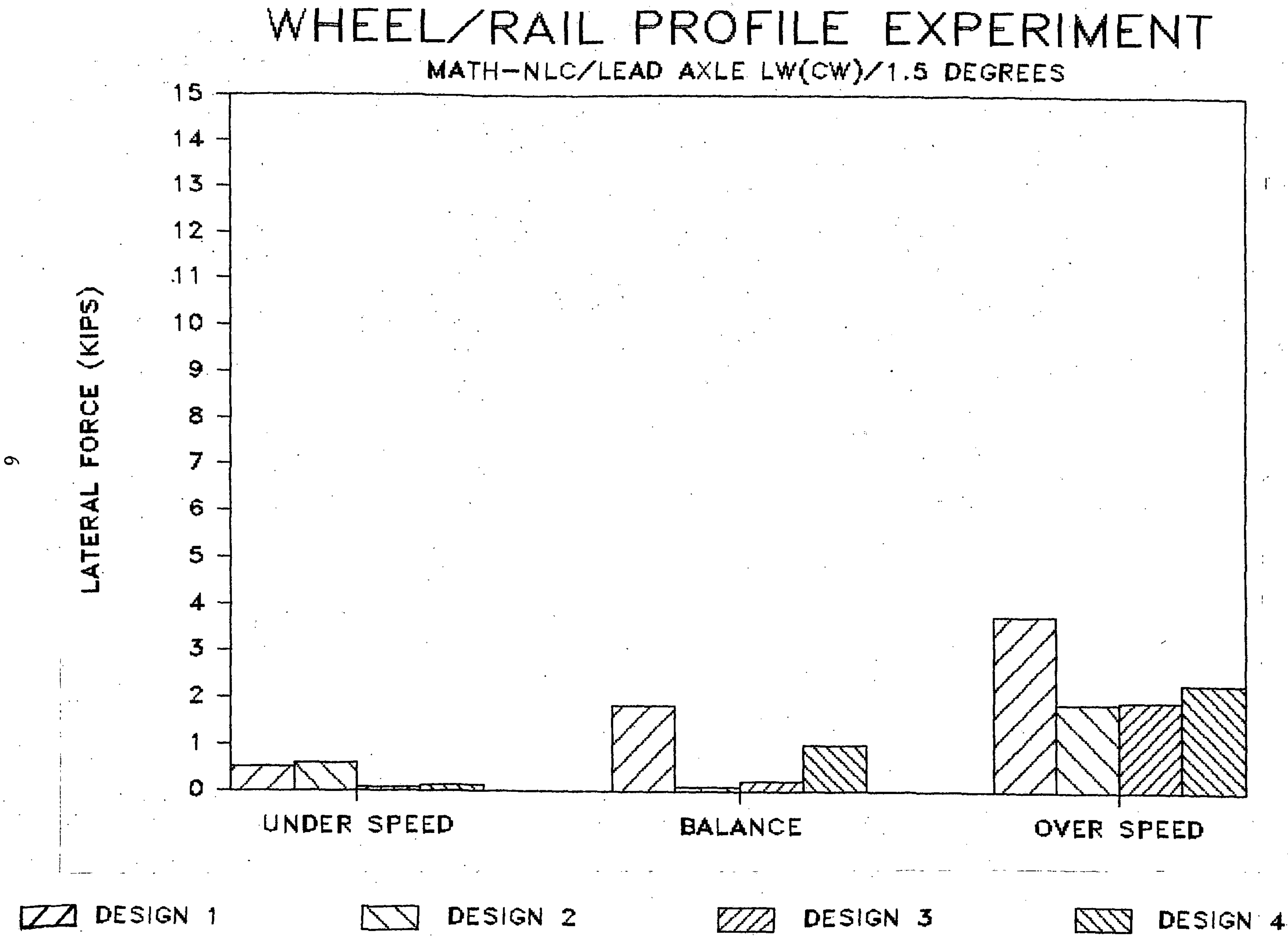


FIGURE 3. MATH MODEL, LATERAL WHEEL FORCES - 1.5° CURVE.

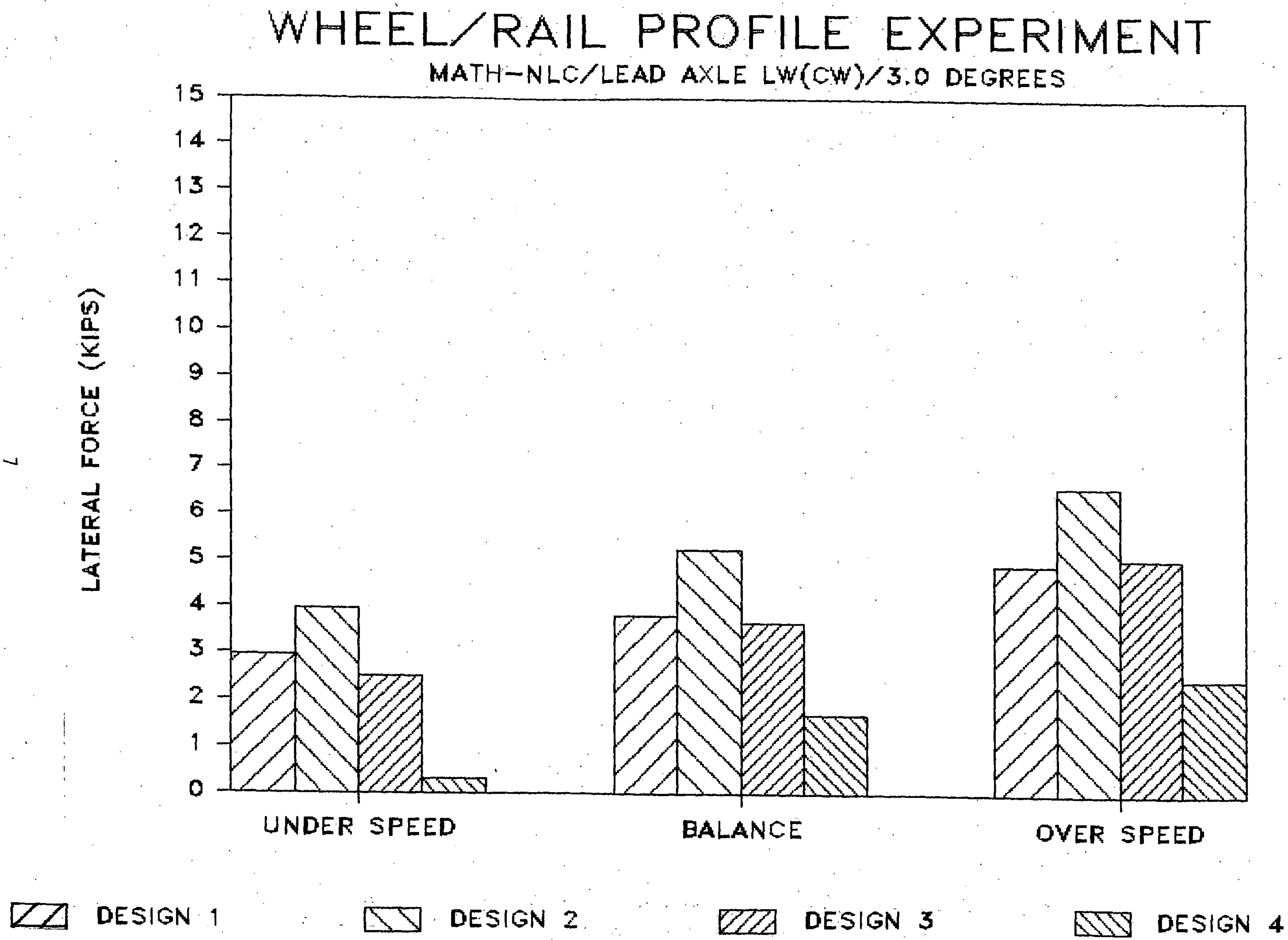


FIGURE 4. MATH MODEL, LATERAL WHEEL FORCES - 3.0° CURVE.

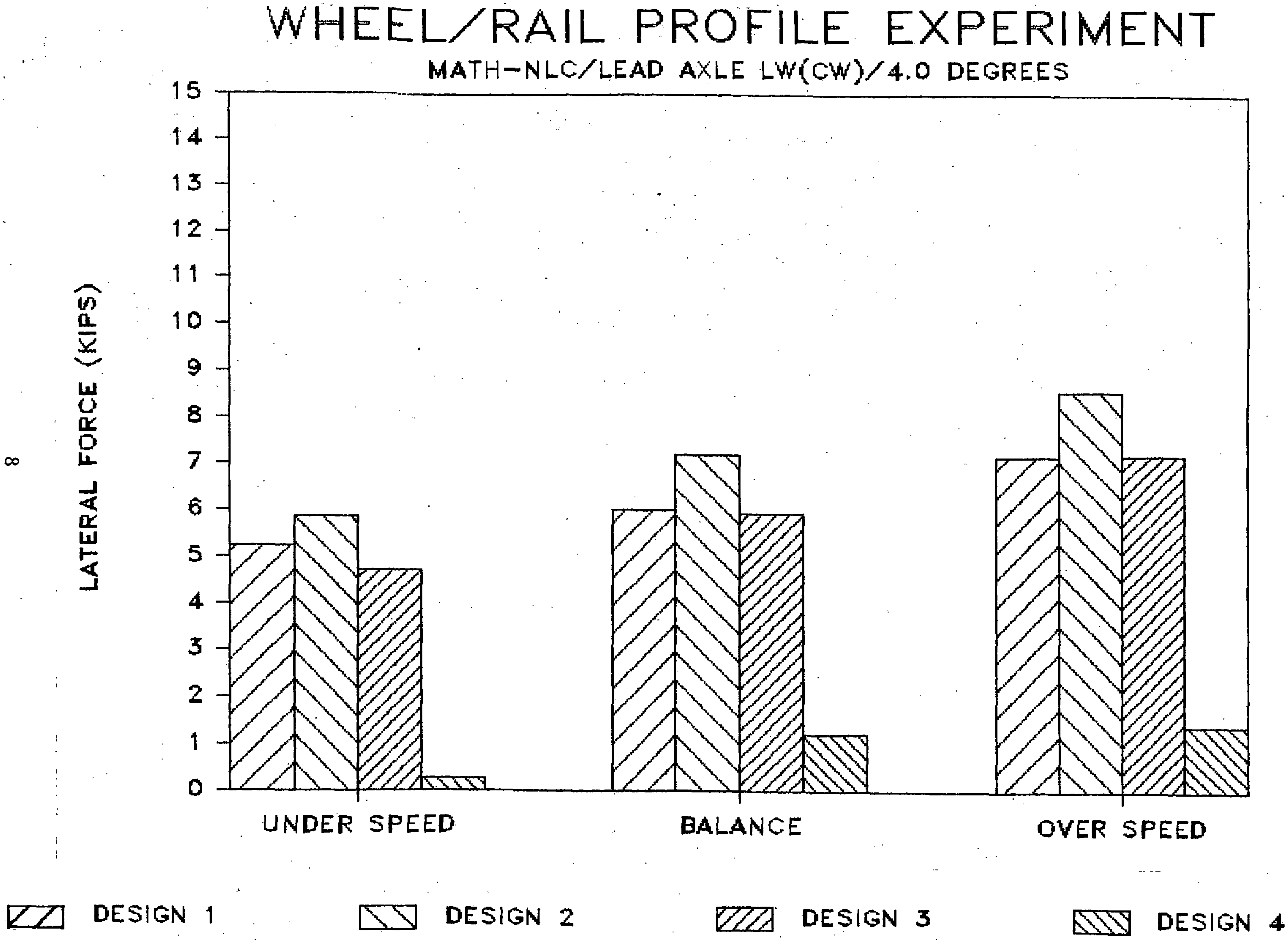


FIGURE 5. MATH MODEL, LATERAL WHEEL FORCES - 4.0°.

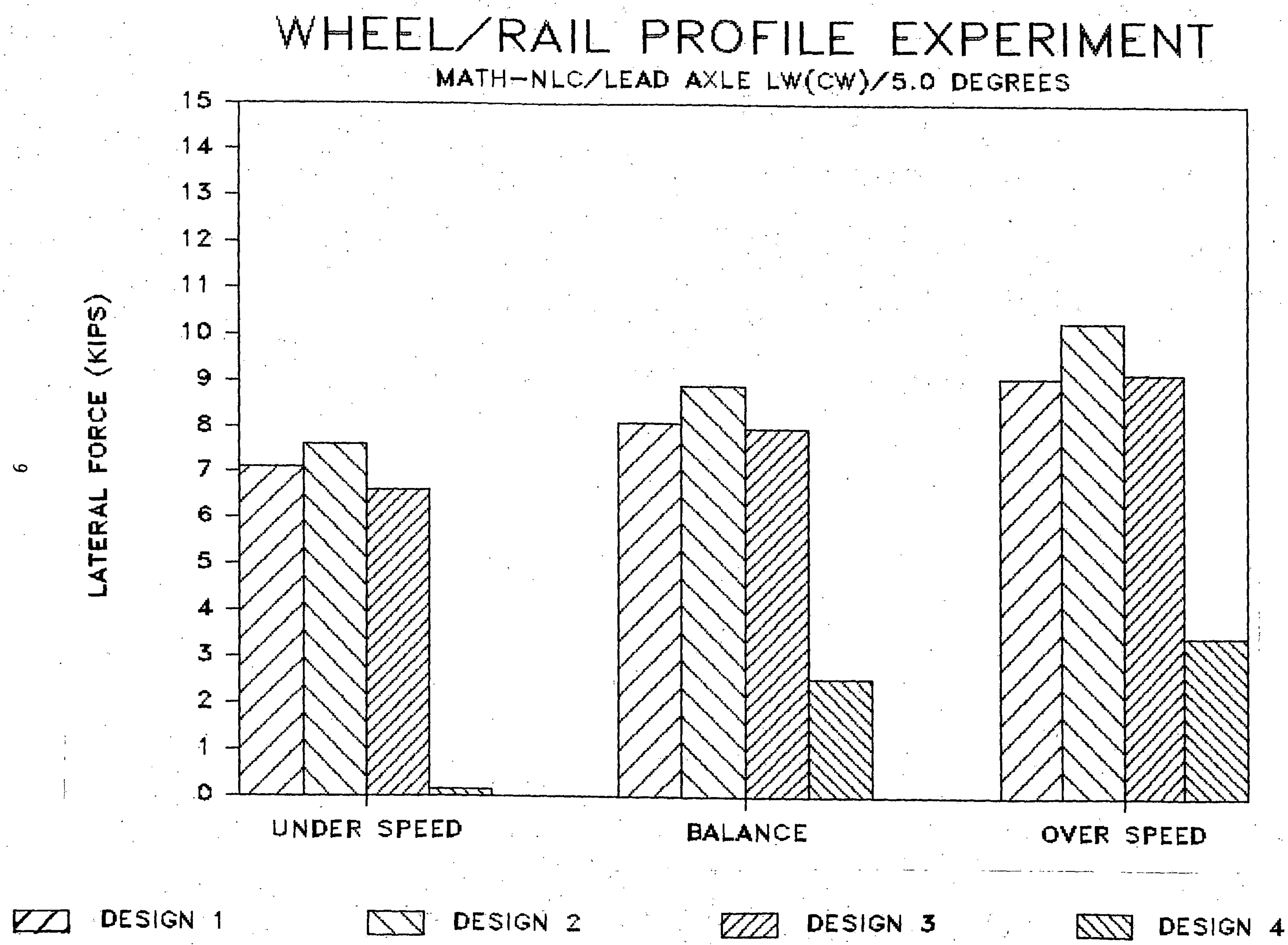


FIGURE 6. MATH MODEL, LATERAL WHEEL FORCES - 5.0°.

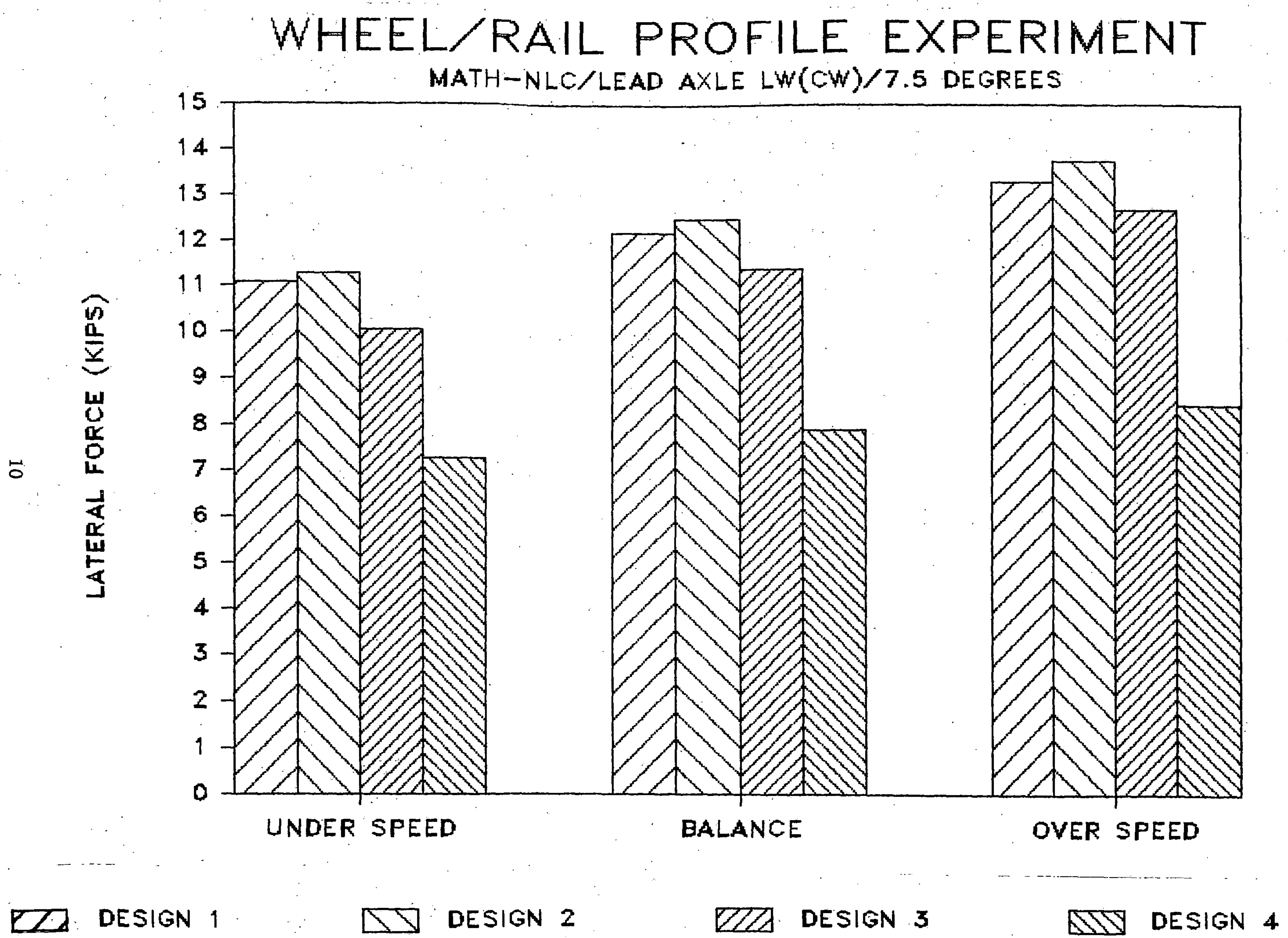


FIGURE 7. MATH MODEL, LATERAL WHEEL FORCES - 7.5°.

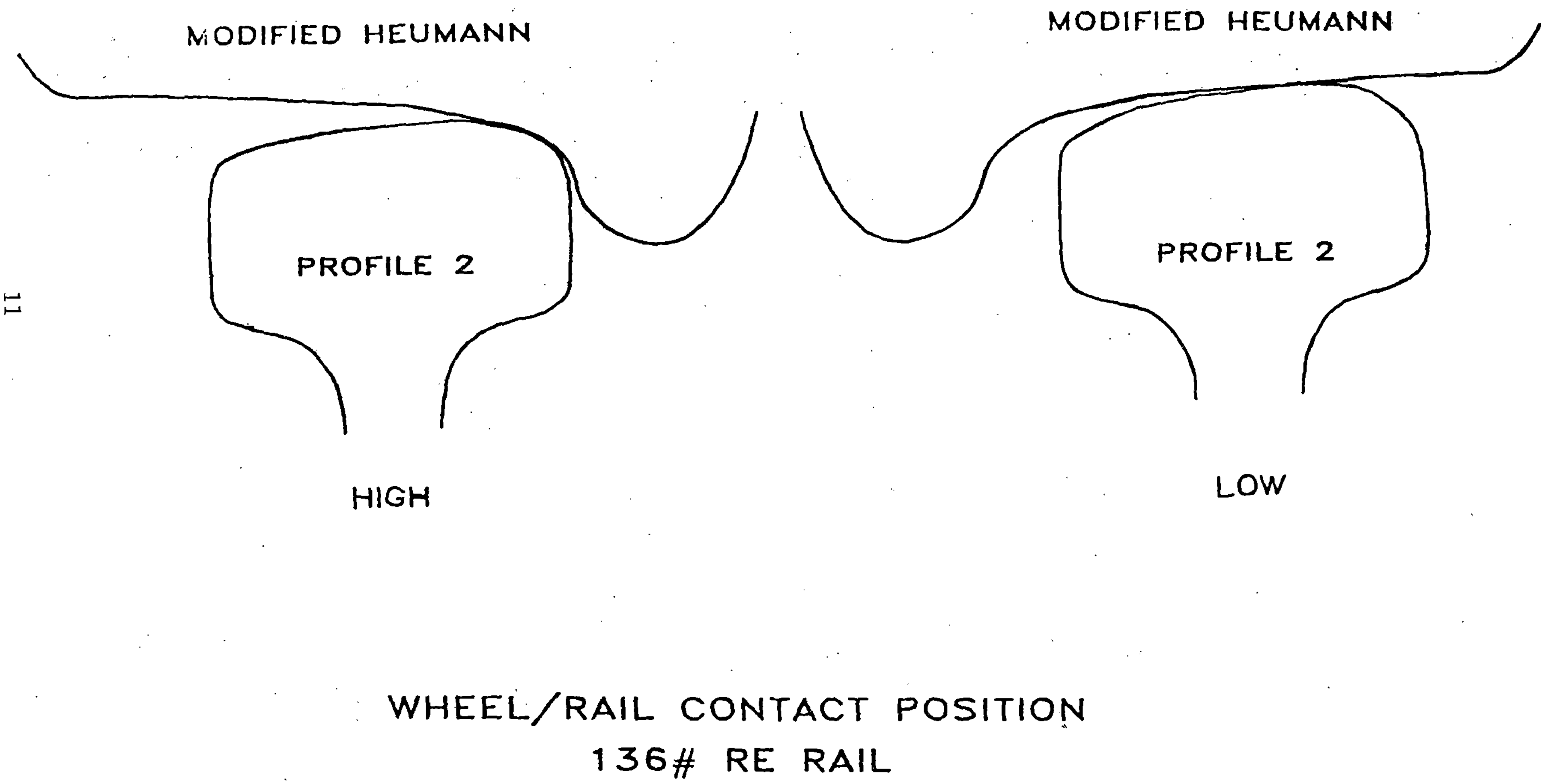


FIGURE 8. WHEEL/RAIL CONTACT POSITION.

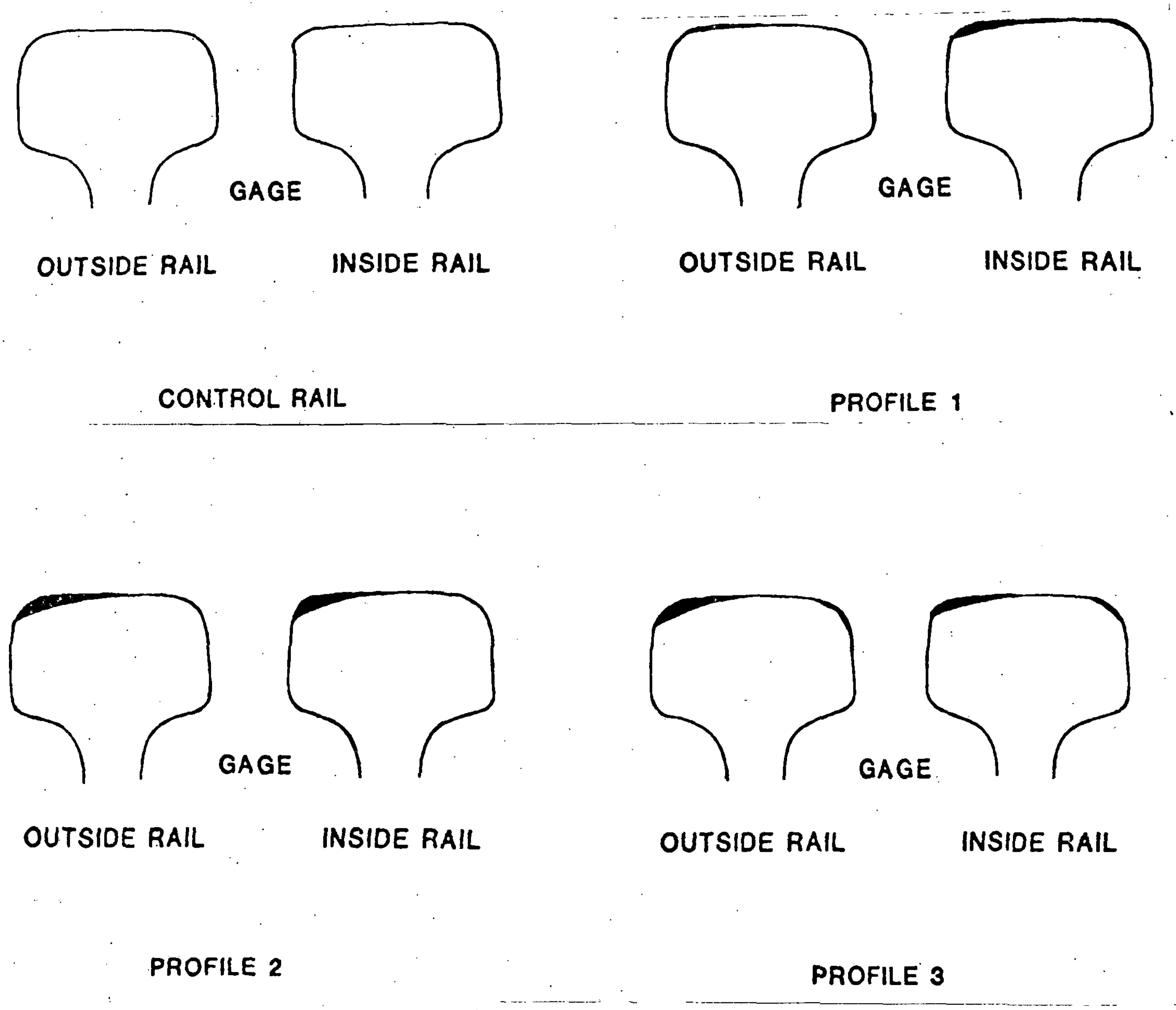


FIGURE 9. GENERAL EXPERIMENTAL TEST PROFILES.

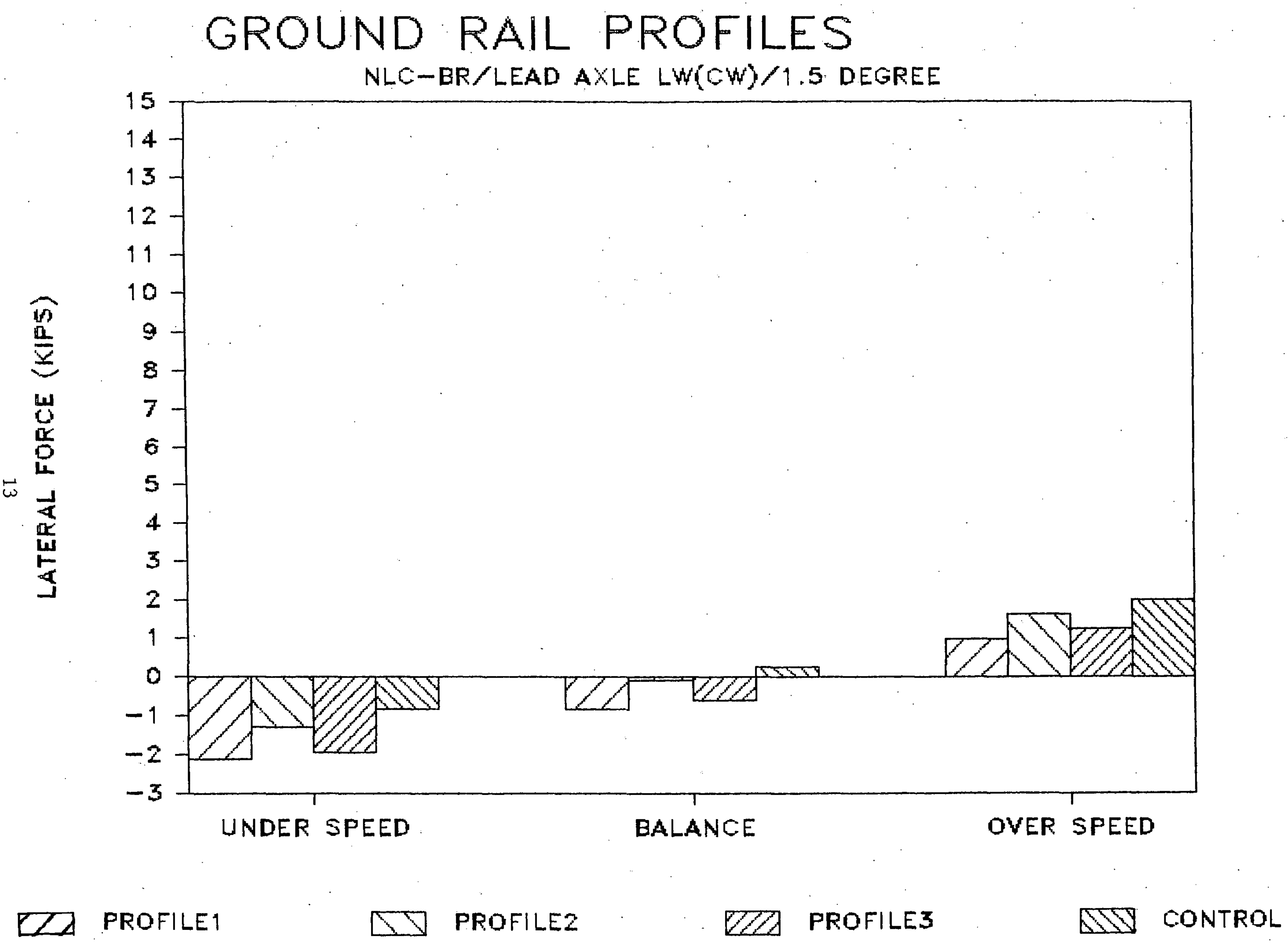


FIGURE 10. NLC/BR WHEEL FORCES - 1.5° CURVE.

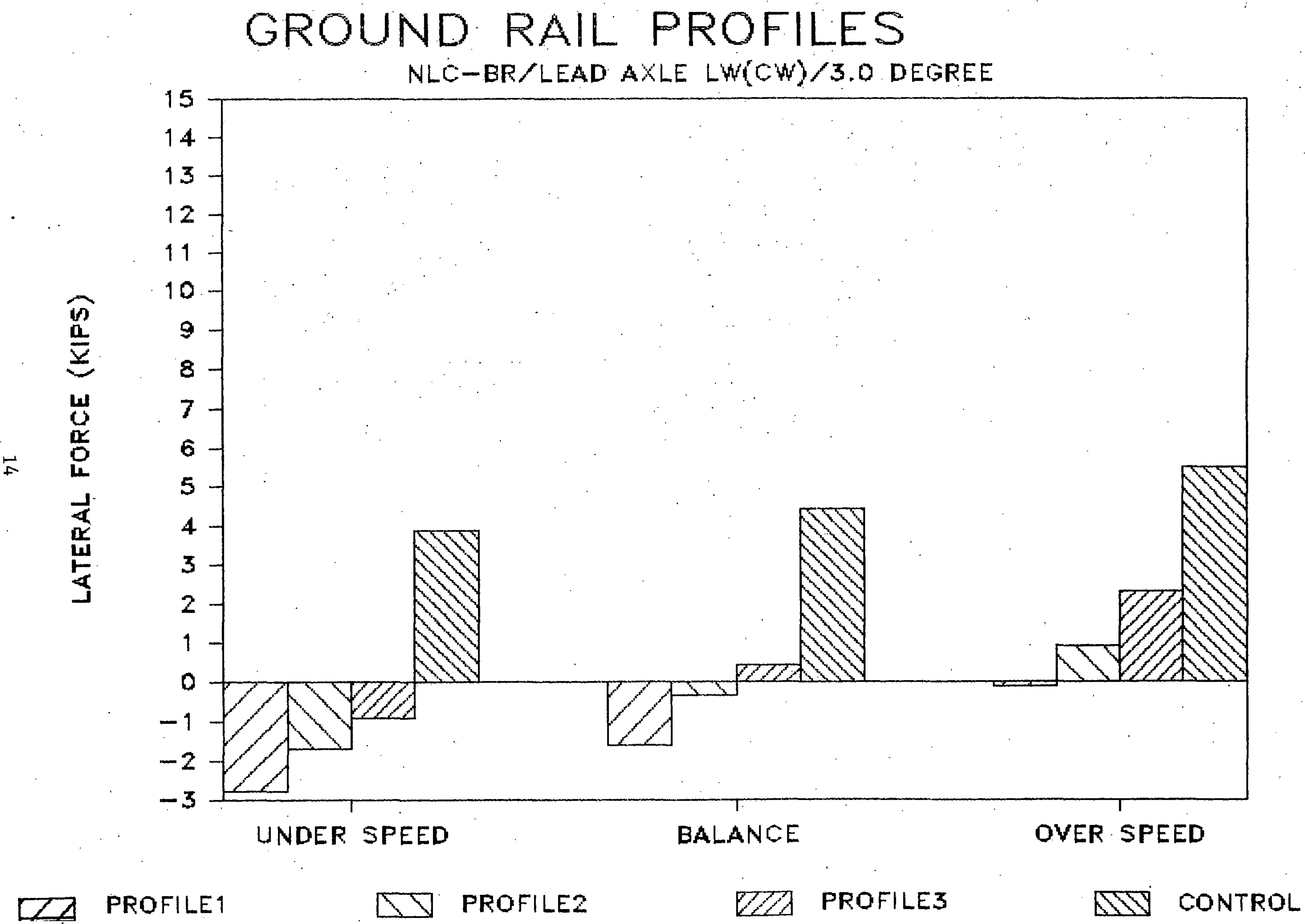


FIGURE 11. NLC/BR WHEEL FORCES - 3.0° CURVE.

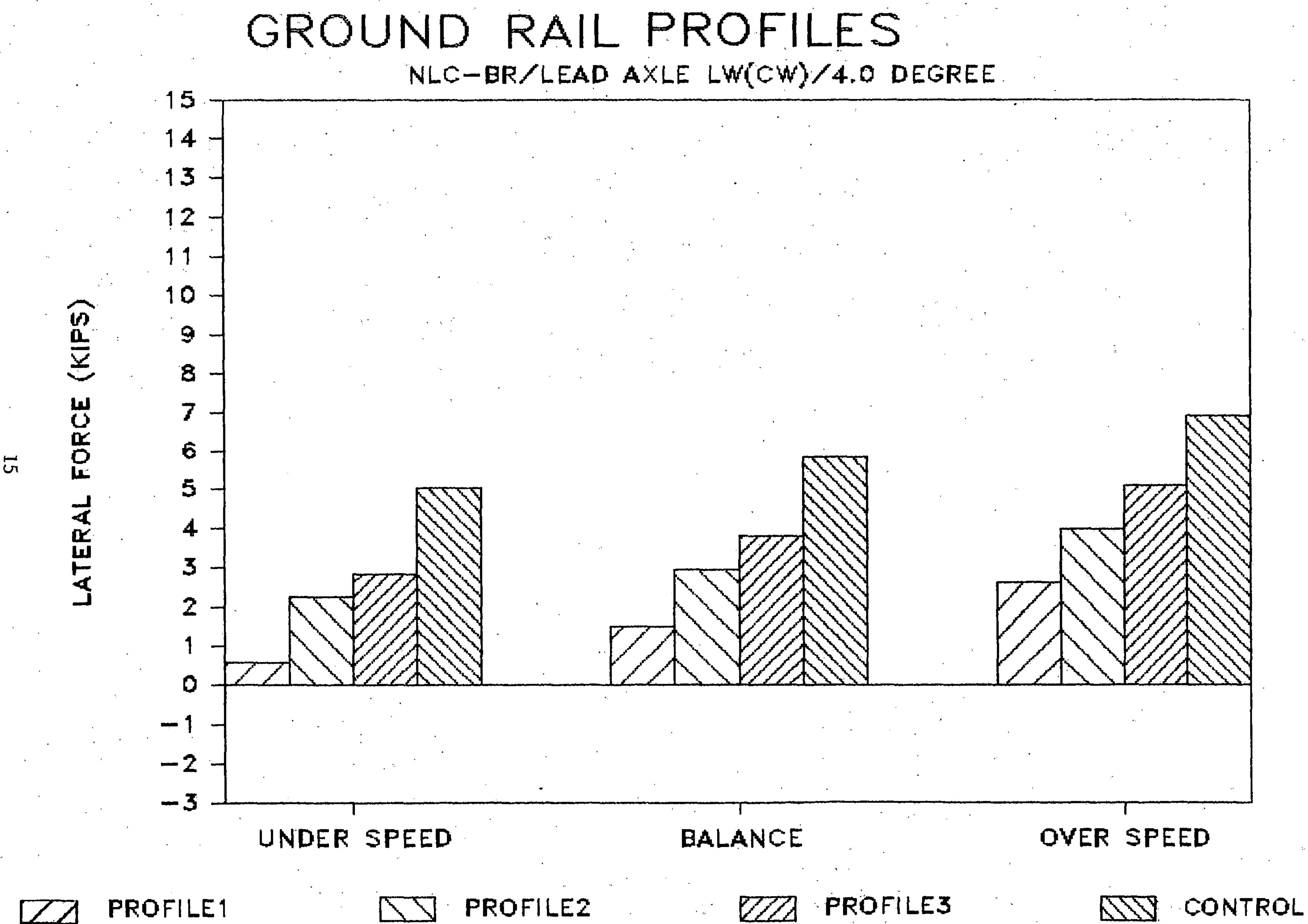


FIGURE 12. NLC/BR WHEEL FORCES - 4.0° CURVE.

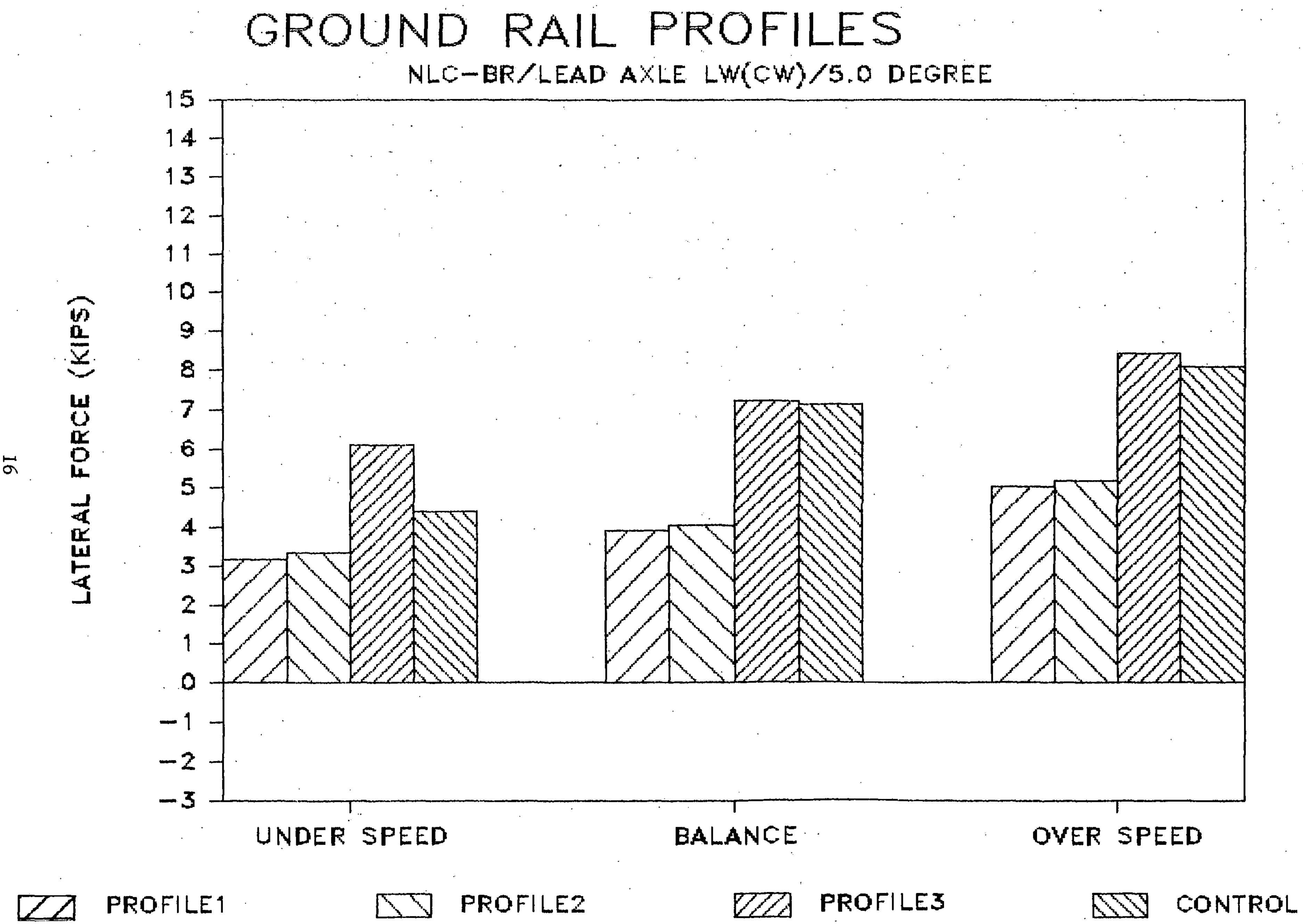


FIGURE 13. NLC/BR WHEEL FORCES - 5.0° CURVE.

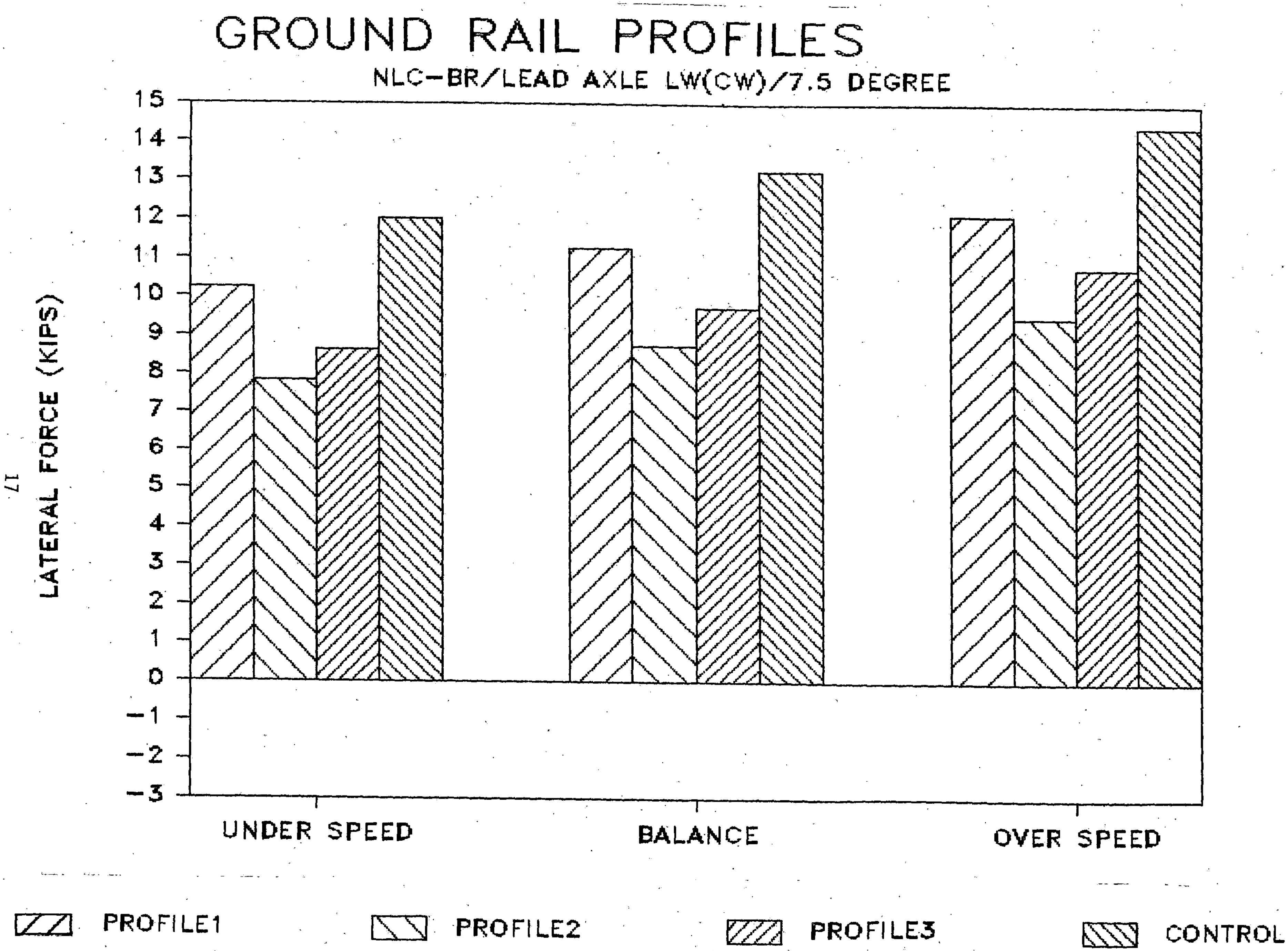


FIGURE 14. NLC/BR WHEEL FORCES - 7.5° CURVE.

4.3 RAIL GRINDING

The TTC Fairmount single-unit rail grinder, shown in Figure 15, was used to grind the test profiles. The unit has eight 15-hp grinding motors, four per rail, adjustable 25° either side of the vertical centerline of the motors. The normal tie plate cant thus governs the maximum degree of grind each rail can receive. In order to provide a smooth grind, each of the four grind motors on each rail were offset by 1° of each other around an average grind angle for each particular grinding pass.

Most of the rails had some degree of worn profile; therefore, the number of grinding passes varied to achieve the final desired rail profile. In order to determine the number of grinding passes required to establish the desired profile, a simple TTC-designed contour gauge--with a magnetic base to attach the gauge to the rail--was used to monitor the profiles. The contour gauge is shown in Figure 16.

5.0 TEST CURVES/INSTRUMENTATION DESCRIPTION

The test tracks on the TTC incorporate a number of track configurations. For this experiment, test sections were chosen which had 1.5°, 3.0°, 4.0°, 5.0° and 7.5° curvature to represent the range of curves encountered on most railroads in the U.S. The test curves are shown in Figure 17.

The instrumentation for acquisition of test data is in two categories: (1) Dynamic instrumented wheelset and (2) Static instrumentation for rail wear evaluation.

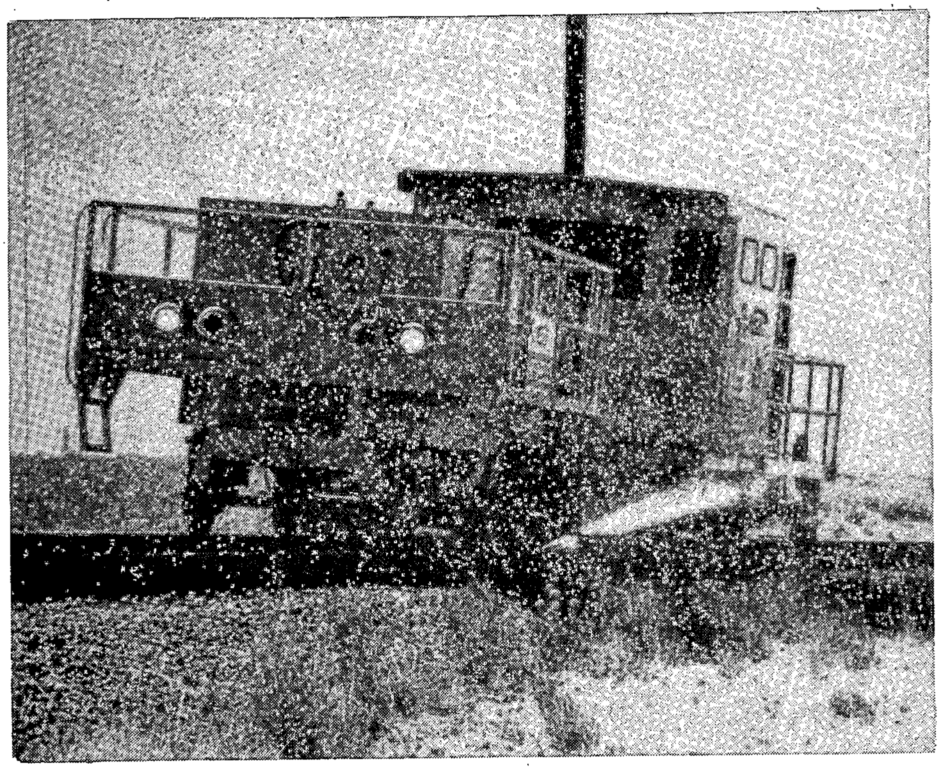
5.1 TEST CURVES DESCRIPTION

The philosophy of this experiment was to investigate, for various curves, the wheel/rail force characteristics due to selective asymmetrical profile grinding of the rail. The test curves were chosen to cover a range of curvature of 1.5° to 7.5°. Because of economic considerations, the test curves were not reconfigured prior to testing to represent each other identically as to rail and roadbed components. With the exception of the 4.0° curve, all of the rails were worn rail profiles. Therefore, the final ground rail profile varied to some degree. The high rails of the 3.0° and 5.0° curves were turned to provide a better head and gage face surface for grinding. The 5.0° curve also had wear resistant premium rail from various manufacturers from a previous metallurgy test.

Each test curve was configured with four zones. Zones 1 through 3 were ground to represent the general profiles 1 through 3 (see Figure 9). Zone 4 represented the unground control rail for each test curve.

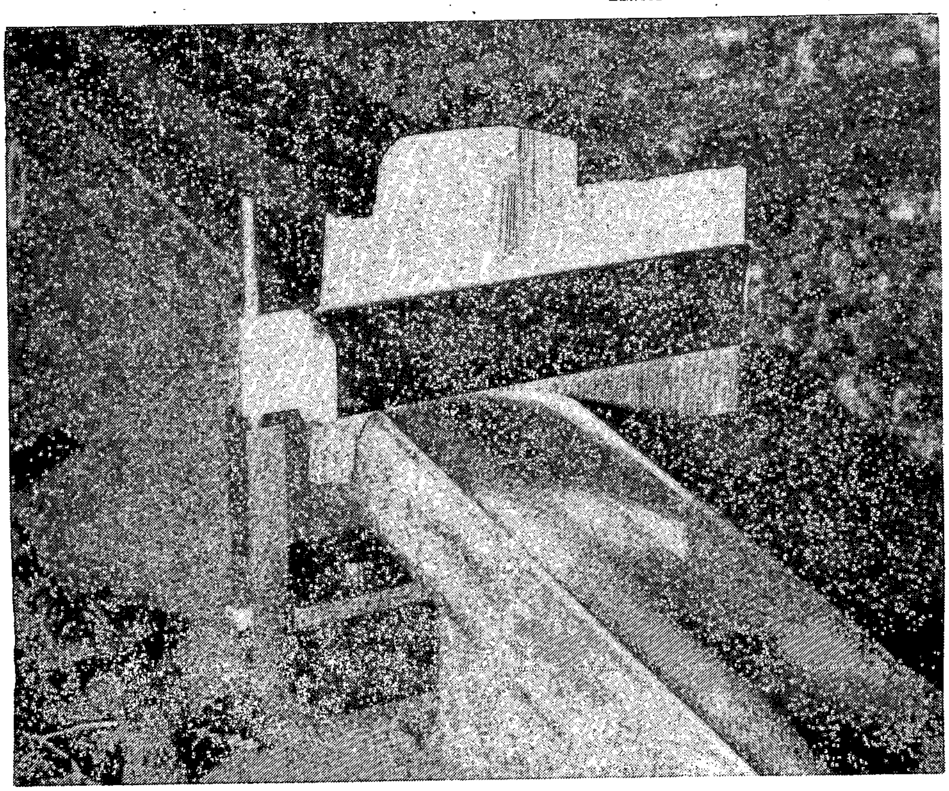
5.2 INSTRUMENTATION DESCRIPTION

The dynamic characteristics of the wheel/rail configurations were evaluated using instrumented wheelsets installed under a loaded 100-ton hopper car. The static rail wear measurements were recorded using hand-held profilometers and snap gages.



TTC N84-1123

FIGURE 15. TTC FAIRMOUNT GRINDER.



TTC N84-1794

FIGURE 16. RAIL CONTOUR GAUGE.

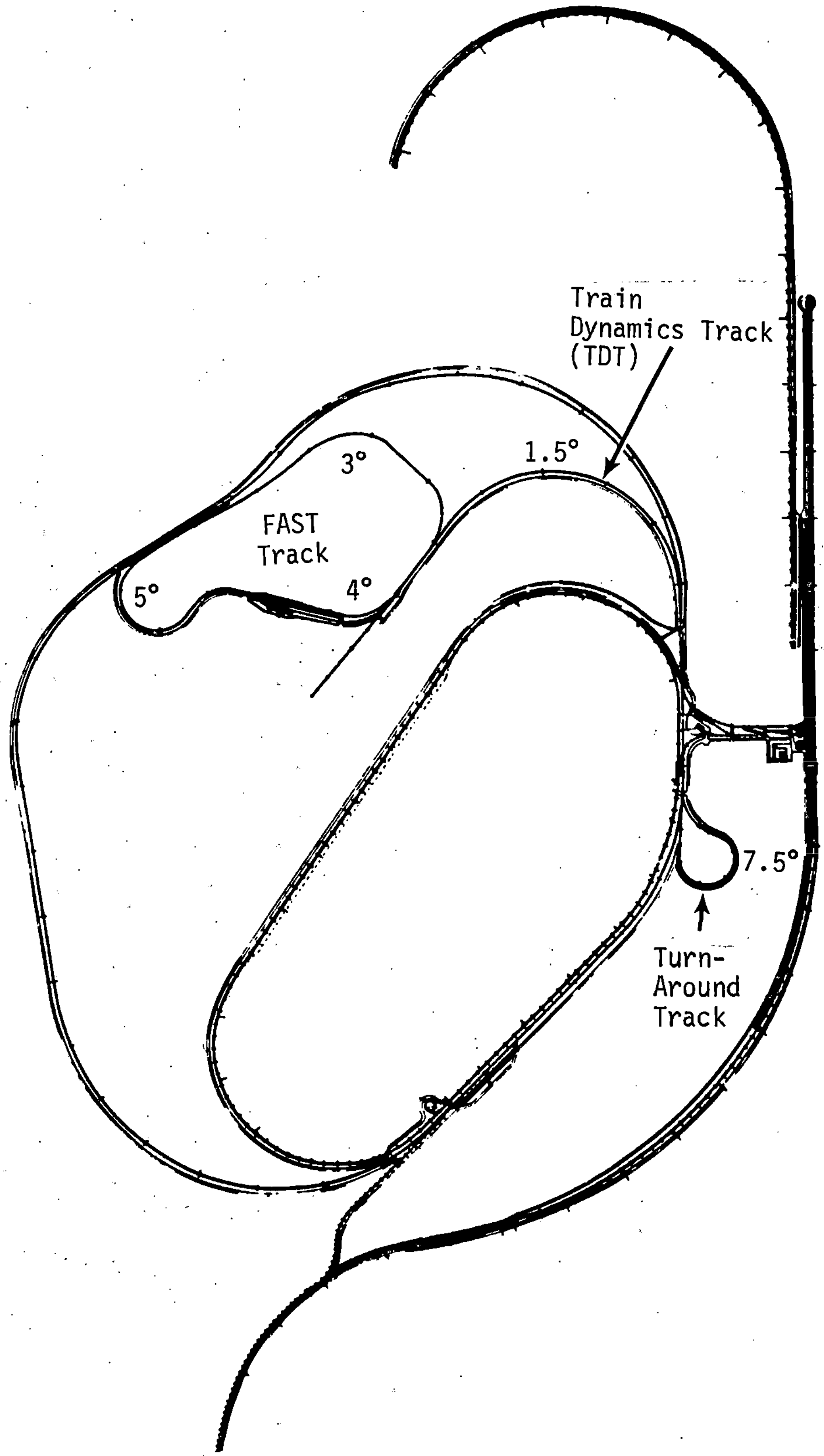


FIGURE 17. RAIL PROFILE EXPERIMENT TEST TRACKS.

5.2.1 Instrumented Wheelset

The two instrumented wheelsets used to measure wheel/rail forces were constructed for the AAR by IIT Research Institute (IITRI). The instrumented wheelset uses strain gauge bridges applied to the plates of the wheel for sensing both vertical and lateral loads. In addition, a third type of bridge is used to provide an indication of the position of line-of-action of the vertical load and the tread of the wheel. The wheelsets have also been instrumented so that axle torque can be measured. The axle torque measurement can be used to determine longitudinal forces at the wheel/rail interface. The wheelsets were installed under a standard three piece truck. Thirty-six inch diameter wrought steel wheels were installed with 6-1/2 x 12 inch journals. The wheel profiles were turned to a modified Heumann profile (refer to Figure 2).

The wheelset system requires a minimum of 30 volts excitation and a signal conditioning system that was mounted in the T-7 instrumentation car for these tests. A view of the instrumented wheelset is presented in Figure 18.

6.0 CURVING TESTS

Dynamic wheel forces were recorded for the 1.5°, 3.0°, 4.0°, 5.0° and 7.5° curves at speeds representing underbalance, balance, and overbalance curving conditions. A "mini consist" (locomotive power, two buffer hopper cars, loaded hopper car with instrumented wheelset installed, and instrumentation car) was used to obtain the dynamic data. The instrumentation is described in Section 5.1.

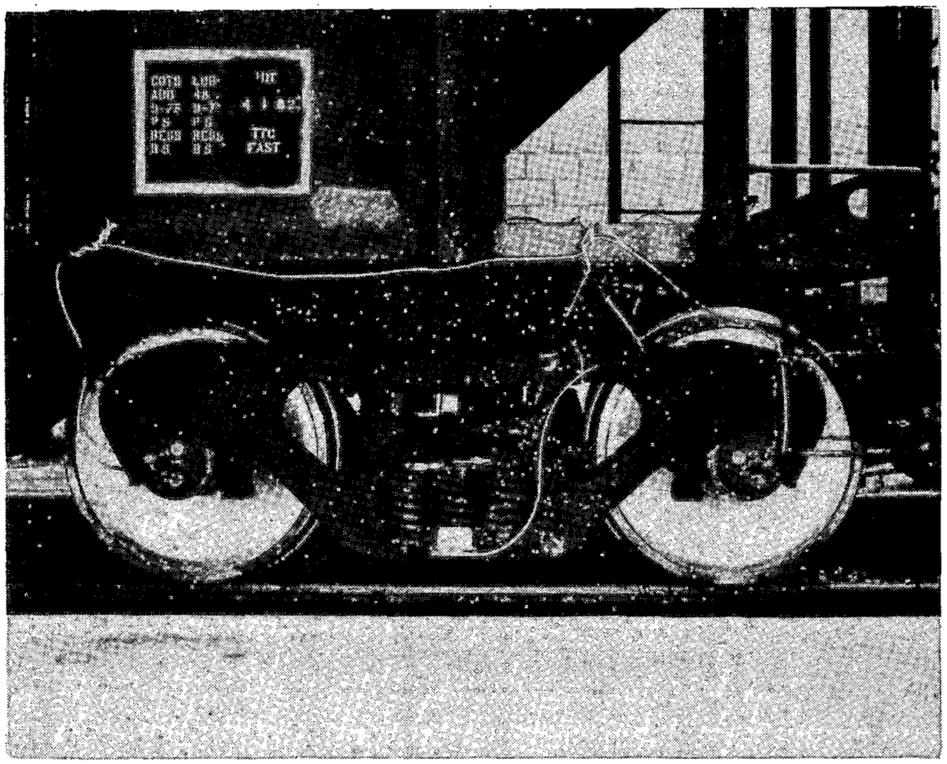
6.1 1.5 DEGREE CURVE

The 1.5° curve (Figure 19) was the lowest degree curve tested. It had 3 inches superelevation and consisted of standard 136# jointed rail on wood ties. Wheel forces were measured while traversing (in a clockwise direction) the test section containing the three test profile zones and the unground control zone. The actual ground rail profiles at 0 MGT are presented in Figures 20a through 20d.

The lateral wheel forces on the lead axle outside rail were reduced for all of the ground profiles as compared to the control profile. Profile 3 was slightly better than the other profiles. The longitudinal forces for the ground profiles were all less than the unground rail for the lead axle. The lateral and longitudinal forces for the 1.5° curve are presented in Figures 21 and 22.

6.2 3.0 DEGREE CURVE

The rail profile locations for the 3.0° curve are shown in Figure 23. The actual rail profiles at 0 MGT are shown in Figures 24a through 24d. The outside worn rail of this curve was turned prior to grinding to provide an unworn gage face. The test curve with 2-inch superelevation was constructed of standard 136#/yd RE jointed rail on wood ties.



TTC N84-1683

FIGURE 18. INSTRUMENTED WHEELSET.

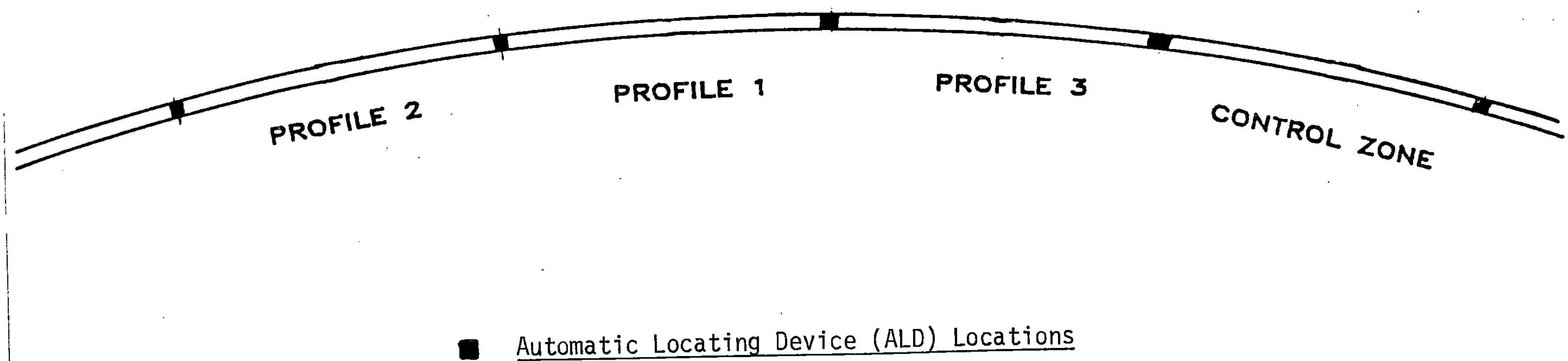


FIGURE 19. MEASUREMENT LOCATION - 1.5° CURVE.

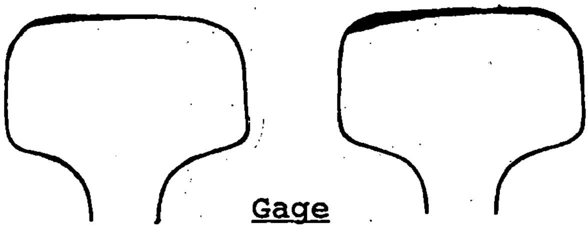


FIGURE 20a. PROFILE 1 - 1.5° CURVE.

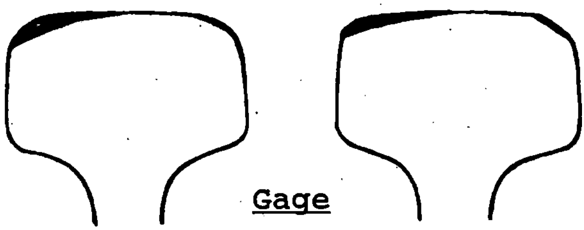


FIGURE 20c. PROFILE 3 - 1.5° CURVE.

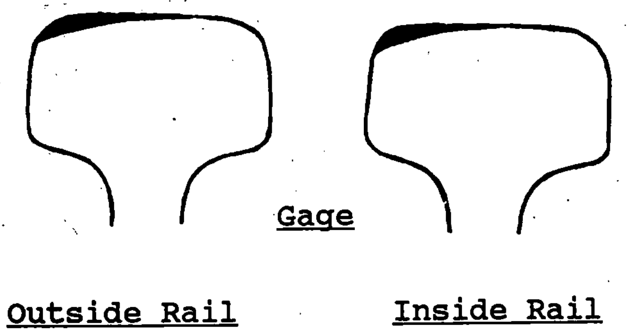


FIGURE 20b. PROFILE 2 - 1.5° CURVE.

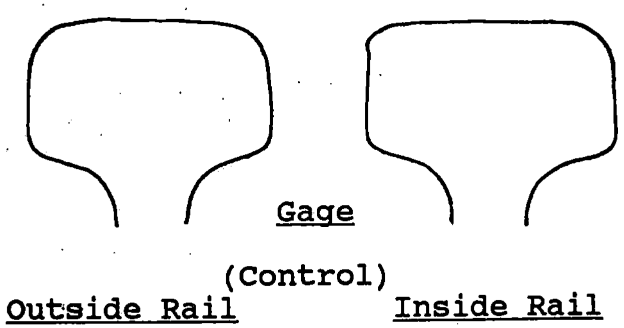


FIGURE 20d. PROFILE 4 - 1.5° CURVE.

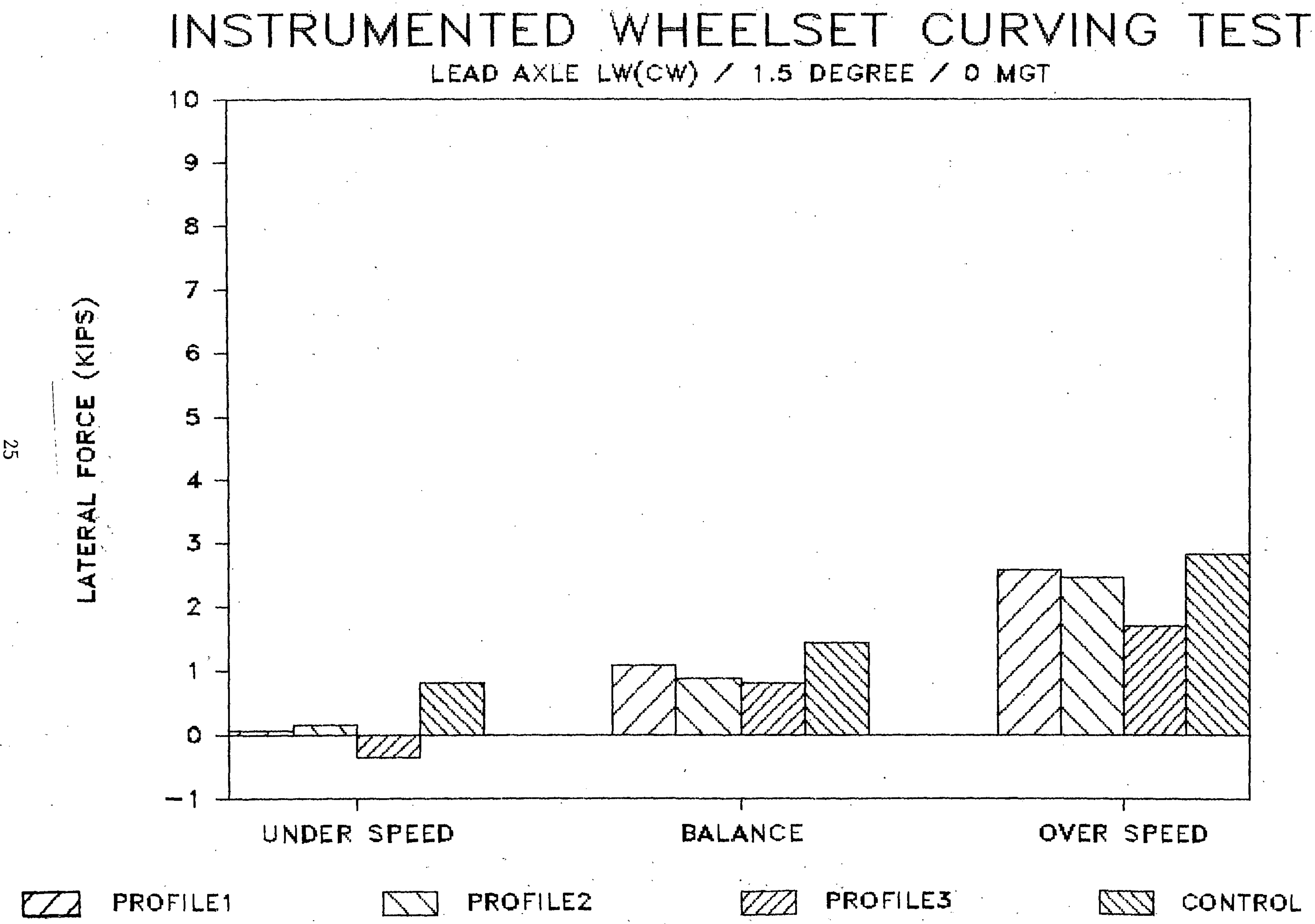


FIGURE 21. LATERAL WHEEL FORCES - 1.5° CURVE.

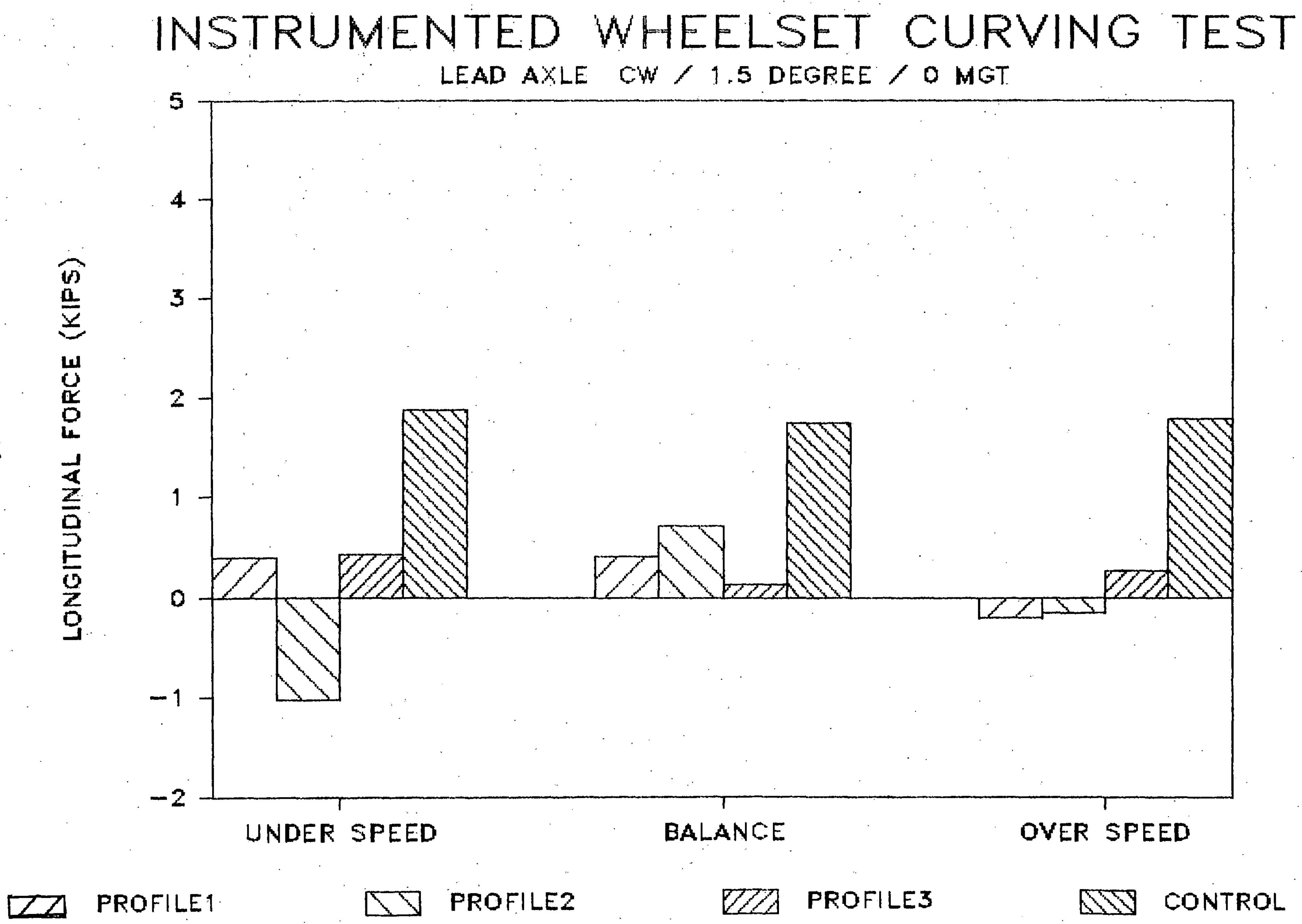


FIGURE 22. LONGITUDINAL WHEEL FORCES - 1.5° CURVE.

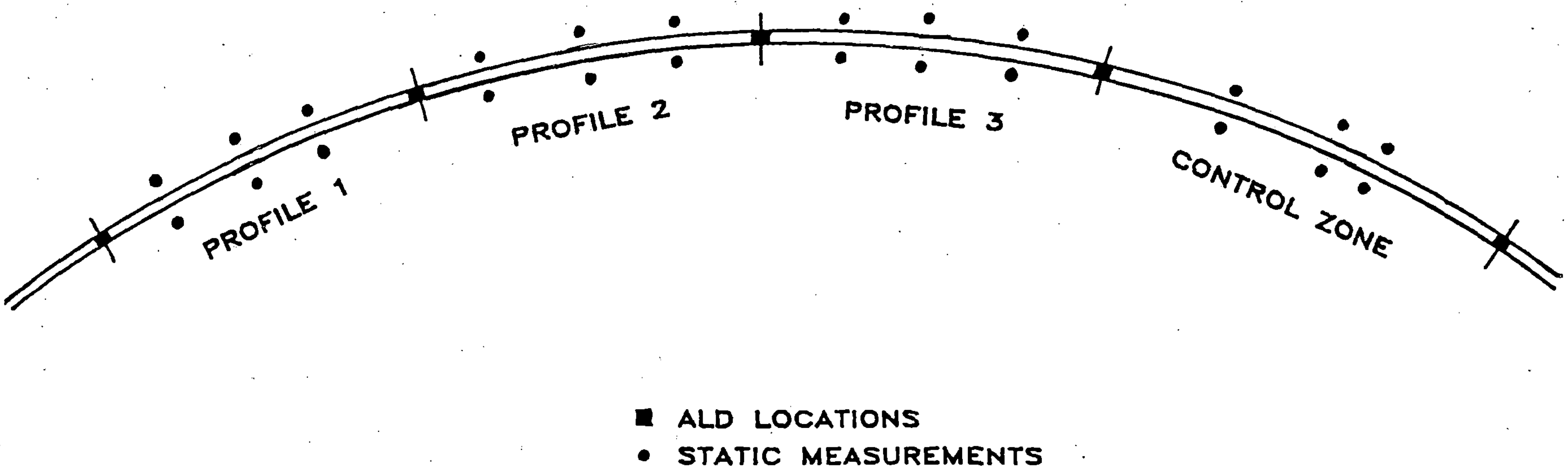


FIGURE 23. MEASUREMENT LOCATION - 3.0° CURVE.

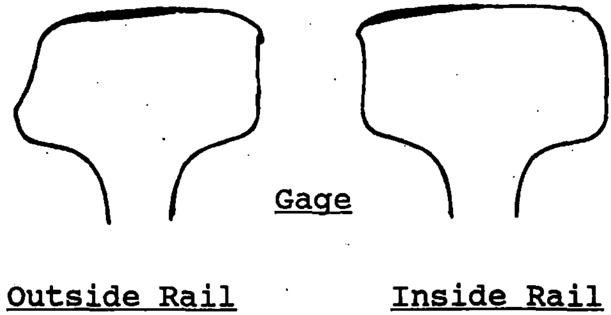


FIGURE 24a. PROFILE 1 - 3.0° CURVE.

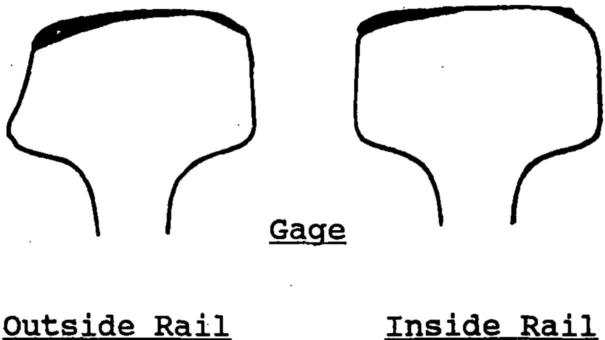


FIGURE 24c. PROFILE 3 - 3.0° CURVE.

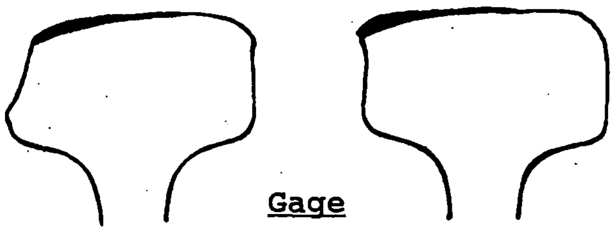


FIGURE 24b. PROFILE 2 - 3.0° CURVE.

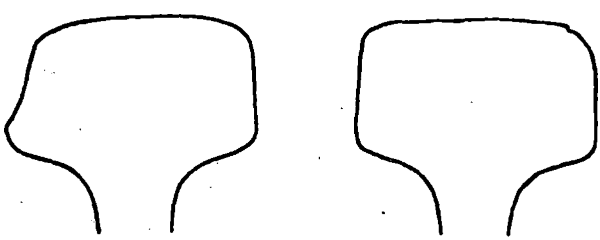


FIGURE 24d. PROFILE 4 - 3.0° CURVE.

The lateral forces on the outside wheel of the lead axle were less for all of the ground profiles compared to the unground control rail. There was very little difference in the forces for the ground profiles.

The longitudinal forces for all of the ground profiles were less than those on the control profile. Profile 3 showed the greatest reduction.

The lateral and longitudinal forces are presented in Figure 25 and Figure 26.

6.3 4.0 DEGREE CURVE

The rail profile locations for the 4.0° curve are shown in Figure 27. New 136#/yd RE standard rail was installed in the 4.0° curve to replace the existing 133# RE rail. The CWR was installed on wood ties with 3 inches of superelevation. The curve location at the TTC is presented in Figure 17. The ground rail profiles at 0 MGT are presented in Figures 28a through 28d.

The lateral wheel forces were reduced for all of the ground profiles as compared with the unground control profile. The most reduction was for Profile 1. The longitudinal wheel forces were less for Profile 3 configuration compared to the control profile for all speeds. The longitudinal forces were all less than the control profile for the underbalance conditions. The wheel forces are presented in Figures 29 and 30.

6.4 5.0 DEGREE CURVE

The rail profile locations in the 5.0° curve are shown in Figure 31. This test section consisted of 136#/yd RE premium CWR, on wood ties, used for previous metallurgy tests. For economic reasons this worn rail in this section was used but the outside rail was turned to present an unworn gage face for grinding. The inside rail remained in place. Due to an ongoing metallurgy test, the worn rail in the control zone was not disturbed. This 5.0° test curve had 4 inches of superelevation. The actual ground profiles at 0 MGT are presented in Figures 32a through 32d.

Wheel forces were recorded while traversing the test curve at underbalance, balance, and overbalance conditions. The lateral forces on the outside wheel of the lead axle, were reduced in the ground profile zones as compared to the unground control zone. The forces for Profile 1 were the lowest for the underbalance condition.

The longitudinal forces for the lead axle were either the same as the unground control zone or slightly greater for all balance conditions. The lateral and longitudinal wheel forces for 0 MGT are presented in Figures 33 and 34.

6.5 7.5 DEGREE CURVE

The location of the rail profiles in the 7.5° curve is shown in Figure 35. This was the highest degree of curvature tested.

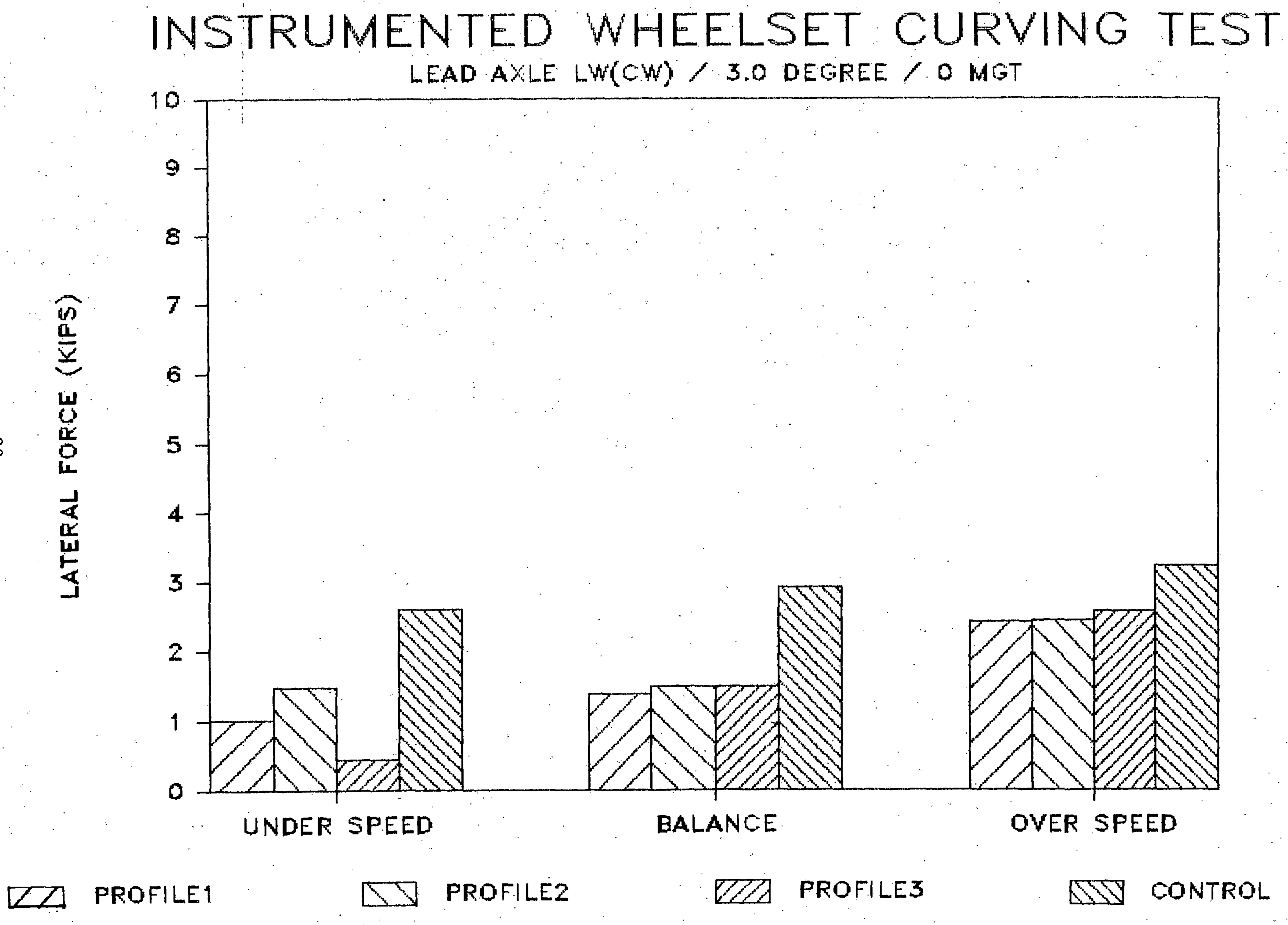


FIGURE 25. LATERAL WHEEL FORCES - 3.0° CURVE.

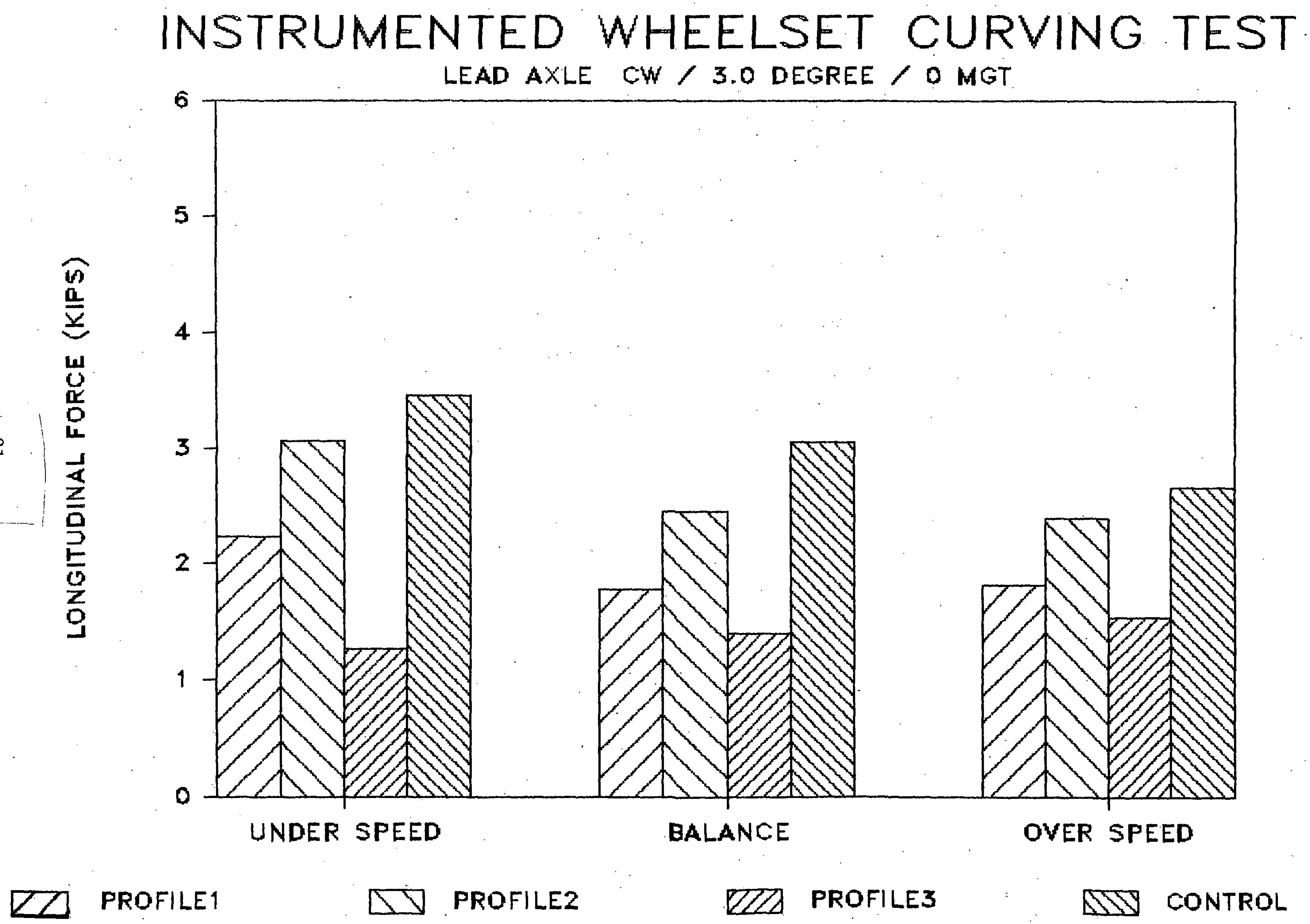


FIGURE 26. LONGITUDINAL WHEEL FORCES - 3.0° CURVE.

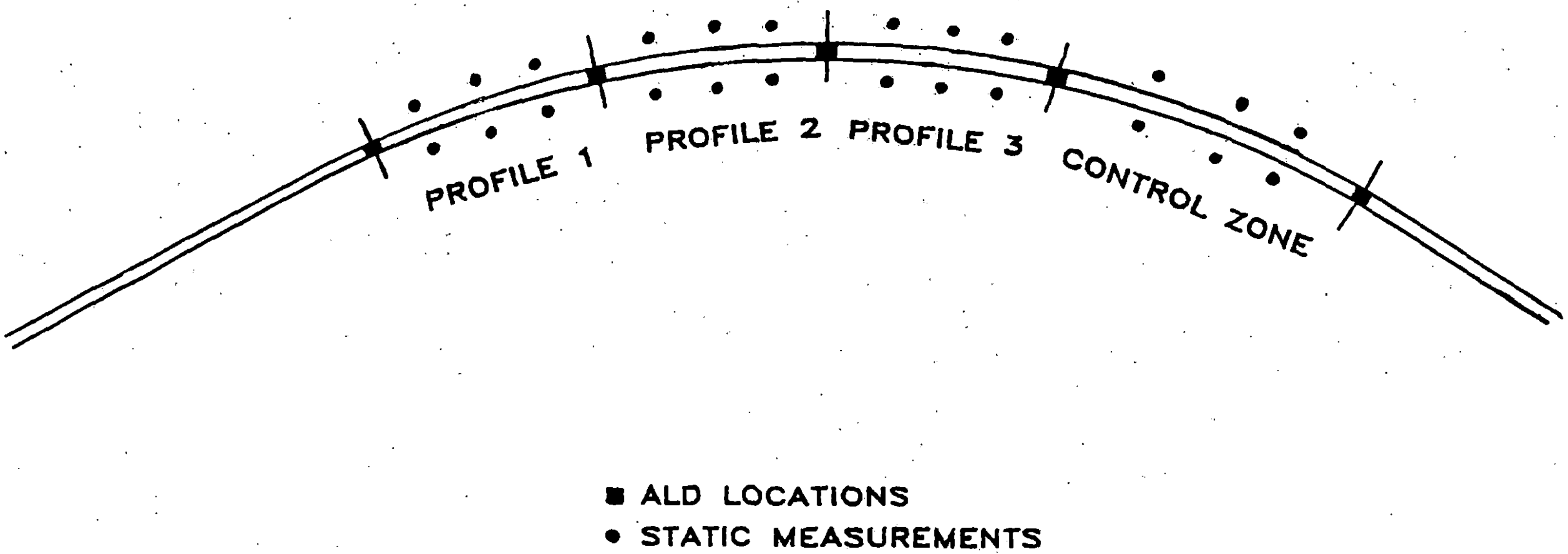


FIGURE 27. MEASUREMENT LOCATION - 4.0° CURVE.

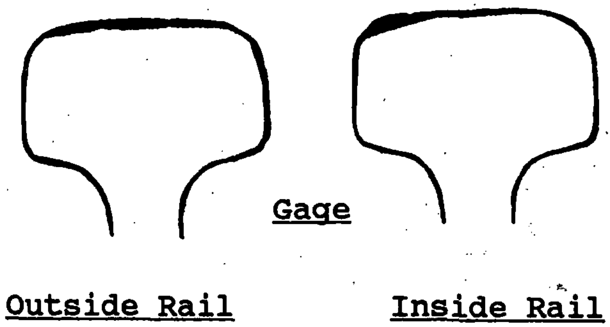


FIGURE 28a. PROFILE 1 - 4.0° CURVE.

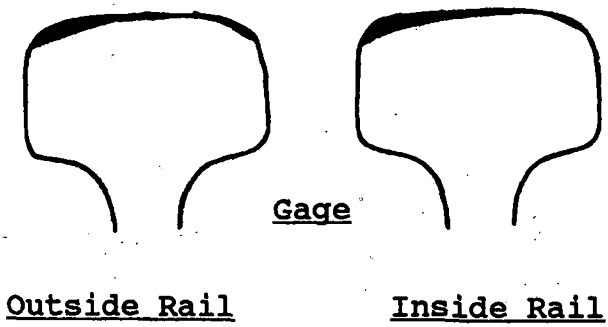


FIGURE 28c. PROFILE 3 - 4.0° CURVE.

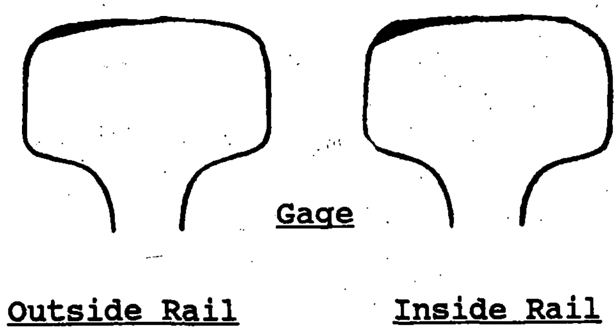


FIGURE 28b. PROFILE 2 - 4.0° CURVE.

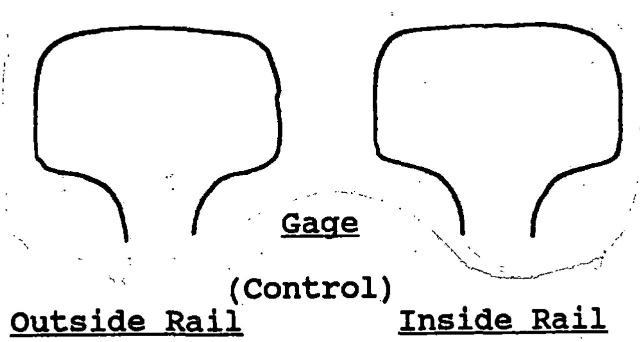


FIGURE 28d. PROFILE 4 - 4.0° CURVE.

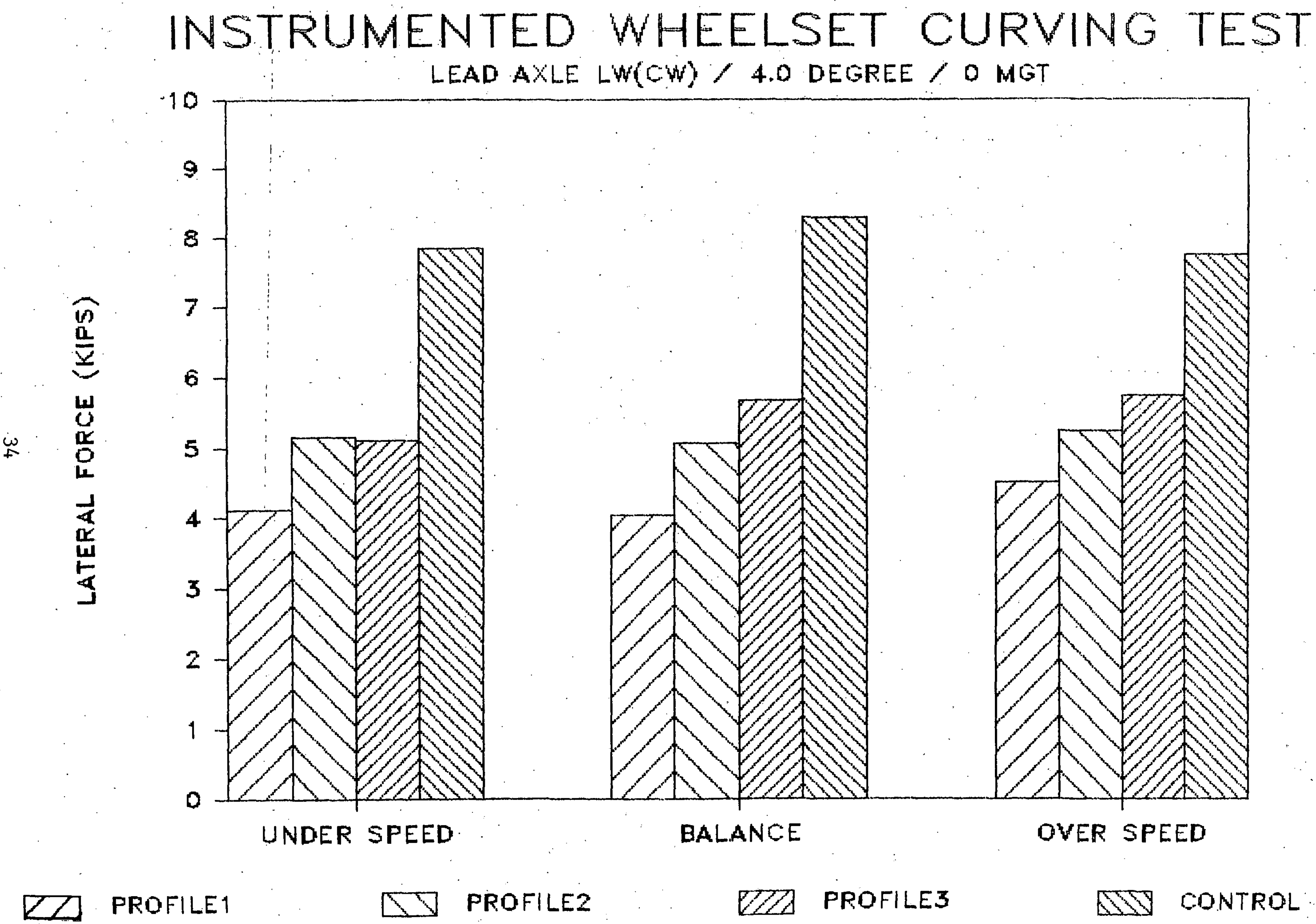


FIGURE 29. LATERAL WHEEL FORCES - 4.0° CURVE.

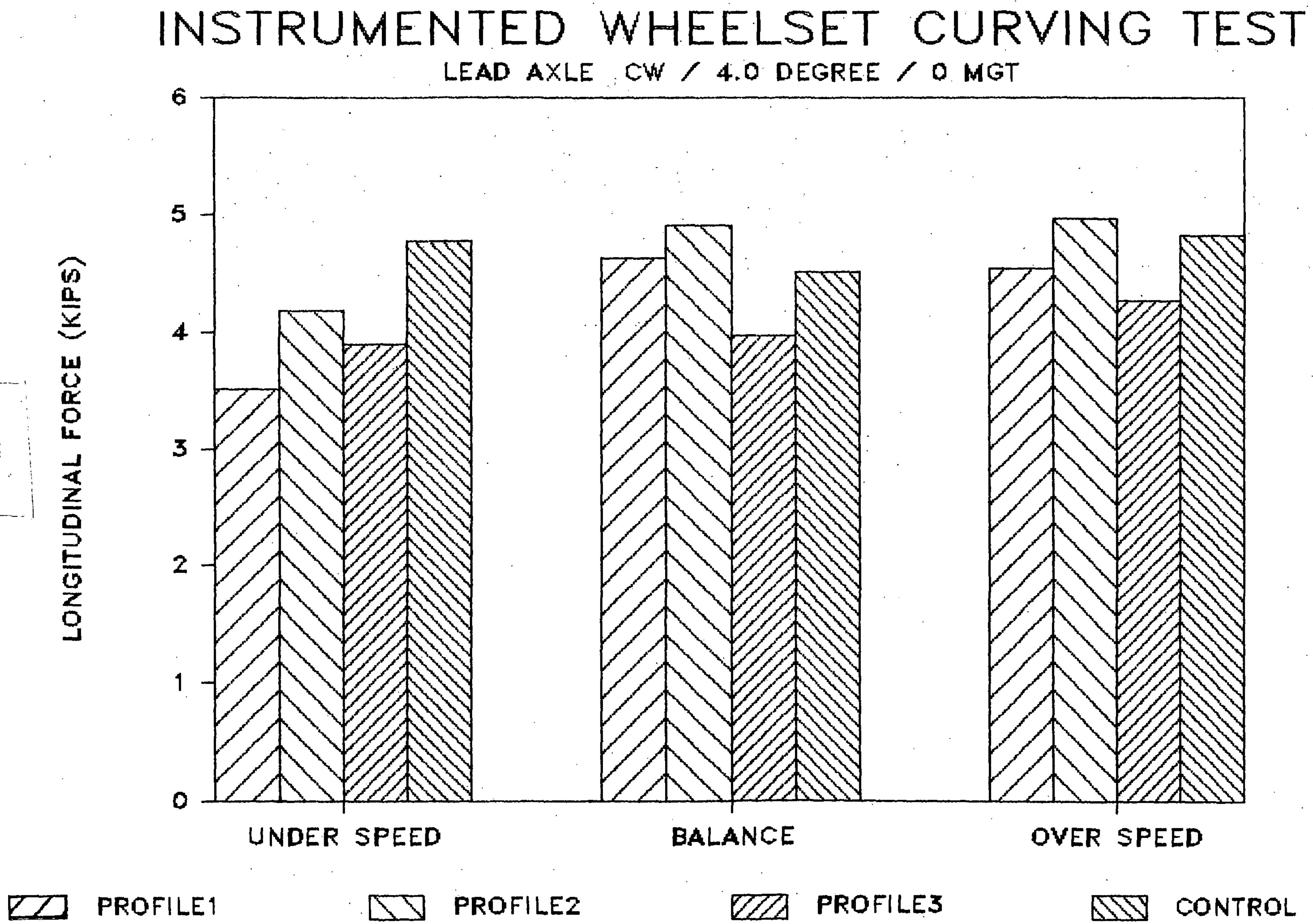


FIGURE 30. LONGITUDINAL WHEEL FORCES - 4.0° CURVE.

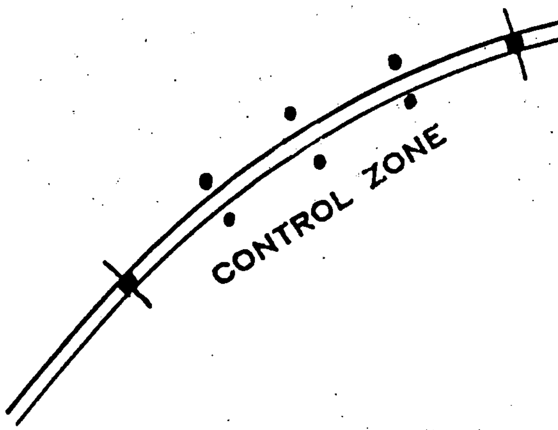
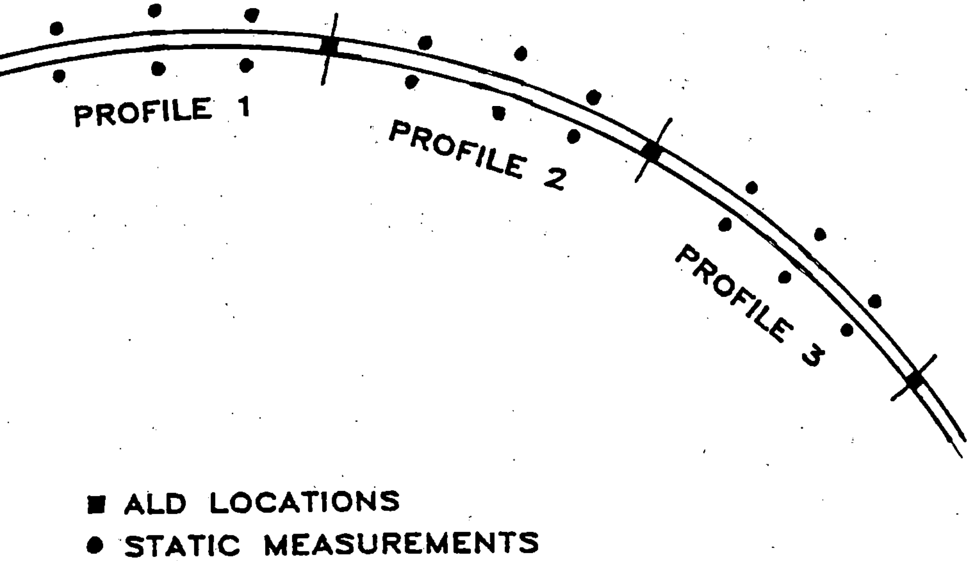


FIGURE 31.



MEASUREMENT LOCATION - 5.0° CURVE.

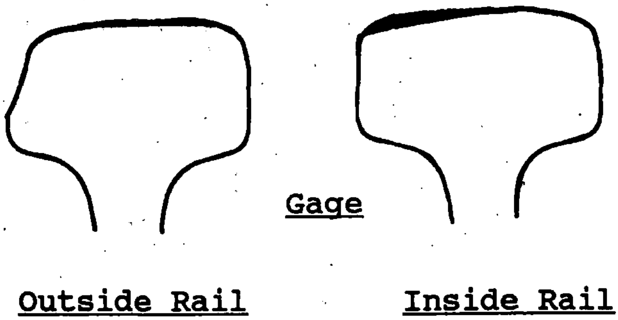


FIGURE 32a. PROFILE 1 - 5.0° CURVE.

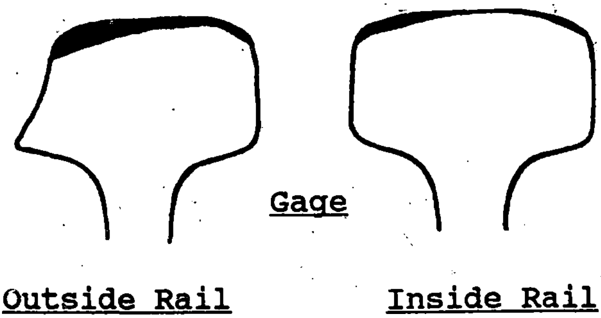


FIGURE 32c. PROFILE 3 - 5.0° CURVE.

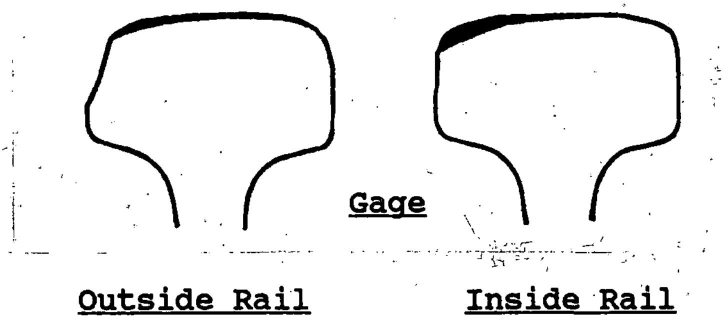


FIGURE 32b. PROFILE 2 - 5.0° CURVE.

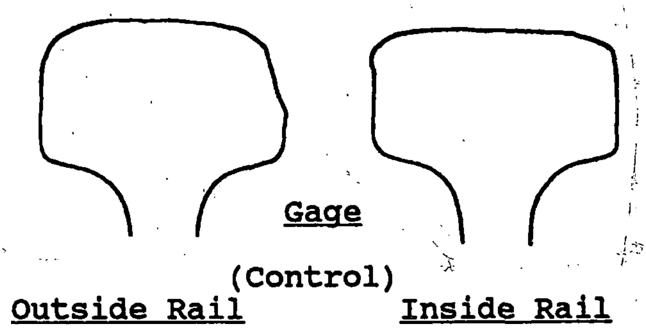


FIGURE 32d. PROFILE 4 - 5.0° CURVE.

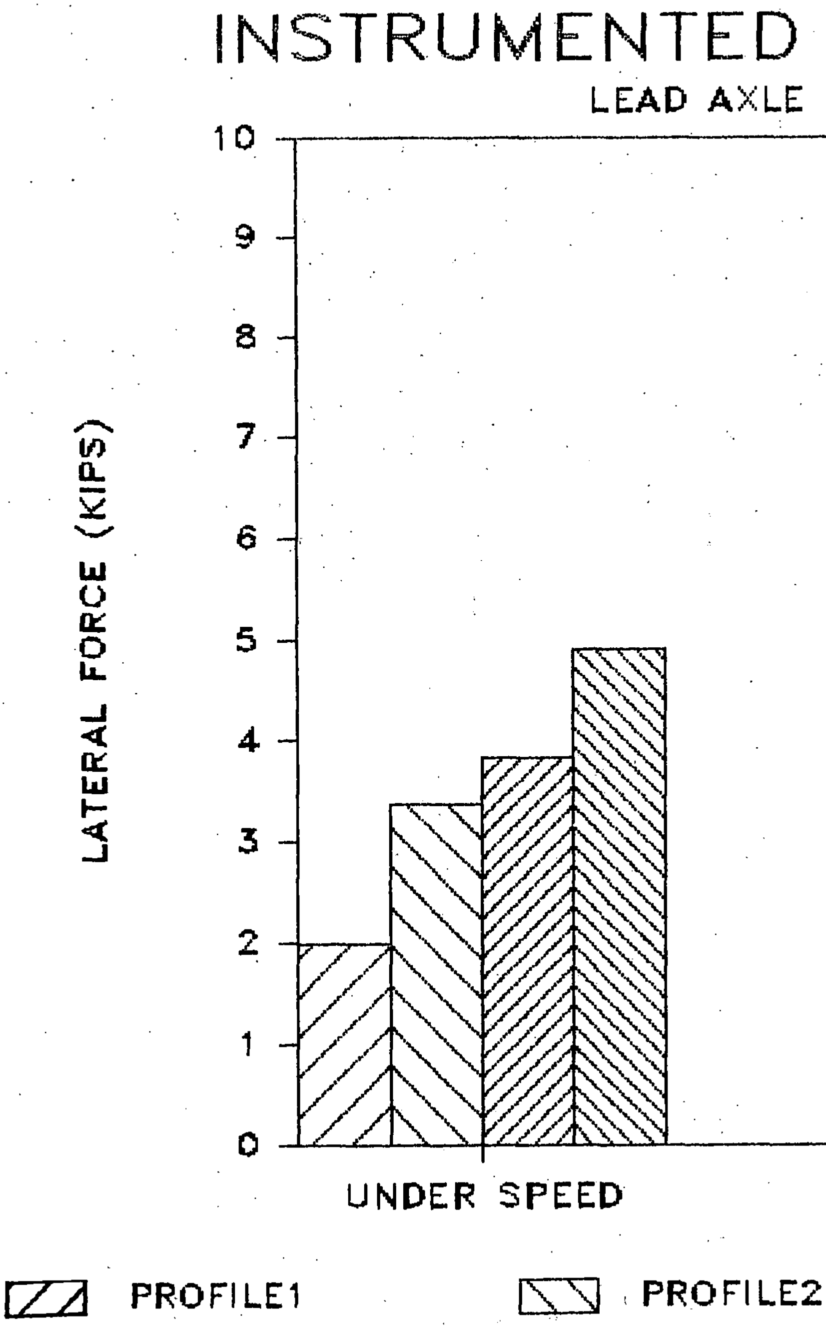
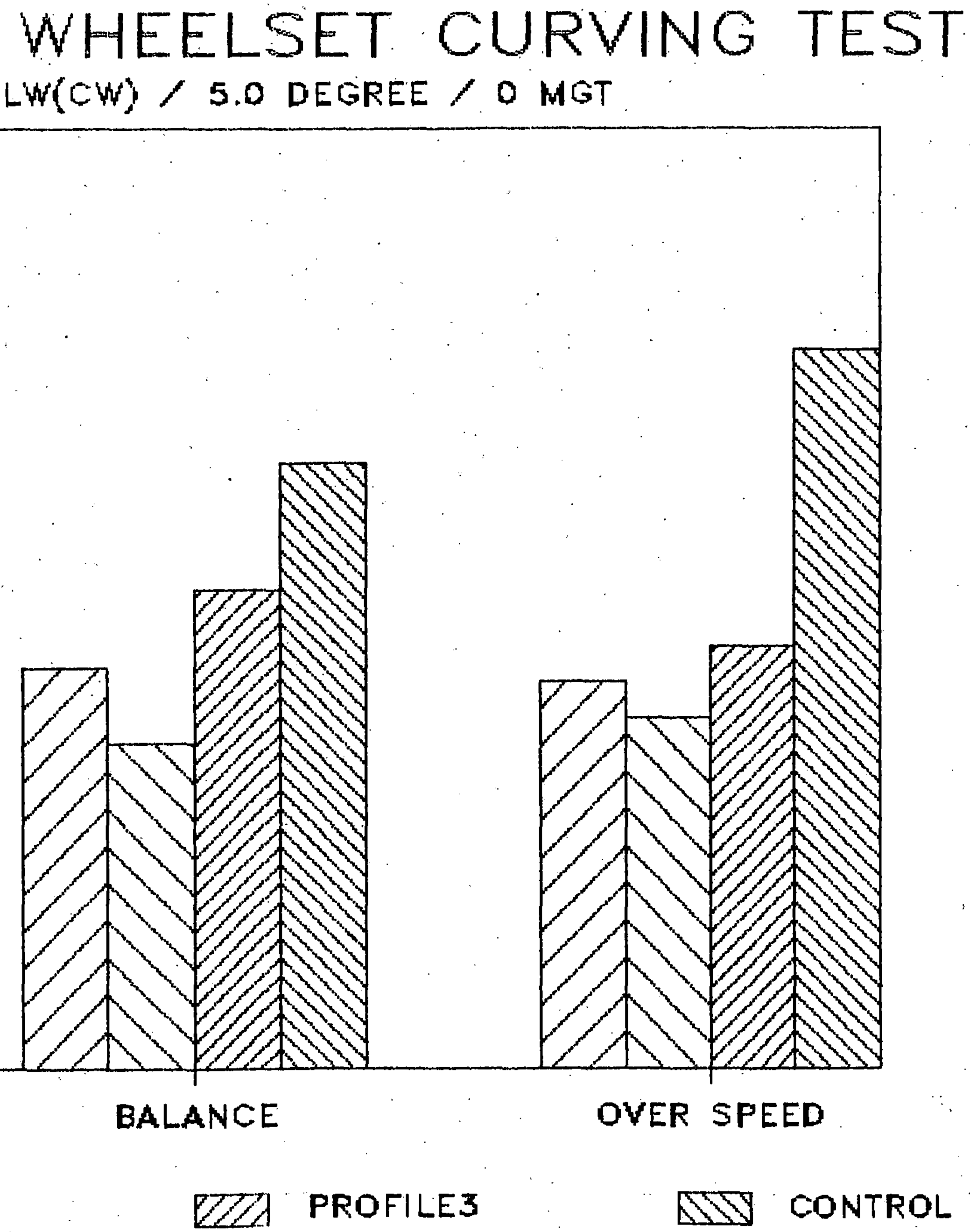

INSTRUMENTED
LEAD AXLE
LATERAL FORCE (KIPS)
10
9
8
7
6
5
4
3
2
1
0
UNDER SPEED
PROFILE1
PROFILE2

FIGURE 33.



LATERAL WHEEL FORCES - 5.0° CURVE.

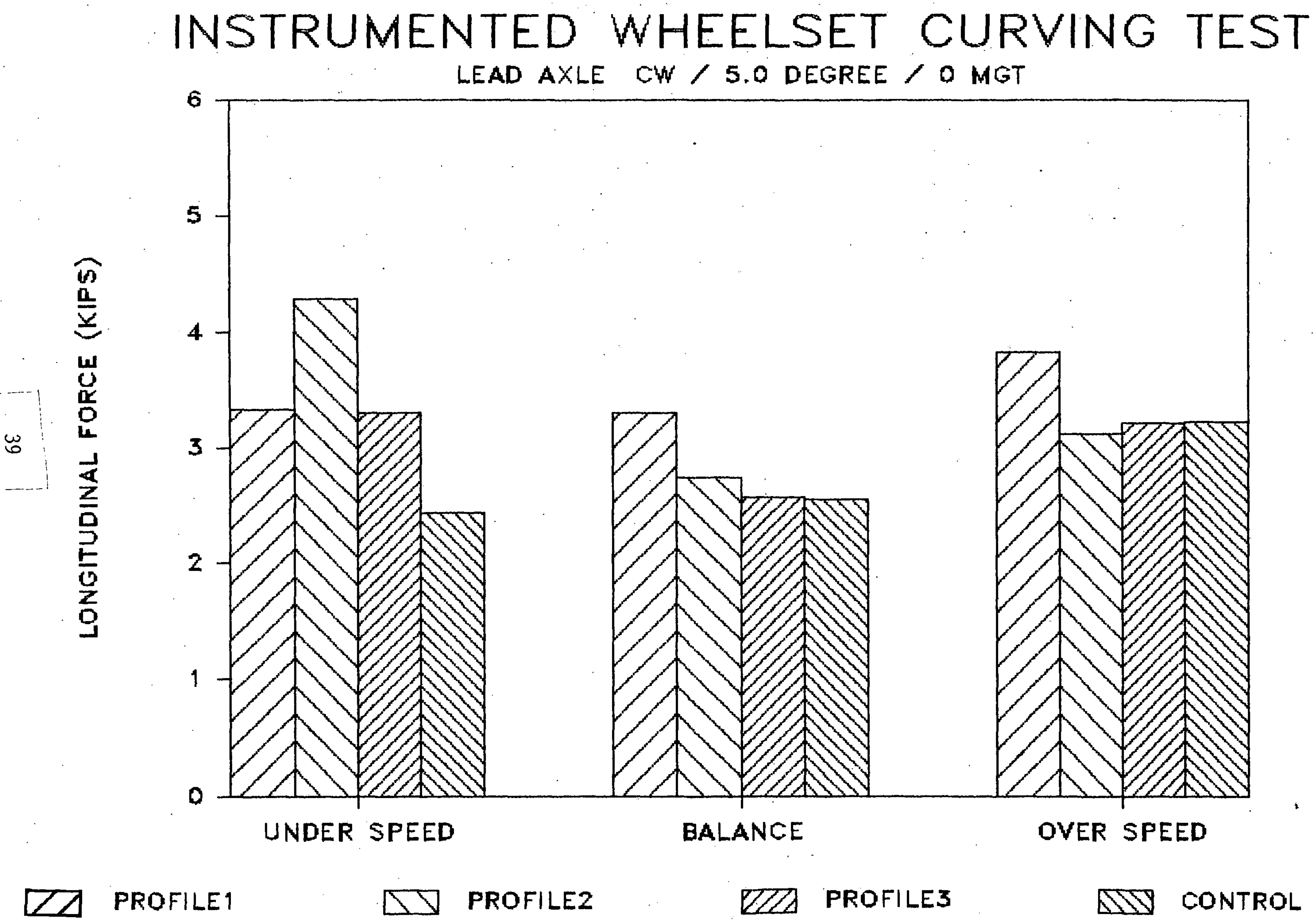


FIGURE 34. LONGITUDINAL WHEEL FORCES - 5.0° CURVE.

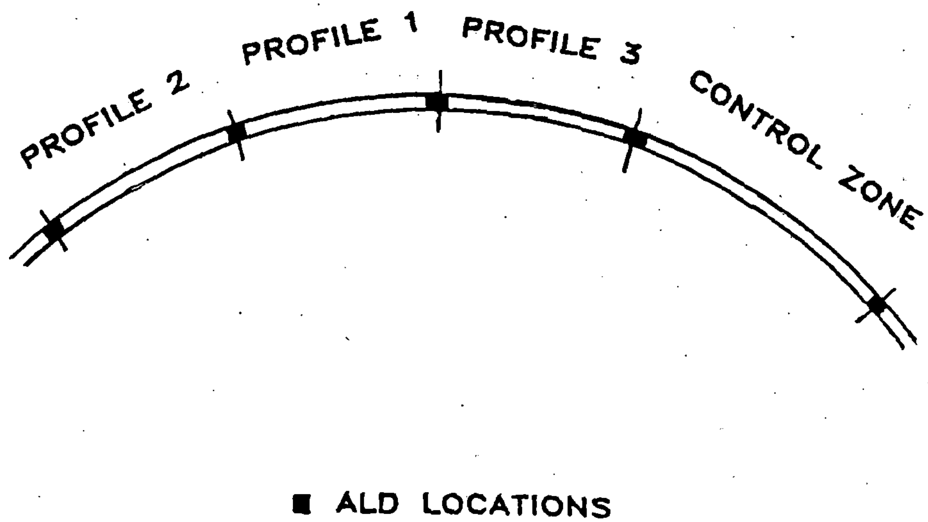


FIGURE 35. MEASUREMENT LOCATION - 7.5° CURVE.

This 7.5° curve consisted of 136#/yd jointed rail on wood ties with 4 inches superelevation. The rail profiles for this curve are shown in Figures 36a through 36d.

The lateral forces on the outside wheel of the lead axle were reduced for Profiles 2 and 3 at all speeds as compared with the unground control zone. Profile 1 lateral forces were less than the unground control zone except for the underbalance conditions, where the forces were the same. The longitudinal forces for the lead axle shows a reduced force for Profiles 2 and 3 as compared with the unground control rail. The lateral and longitudinal forces are presented in Figures 37 and 38.

6.6 CURVING TEST SUMMARY

The objective of the curving test portion of the experiment was to evaluate the wheel forces encountered during the traverse of curves of various degrees of curvature with various rail profiles. Dynamic data were taken for 1.5°, 3.0°, 4.0° 5.0° and 7.5° curves. Each curve had an unground rail section and additional sections with the three experimental rail profiles. A summary of the lateral forces associated with the outside wheel of the lead axle is presented in Figure 39. A summary of the longitudinal forces on the lead axle for the various degree test curves is presented in Figure 40. The forces presented are average values for several runs over the test area using a mini-consist of locomotive power, instrumentation car, buffer cars and a loaded hopper car having instrumented wheelsets.

The summary plots show that all of the experimental rail profile grinds reduced the lateral forces as compared to the unground control rail for balance speed conditions. The Profile 2 design appears to have given better results at the high degree of curvature. The experimental rail profiles also reduced the longitudinal forces at the balance speed for curvature below 4°. The Profile 2 design reduced the longitudinal forces for curvatures below and above 4.0°.

The dynamic curving force data used in this report are exclusively from the instrumented wheelsets. The data represent the average results of several continuous runs over the complete length of each test section.

7.0 WEAR TESTS

The objective of the long term wear portion of this experiment was to evaluate rail wear characteristics of the rail profile test sections after 20 million gross tons (MGT) of unlubricated heavy train traffic. Three test curves, 3.0°, 4.0°, and 5.0° were evaluated on the FAST loop. Static rail measurements were used to determine the rail wear on each curve. The wear tests were initiated on the dry (unlubricated) FAST track on January 21, 1985 and the 20 MGT of running was completed on April 23, 1985.

7.1 STATIC RAIL WEAR MEASUREMENTS

The instrumentation used for the long term rail wear tests were: (1) rail profilometers, (2) hardness testers, and (3) snap (dial indicator) gages.

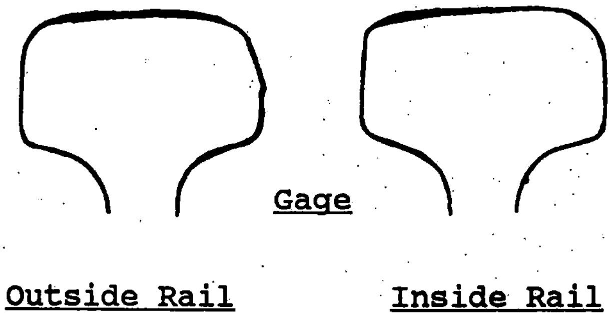


FIGURE 36a. PROFILE 1 - 7.5° CURVE.

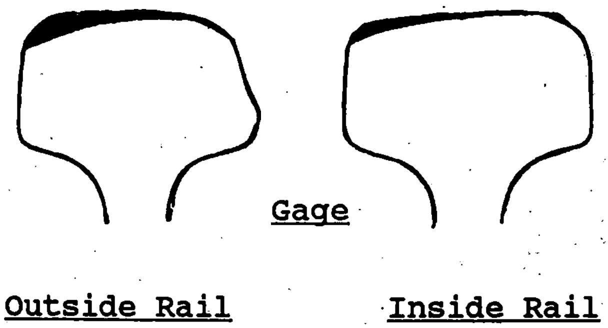


FIGURE 36c. PROFILE 3 - 7.5° CURVE.

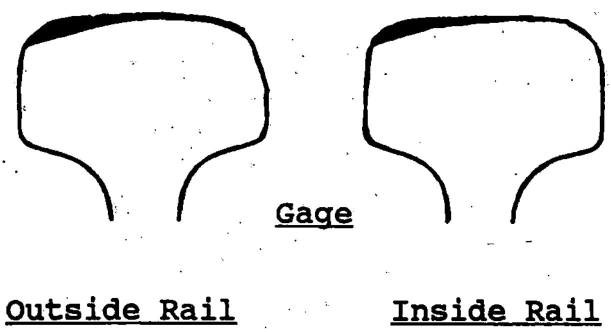


FIGURE 36b. PROFILE 2 - 7.5° CURVE.

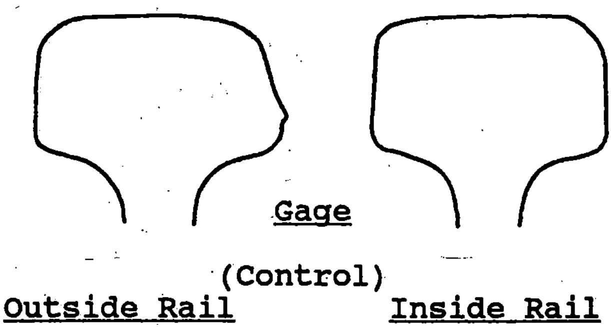


FIGURE 36d. PROFILE 4 - 7.5° CURVE.

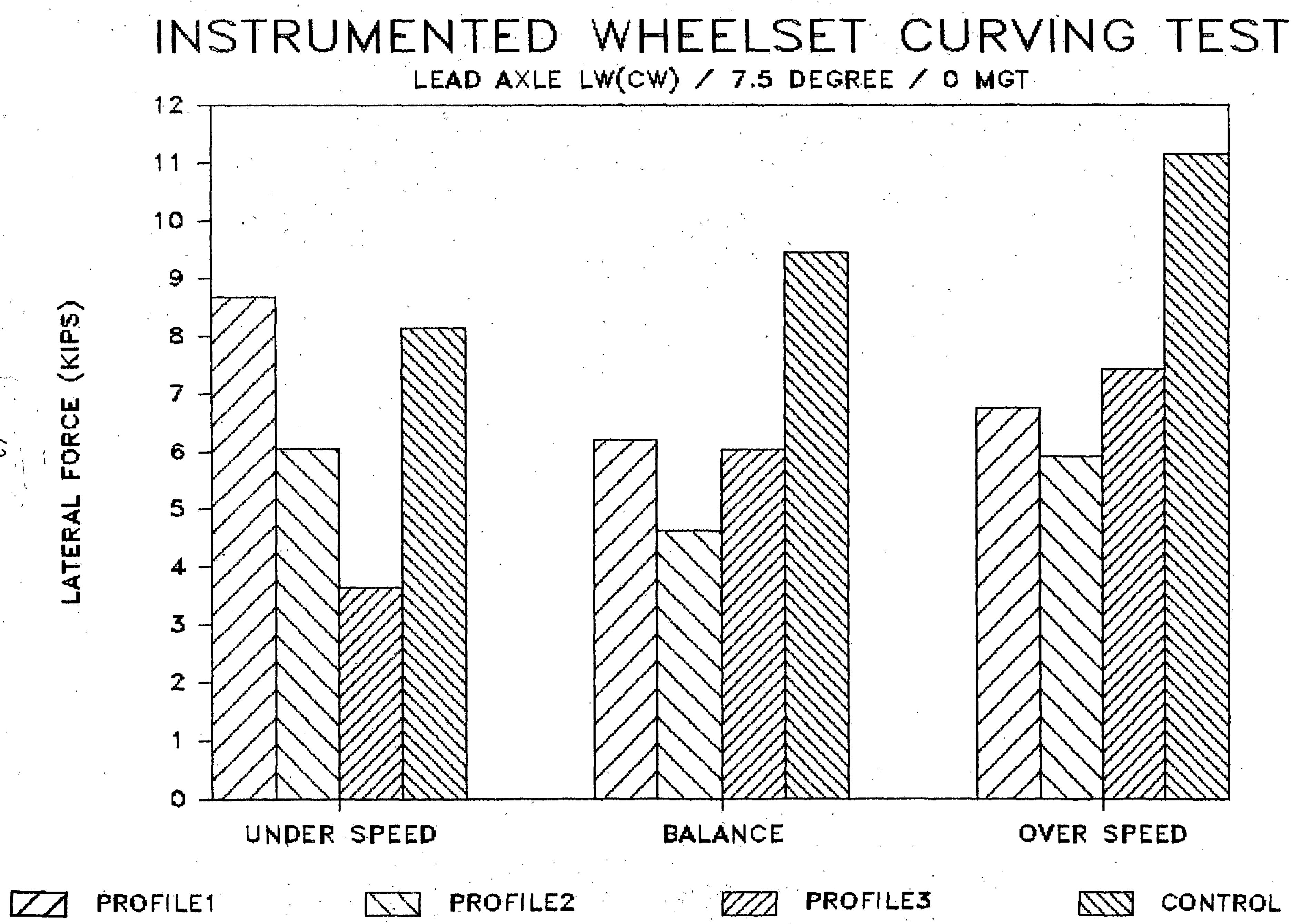


FIGURE 37. LATERAL WHEEL FORCES - 7.5° CURVE.

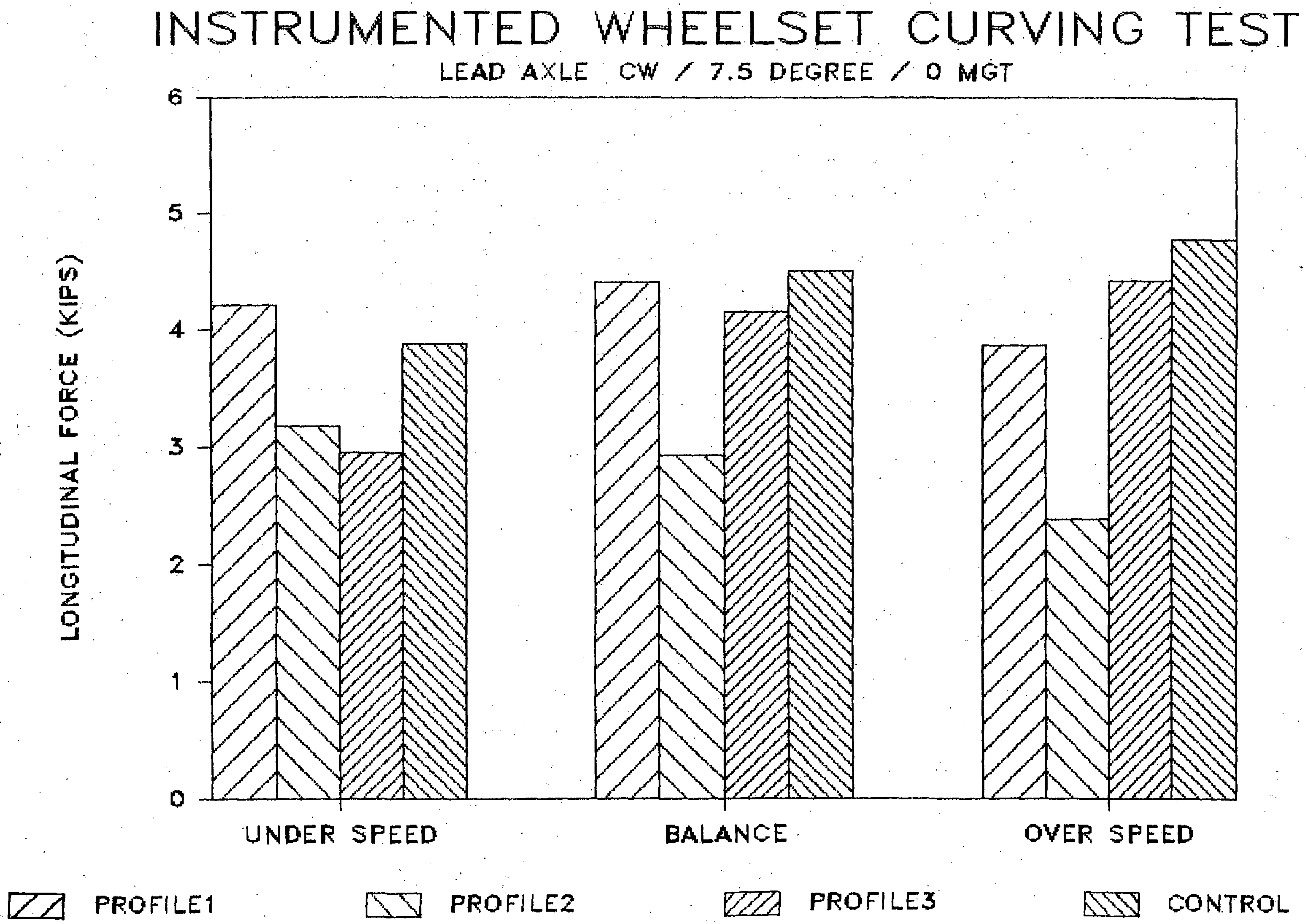


FIGURE 38. LONGITUDINAL WHEEL FORCES - 7.5° CURVE.

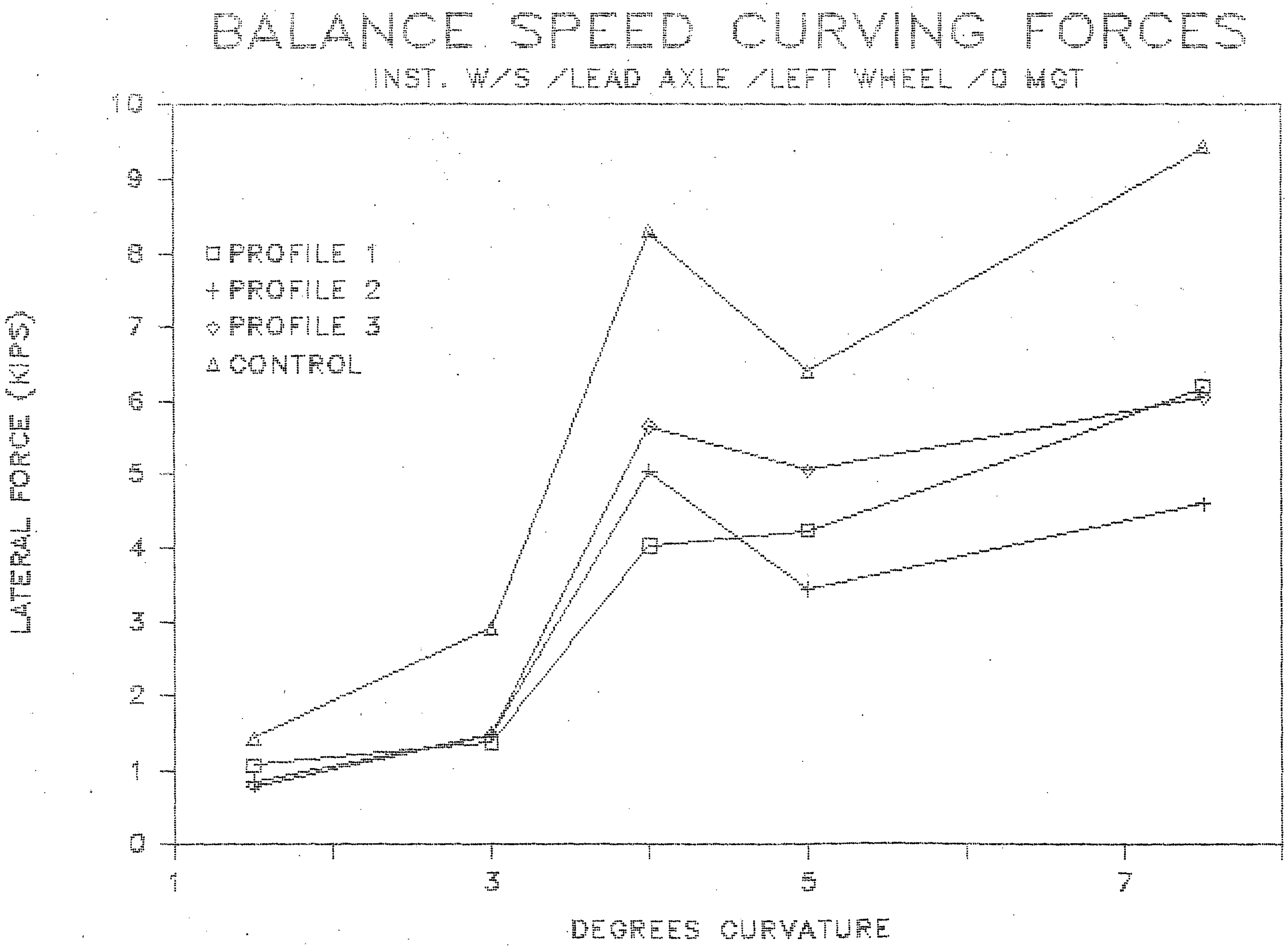


FIGURE 39. SUMMARY OF LATERAL FORCES.

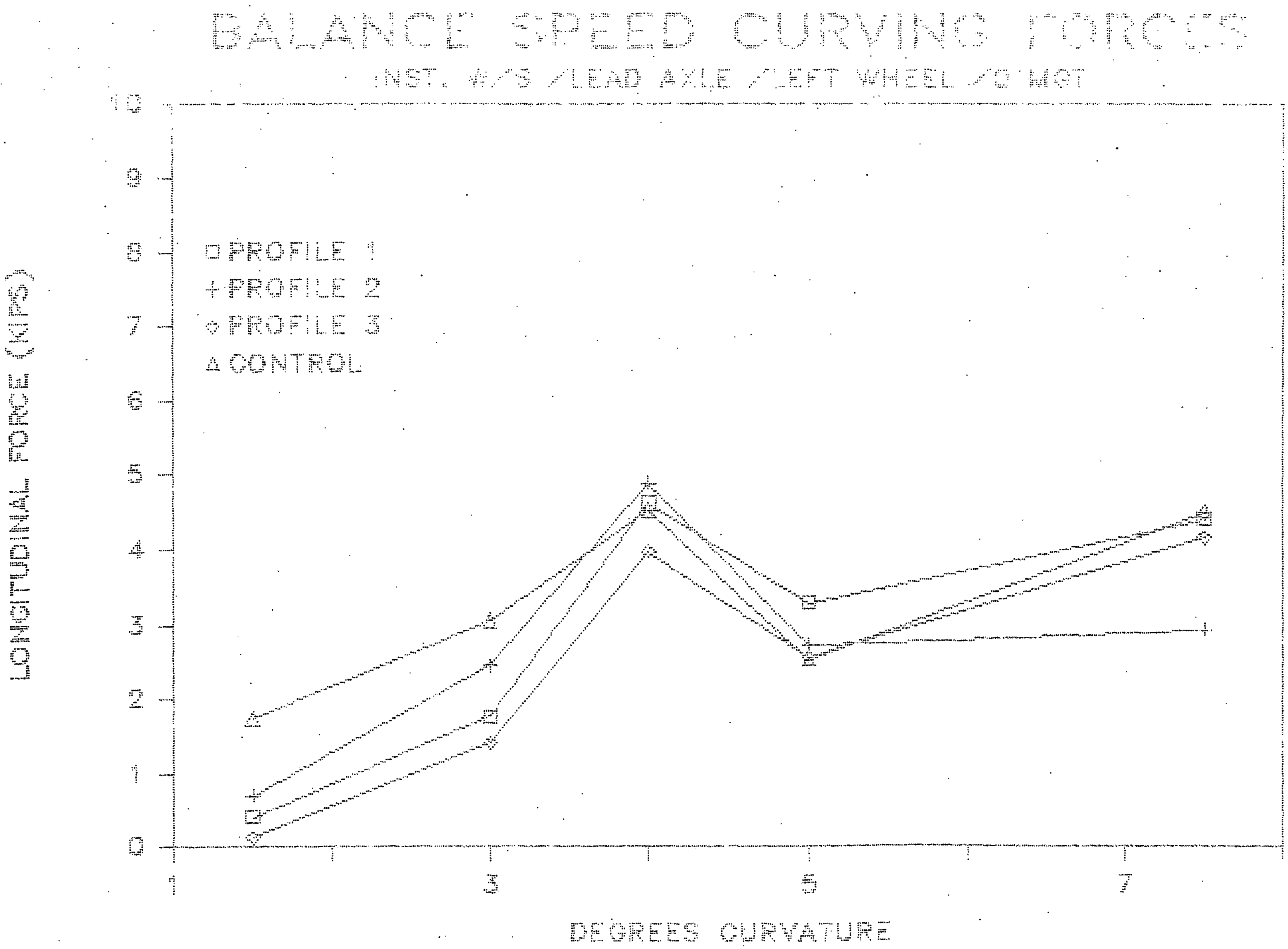


FIGURE 40. SUMMARY OF LONGITUDINAL FORCES.

Measurements were taken periodically during the 20 MGT of dry track train operations. Several locations in each curve were chosen for the periodic measurements to provide insurance against the possibility of a portion of test rail being replaced for various reasons during the testing.

The static rail measurement locations are presented in Section 6.0 of this report.

7.1.1 Rail Profiles

A Yoshida rail profilometer was used to record the original, final, and interim profiles of each rail in the test zones for each test curve. A profile of a calibration rail was taken for each measurement cycle to ensure good data. The Yoshida rail profilometer is shown in Figure 41.

7.1.2 Rail Hardness

The Brinell and Shore hardness testers were used for the original 0 MGT and periodic measurements of rail hardness, with a final measurement at 20 MGT. The Brinell hardness tester is shown in Figure 42. The Shore tester is shown in Figure 43.

7.1.3 Snap Gauges

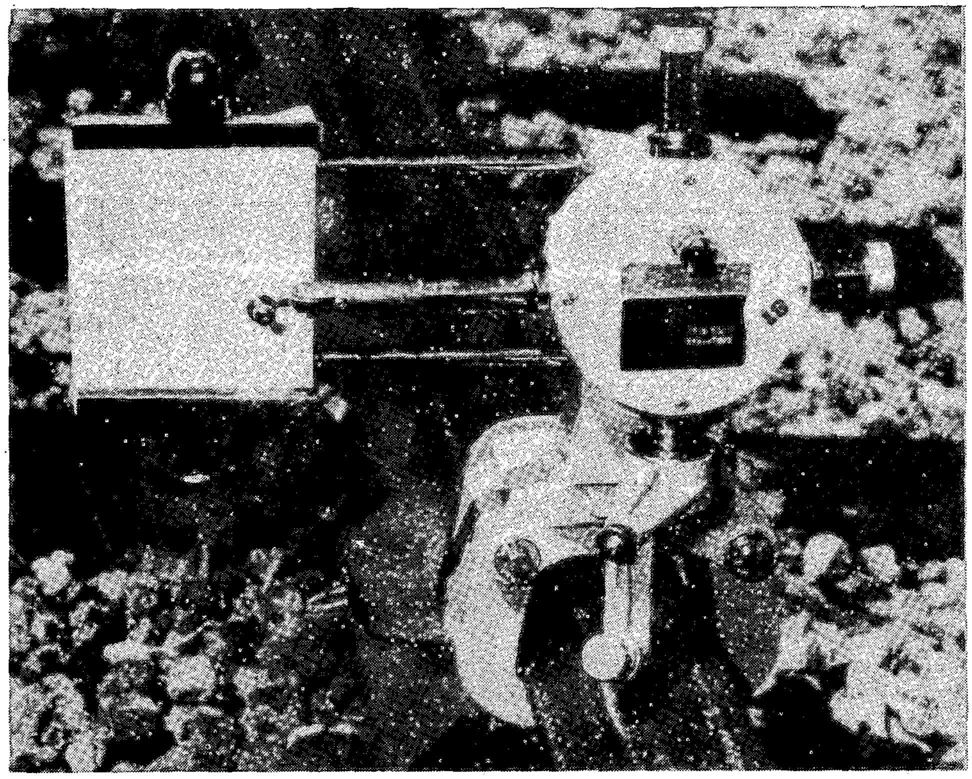
Snap gauges were used to monitor the wear of the rail during the long term wear tests. The gauges used dial indicators to measure the change in rail shape at specific locations.

The head height loss (HL) measured the change in relative height of the rail head due to running surface wear. A recording was made of both high and low rail in the curves. The gage face (GF) was measured at a point 5/8" and 3/8" below the top of the rail head on the high rail. In order to determine if a lip was forming on the gage and field sides of the low rail, metal flow (MF) measurements were taken periodically. The snap gauges are shown in Figures 44 through 46.

7.2 RAIL WEAR SUMMARY

The rail wear data presented in this report are for the 4.0° curve as representative of the type of curve found on most U.S. railroads. The 4.0° curve and the FAST track also contained all new 136# standard rail at the start of the tests, thus presenting a more unbiased environment for evaluation.

The test rails were monitored very closely for signs of corrugations, since tests by other railroads indicated the occurrence of this condition on the low rails with similar grind configurations. No corrugations were found during the 20 MGT of unlubricated testing. Corrugations did occur on the low rail of the 4.0° curve during continued running after the completion of the 20 MGT tests. This was not attributed to the rail grinds since all the profile patterns had reverted to a worn rail profile. The rail wear characteristics for the different rail profiles of the 4.0° curve are discussed below.

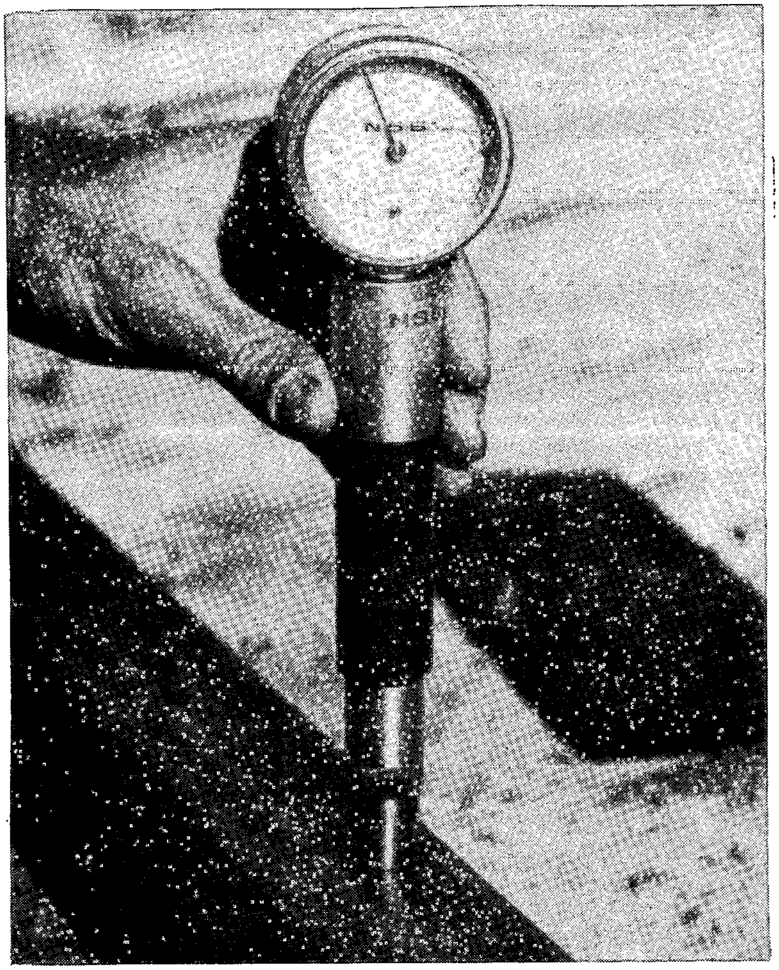


TTC N81-1237

FIGURE 41. YOSHIDA RAIL PROFILOMETER.

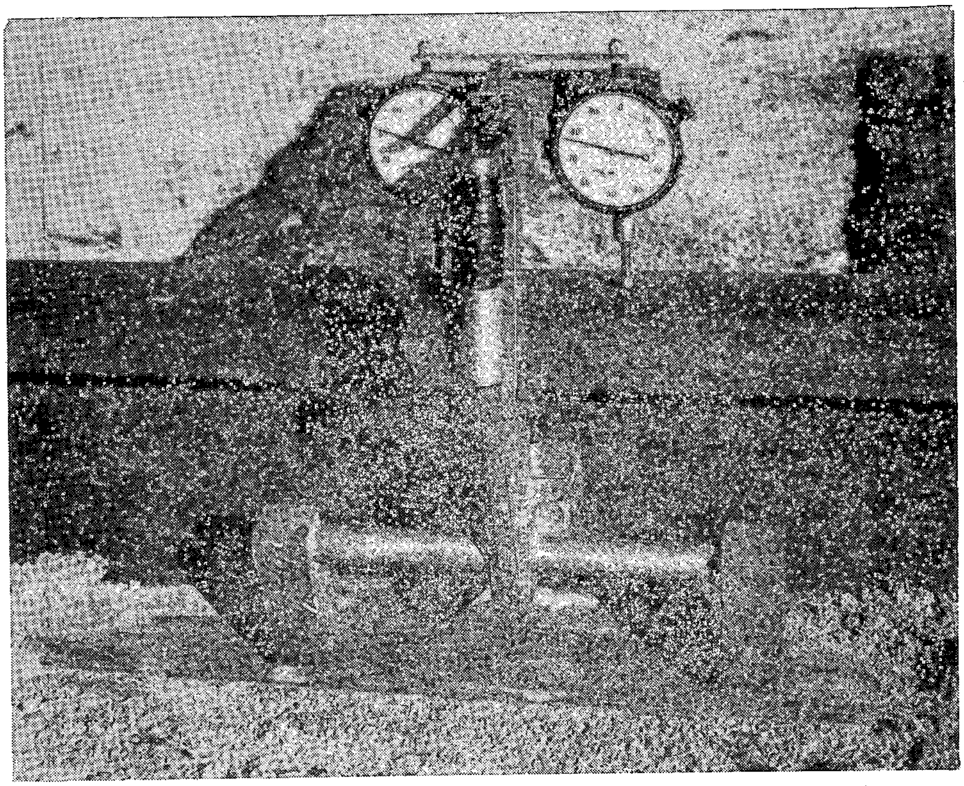
TTC N85-1673

FIGURE 42. BRINELL HARDNESS TESTER.



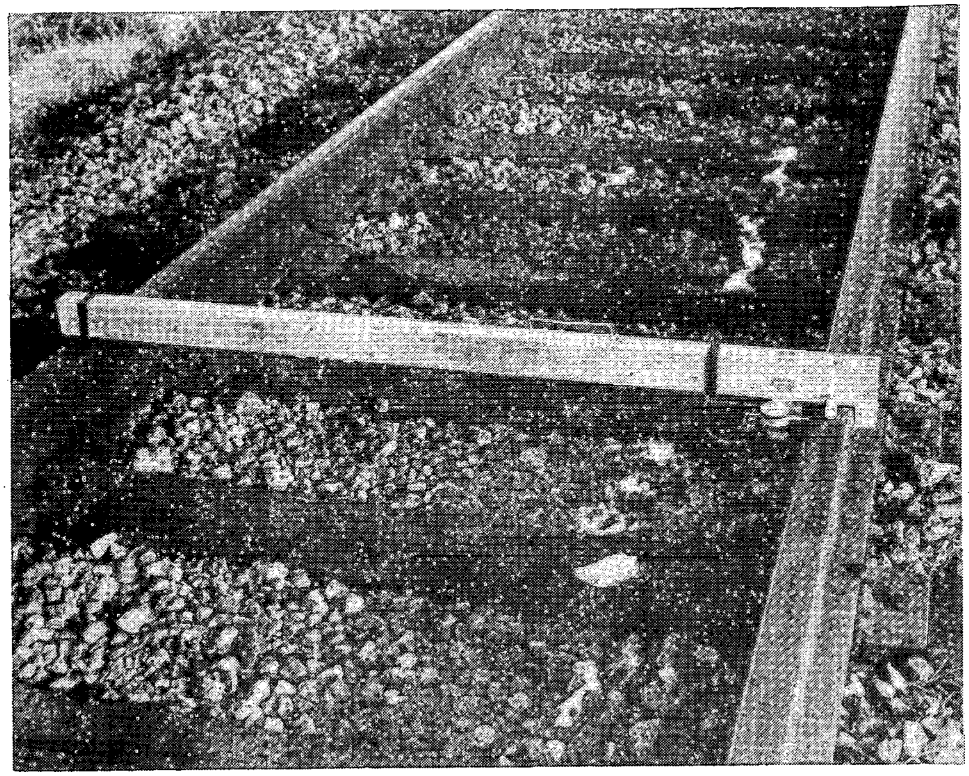
TTC N85-1680

FIGURE 43. SHORE HARDNESS TESTER.



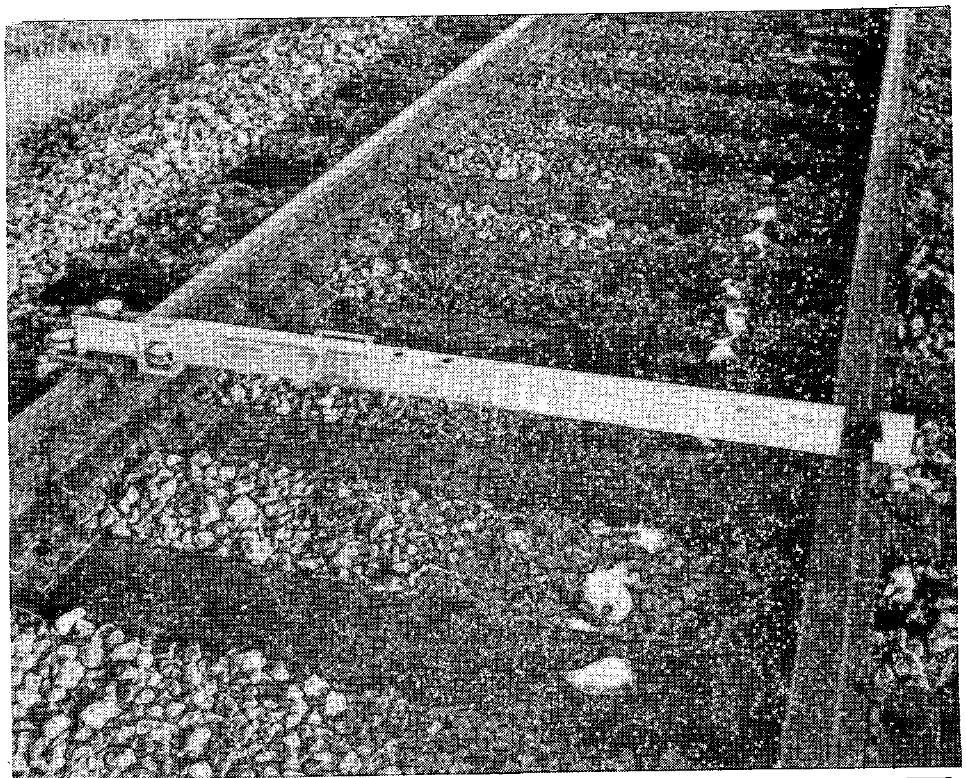
TTC N85-1760

FIGURE 44. SNAP GAUGE - HEAD HEIGHT LOSS.



TTC N85-1674

FIGURE 45. SNAP GAUGE - GAGE FACE WEAR.



TTC N85-1676

FIGURE 46. SNAP GAUGE - METAL FLOW.

7.2.1 Rail Profiles

The actual worn rail profiles for the 4.0° curve and control rail after 20 MGT are presented in Figures 47a through 47d. The rail head total area wear rate after 10 MGT is presented in Figure 48. The test profiles taken with the Yoshida Profilometer show slightly less wear rate based on total rail head area loss then the control area for the inside rail. Except for profile No.1, the outside rail shows less wear rate than the control rail, based on total rail head area loss. Figure 49 shows the area loss rate essentially the same for all rails, indicating that the rails have worn to a common profile between 10 and 20 MGT. The outside rail showed a greater total area loss than the inside rail.

7.2.2 Outside Rail Gage Face Wear

The outside rail gage face wear for the 4.0° curve is presented in Figures 50 and 51. At the 12 MGT point, the gage face wear was slightly less for the ground profiles as compared to the control rail. However, by 20 MGT, rails had worn to a common profile; thus, the wear rates were all the same.

7.2.3 Head Height Loss (Both Rails)

The head height loss, measured at the center of the rail head (4.0° curve), was greater for the inside rail than for the outside rail.

The head height loss rate was essentially the same for all profiles at both the 12 MGT and 20 MGT point of the test. The head height loss rates are presented in Figures 52 and 53.

7.2.4 Rail Hardness

The Brinell rail hardness tester was shown in Figure 42. This device measures the hardness of the rail near the center of the rail head. The Shore hardness tester was shown in Figure 43. This device can measure the hardness on a more curved surface. Therefore, it was used to measure the rail hardness on the field and gage side of the rail head centerline. The time history of the (Brinell) rail hardness at the center of the outside and inside rail of the 4.0° curve is presented in Figures 54 and 55. The time history for the field and gage side of the rail head, taken with the Shore device, is presented in Figures 56 and 57. The centerline hardness of this new standard rail changed slightly during the break-in period but remained consistent during the 20 MGT wear test. The hardness of the field side of the head of the inside rail showed an increase for the ground profiles, until the profiles reverted to the normal worn profile after approximately 12 to 14 MGT.

7.2.5 Lateral Forces

The visual and measured profile patterns observed during the 20 MGT wear tests indicate that the profiles tend to return to a normal worn rail profile between 10 and 20 MGT. The lateral forces on the outside wheel of the lead axle were measured at 0, 10 and 20 MGT in the 4.0° curve. The forces are presented in Figures 58 through 60.

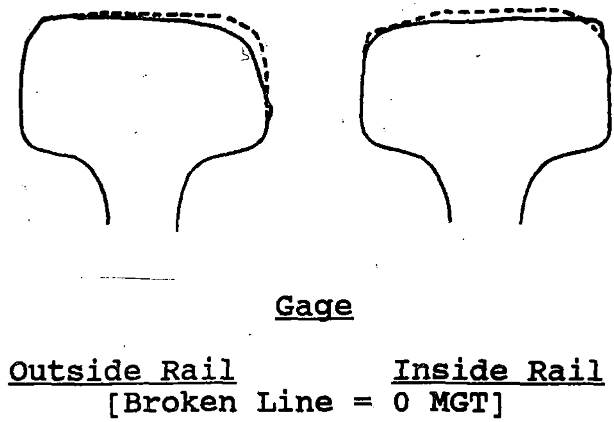


FIGURE 47a. PROFILE 1 - 4.0° CURVE.

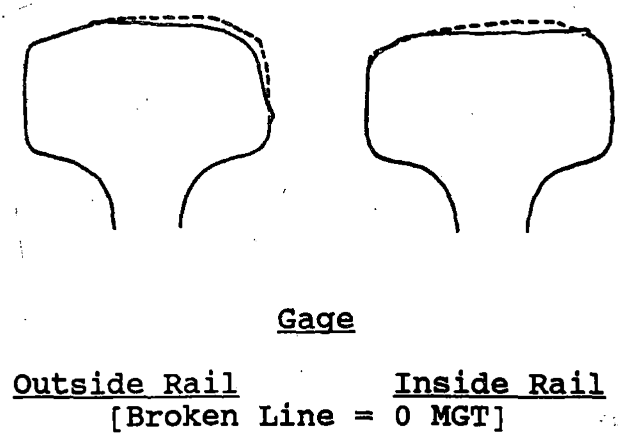
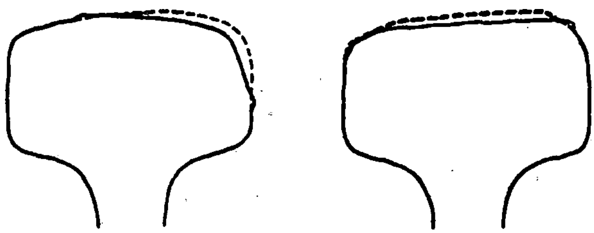


FIGURE 47c. PROFILE 3 - 4.0° CURVE.

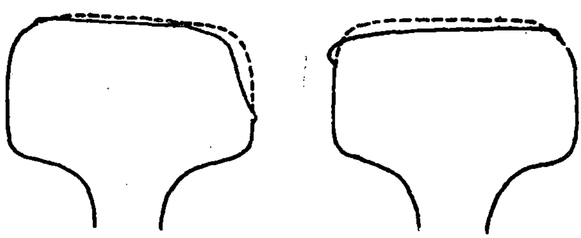
- LONG TERM WEAR PATTERNS, FOUR PROFILES.



Gage

Outside Rail Inside Rail
[Broken Line = 0 MGT]

FIGURE 47b. PROFILE 2 - 4.0° CURVE.



Gage
(Control)
Outside Rail Inside Rail
[Broken Line = 0 MGT]

FIGURE 47d. PROFILE 4 - 4.0° CURVE.

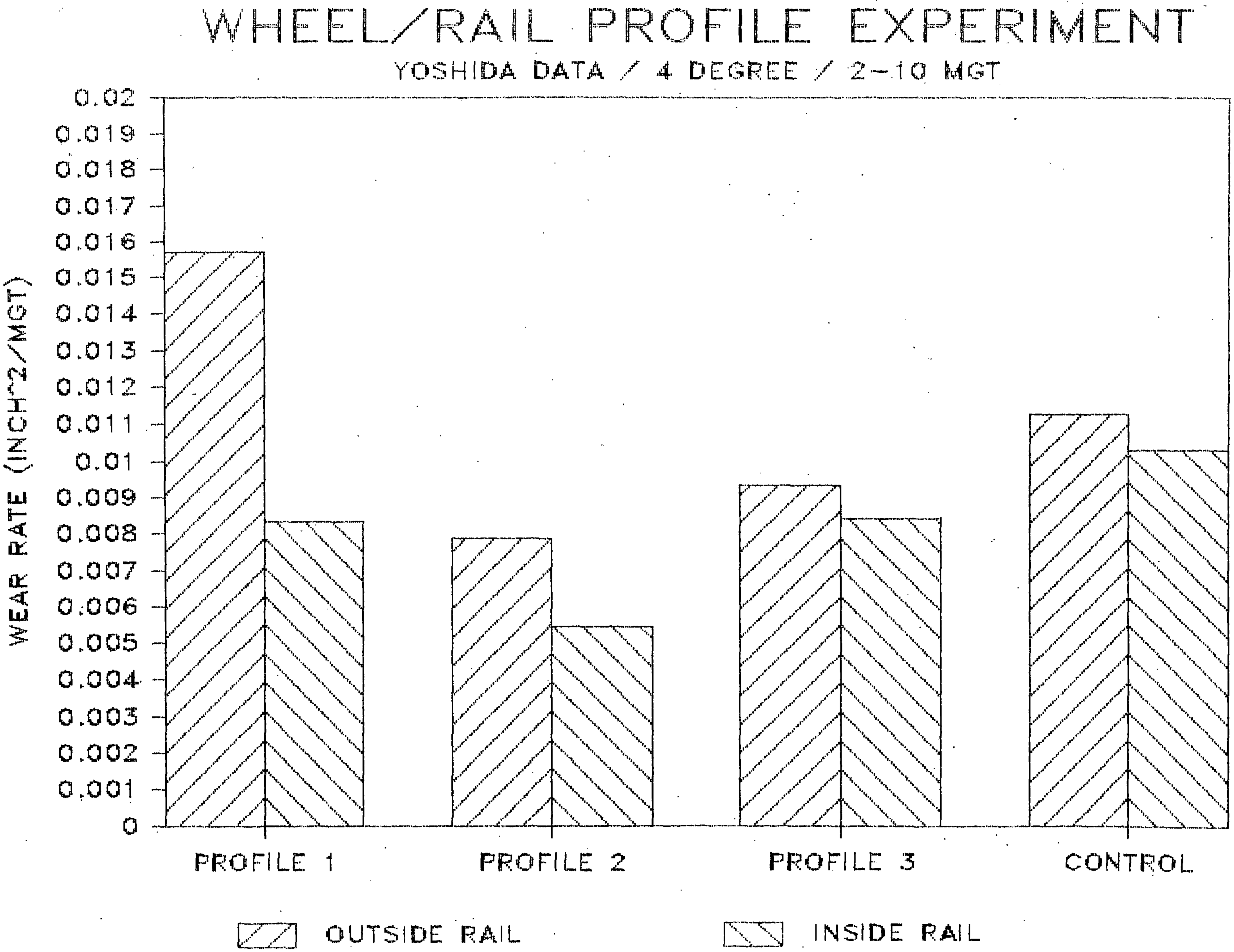


FIGURE 48. RAIL HEAD AREA LOSS - 4.0° - 2-10 MGT.

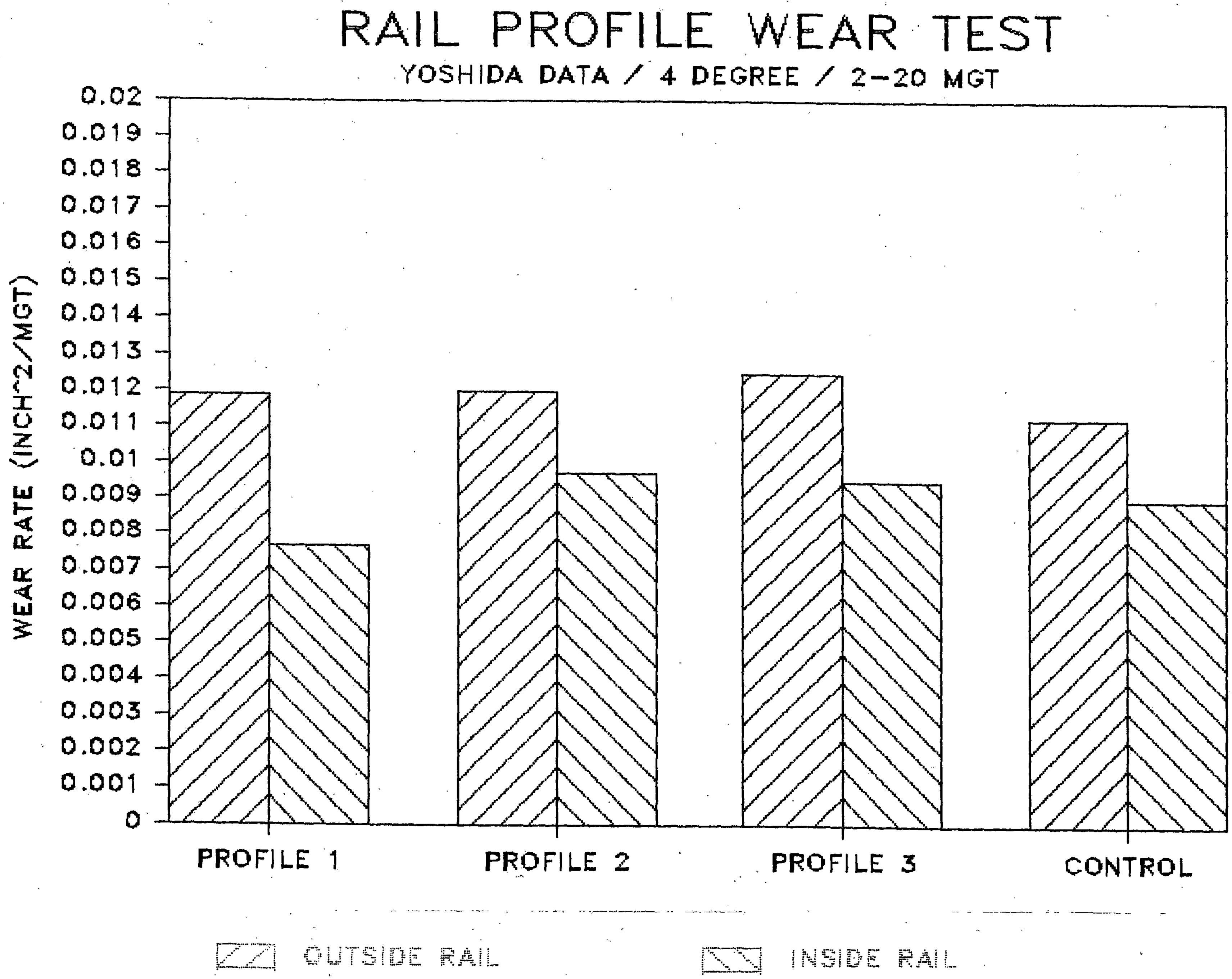


FIGURE 49. RAIL HEAD AREA LOSS - 4.0° CURVE - 2-20 MGT.

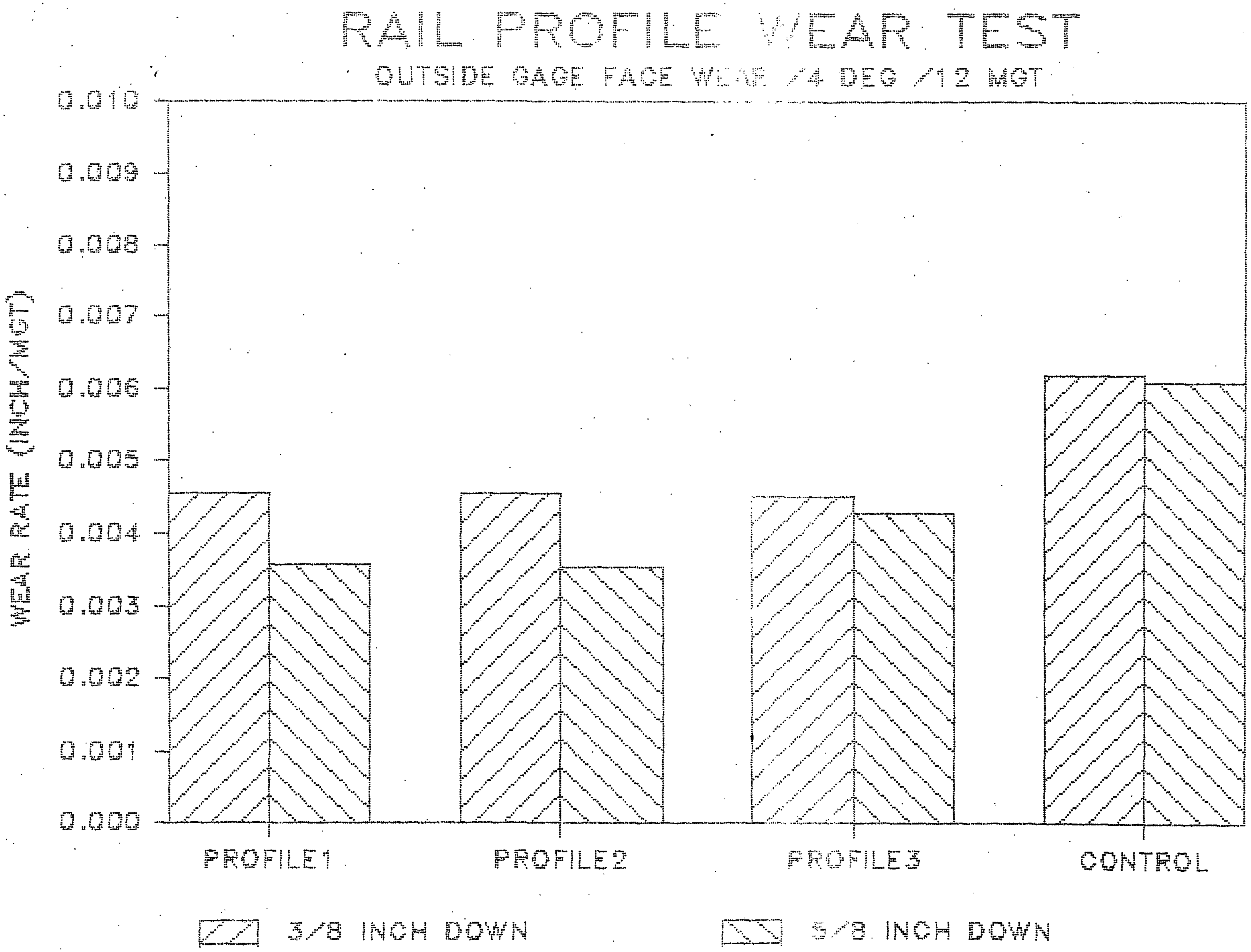


FIGURE 50. OUTSIDE RAIL GAGE FACE WEAR - 12 MGT.

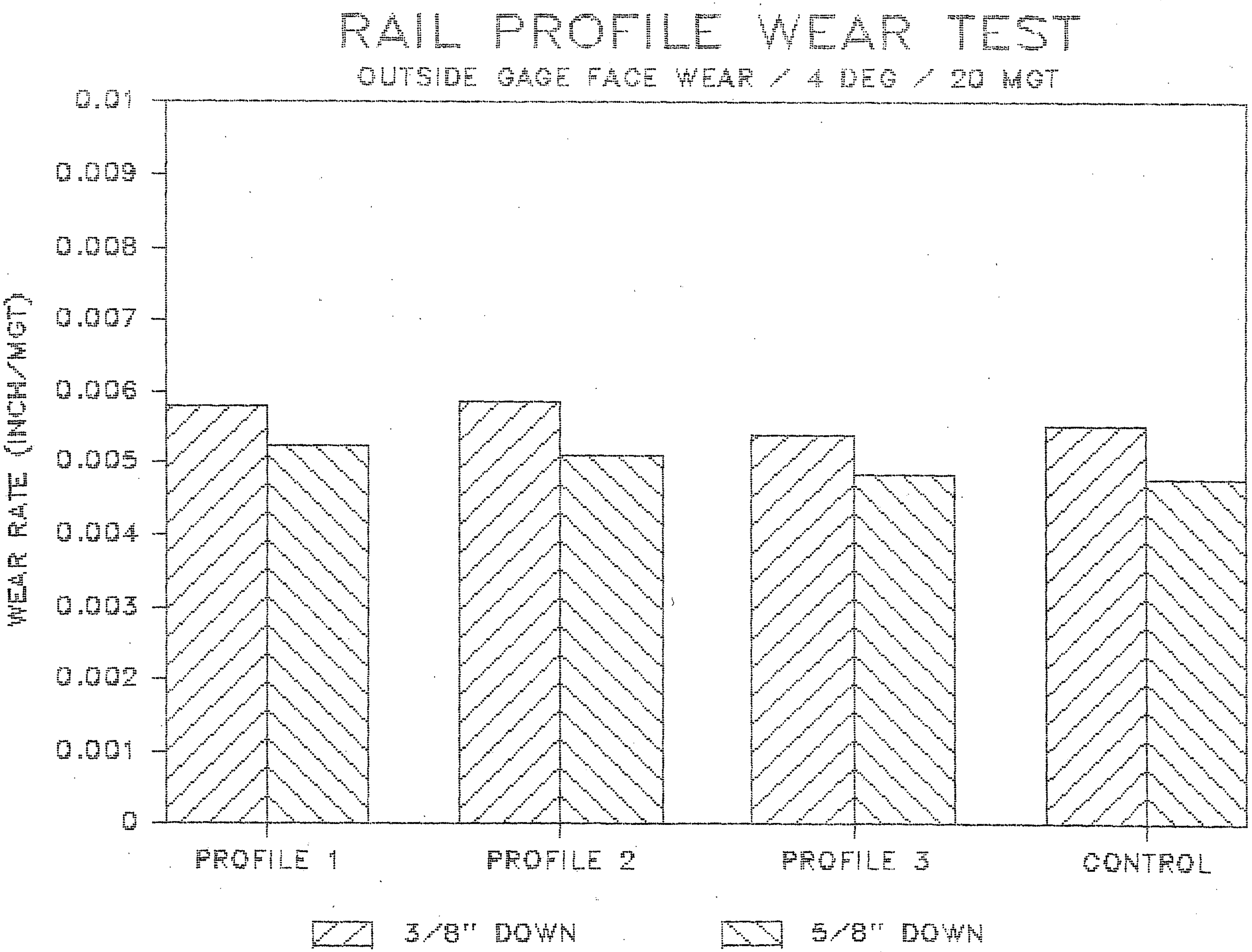


FIGURE 51. OUTSIDE RAIL GAGE FACE WEAR - 20 MGT.

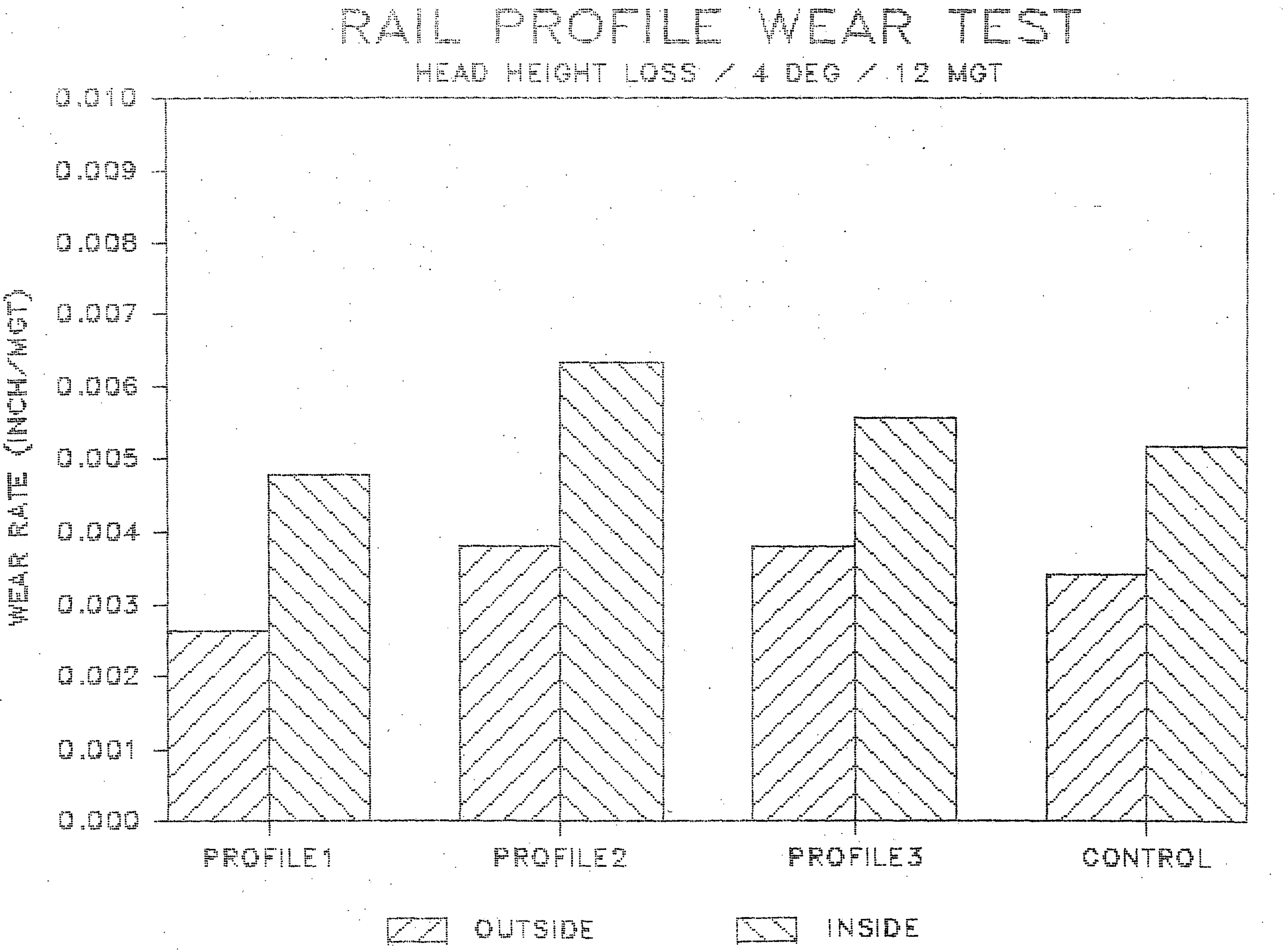


FIGURE 52. HEAD HEIGHT LOSS - 12 MGT.

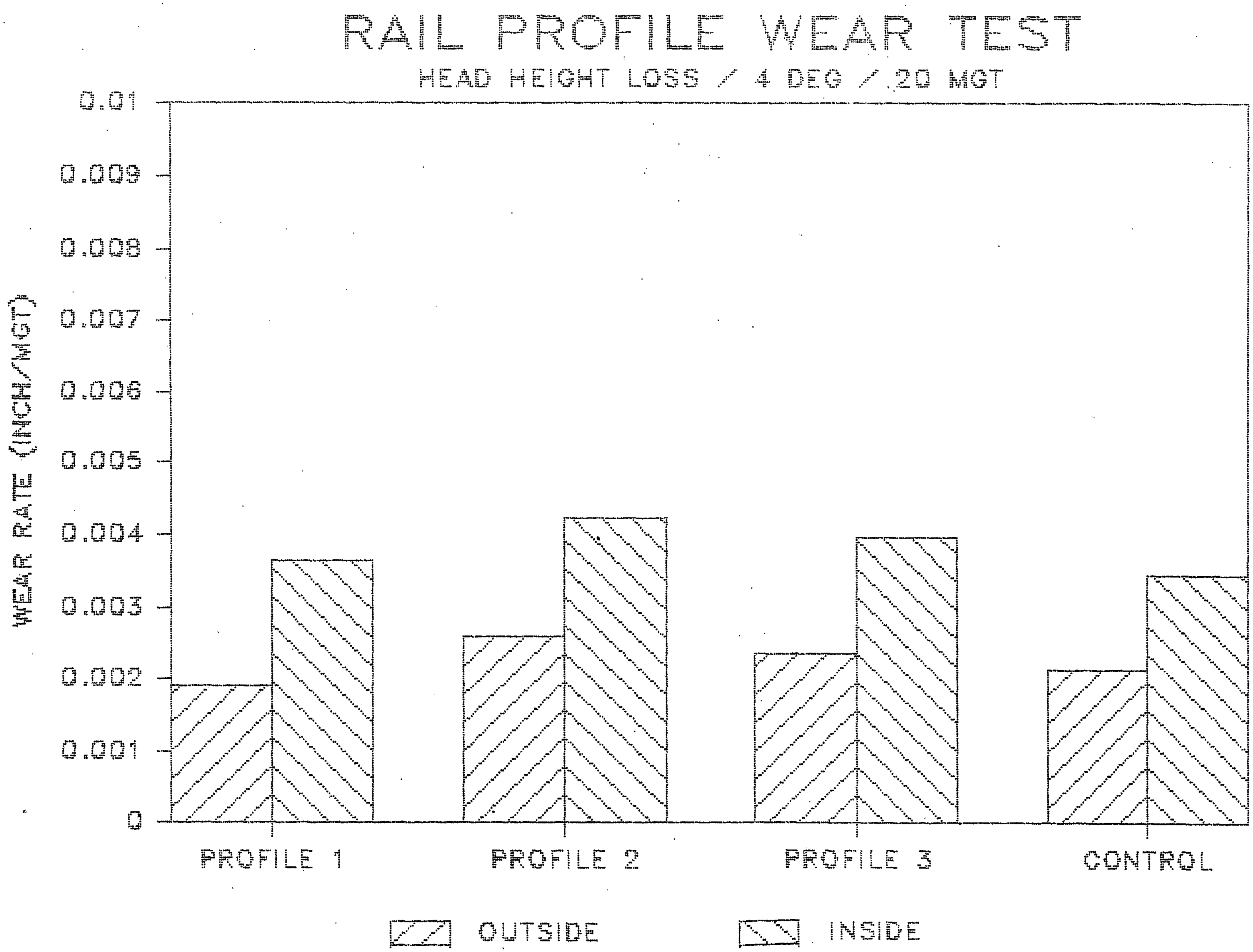


FIGURE 53. HEAD HEIGHT LOSS - 20 MGT.

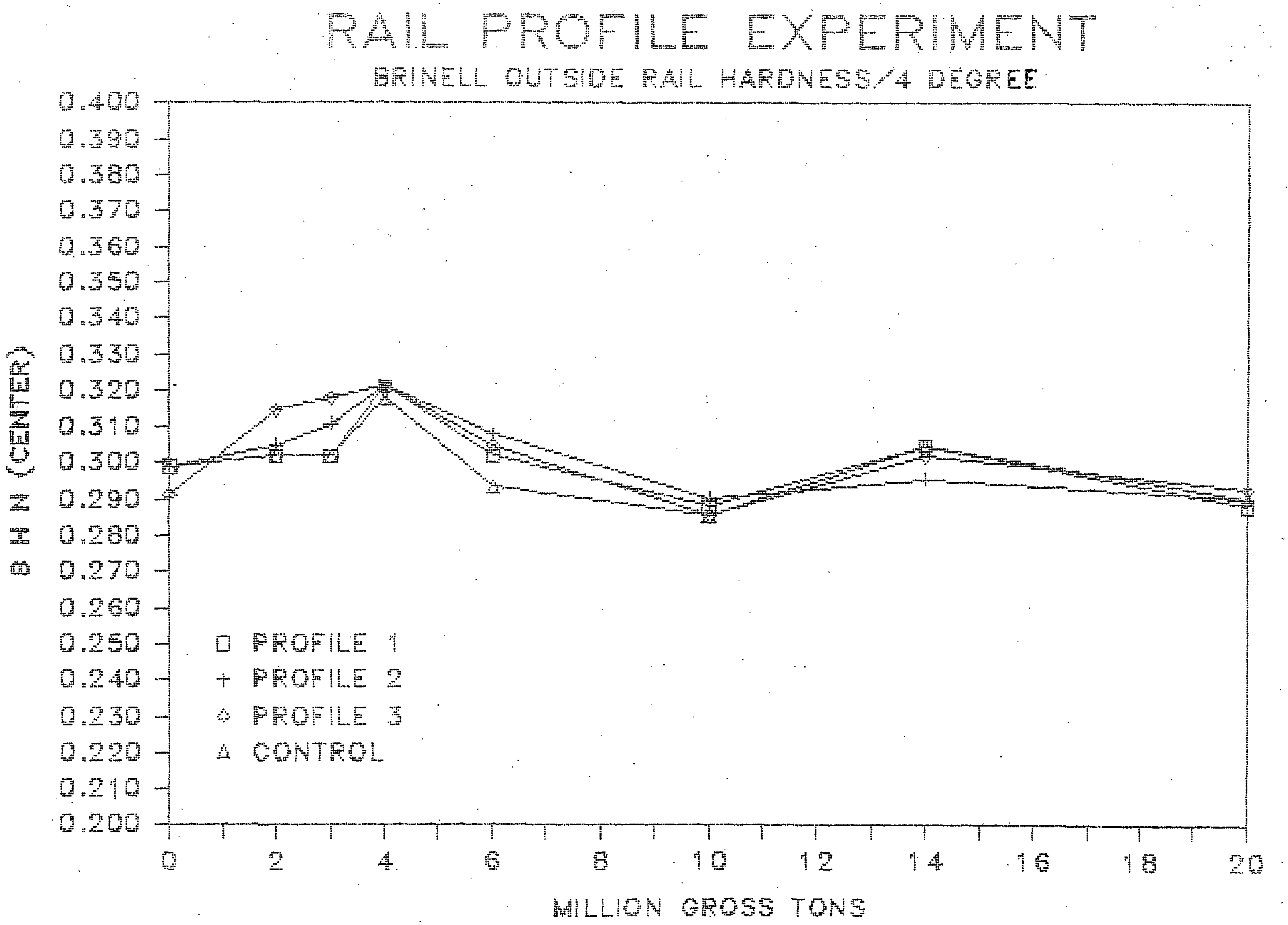


FIGURE 54. OUTSIDE RAIL HARDNESS (RAIL HEAD CENTERLINE).

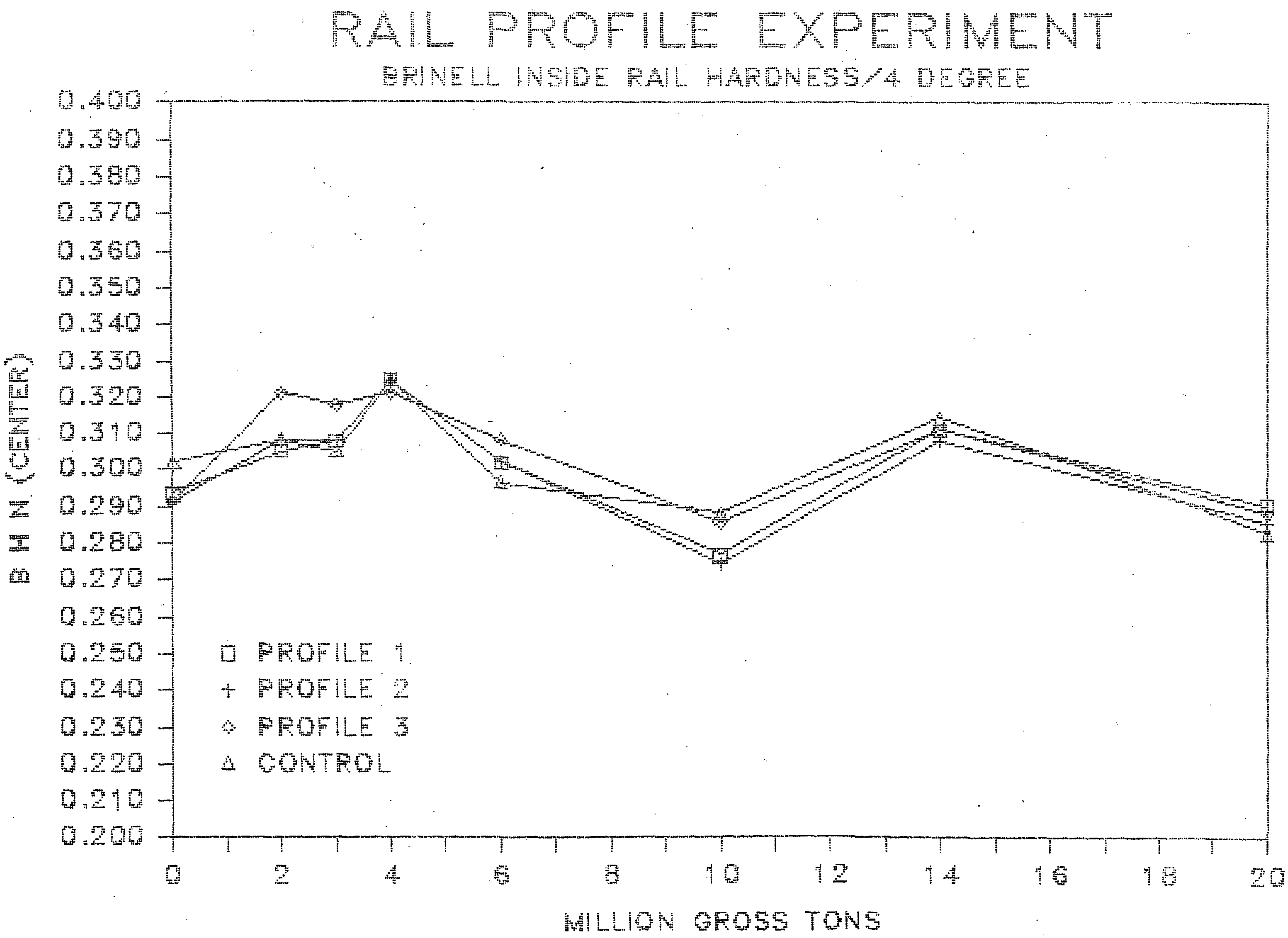


FIGURE 55. INSIDE RAIL HARDNESS (RAIL HEAD CENTERLINE).

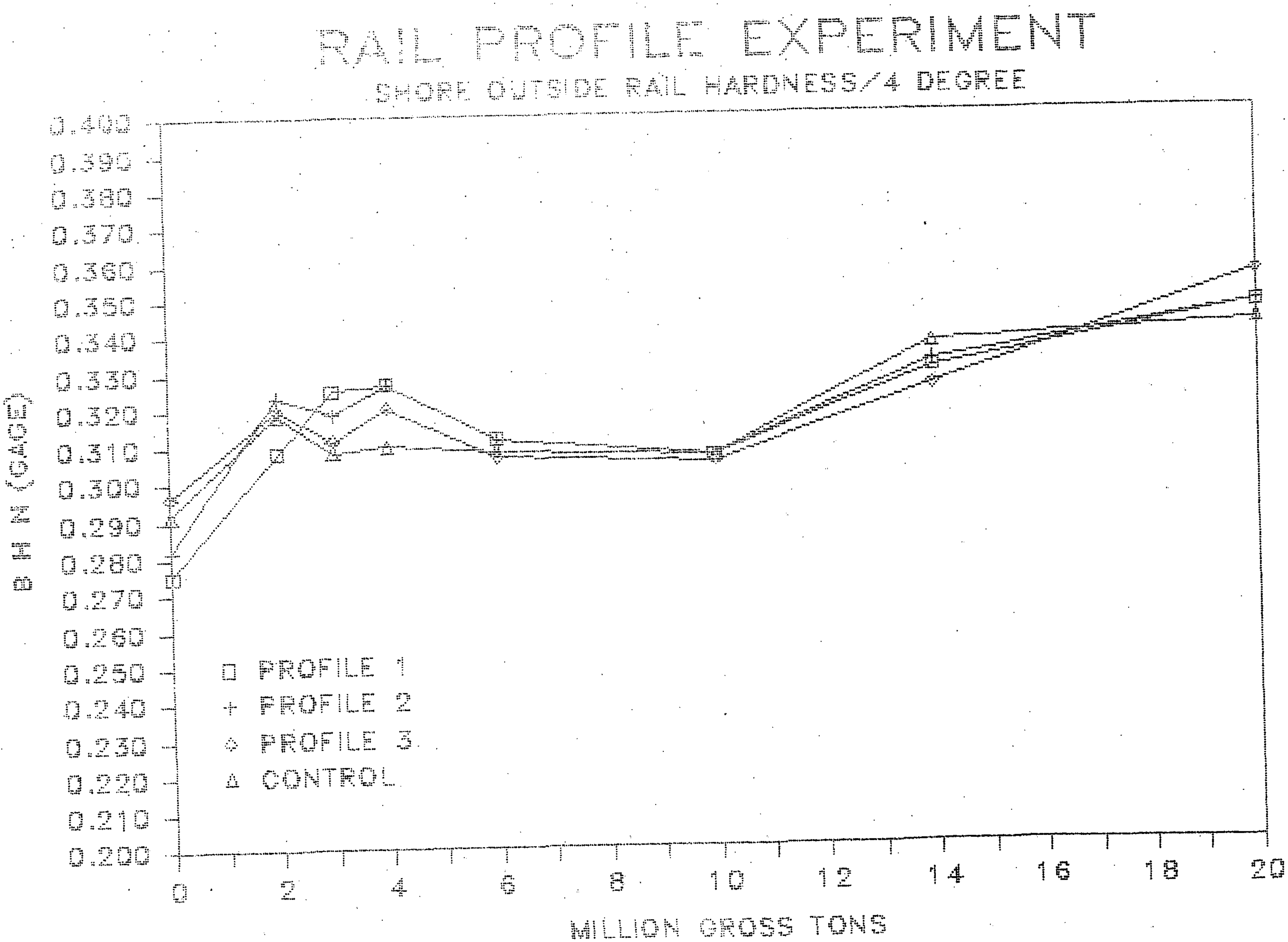


FIGURE 56. OUTSIDE RAIL HARDNESS (RAIL HEAD GAGE SIDE).

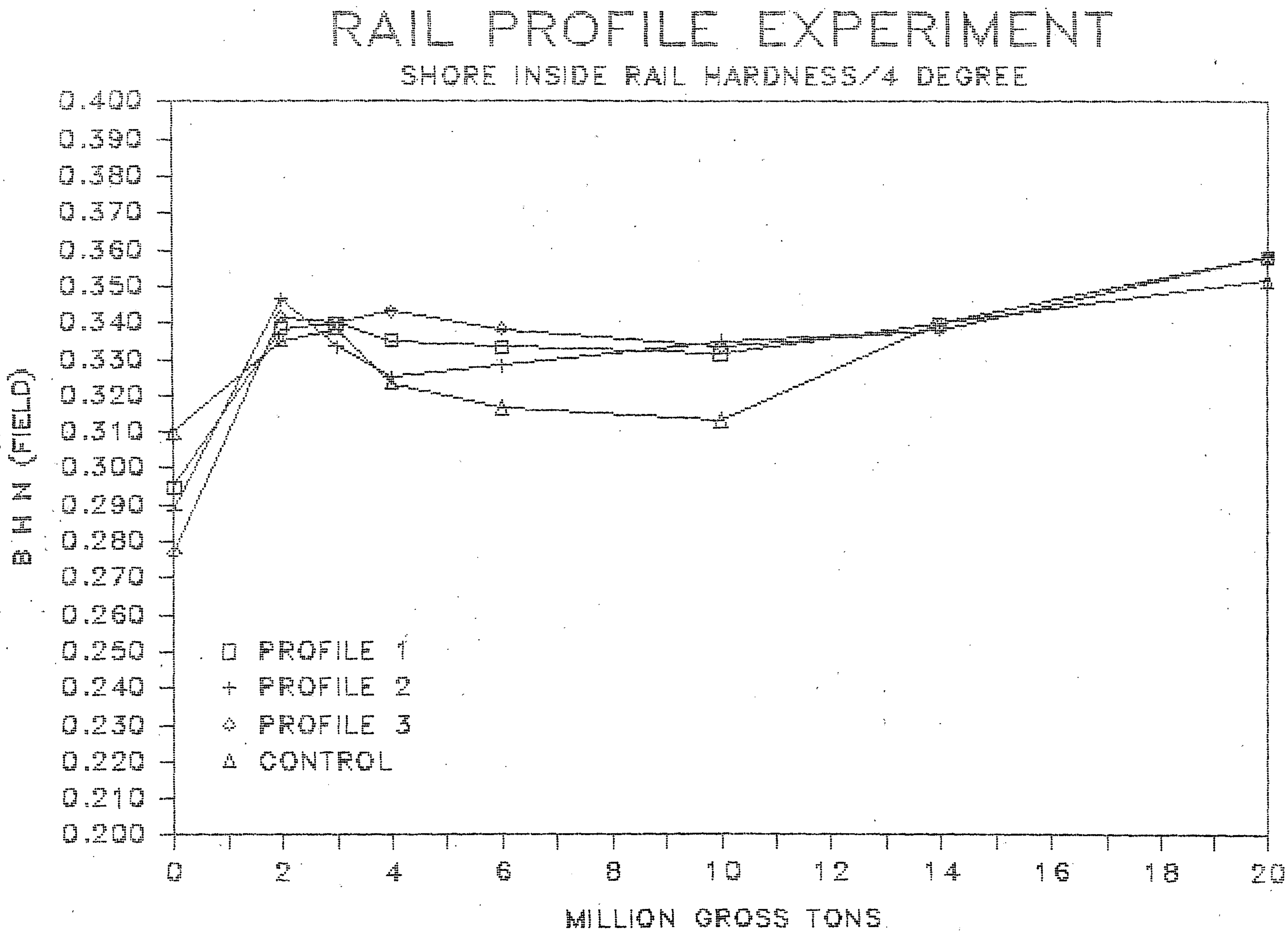


FIGURE 57. INSIDE RAIL HARDNESS (RAIL HEAD FIELD SIDE).

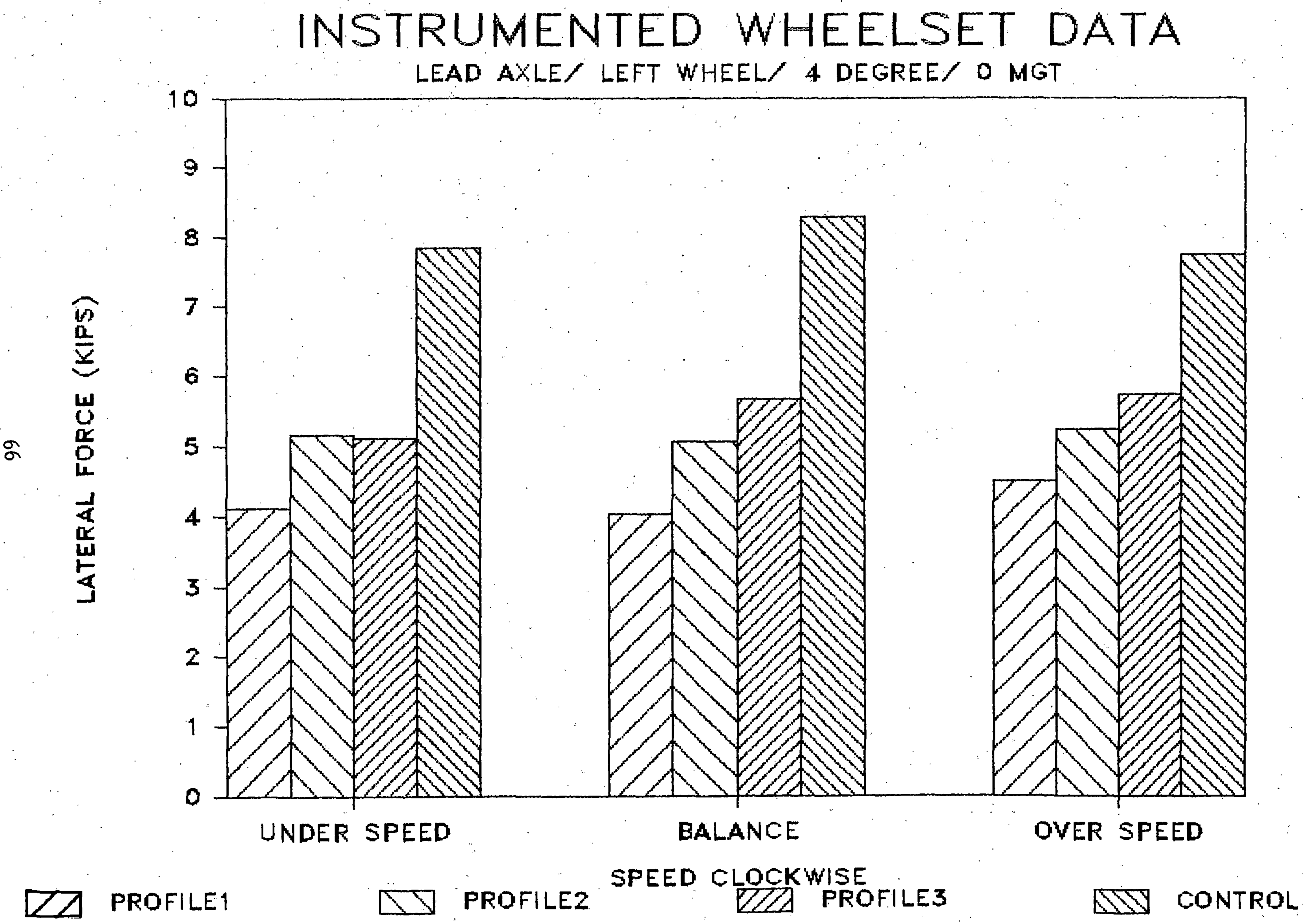


FIGURE 58. INSTRUMENTED WHEELSET DATA - 4.0° - 0 MGT.

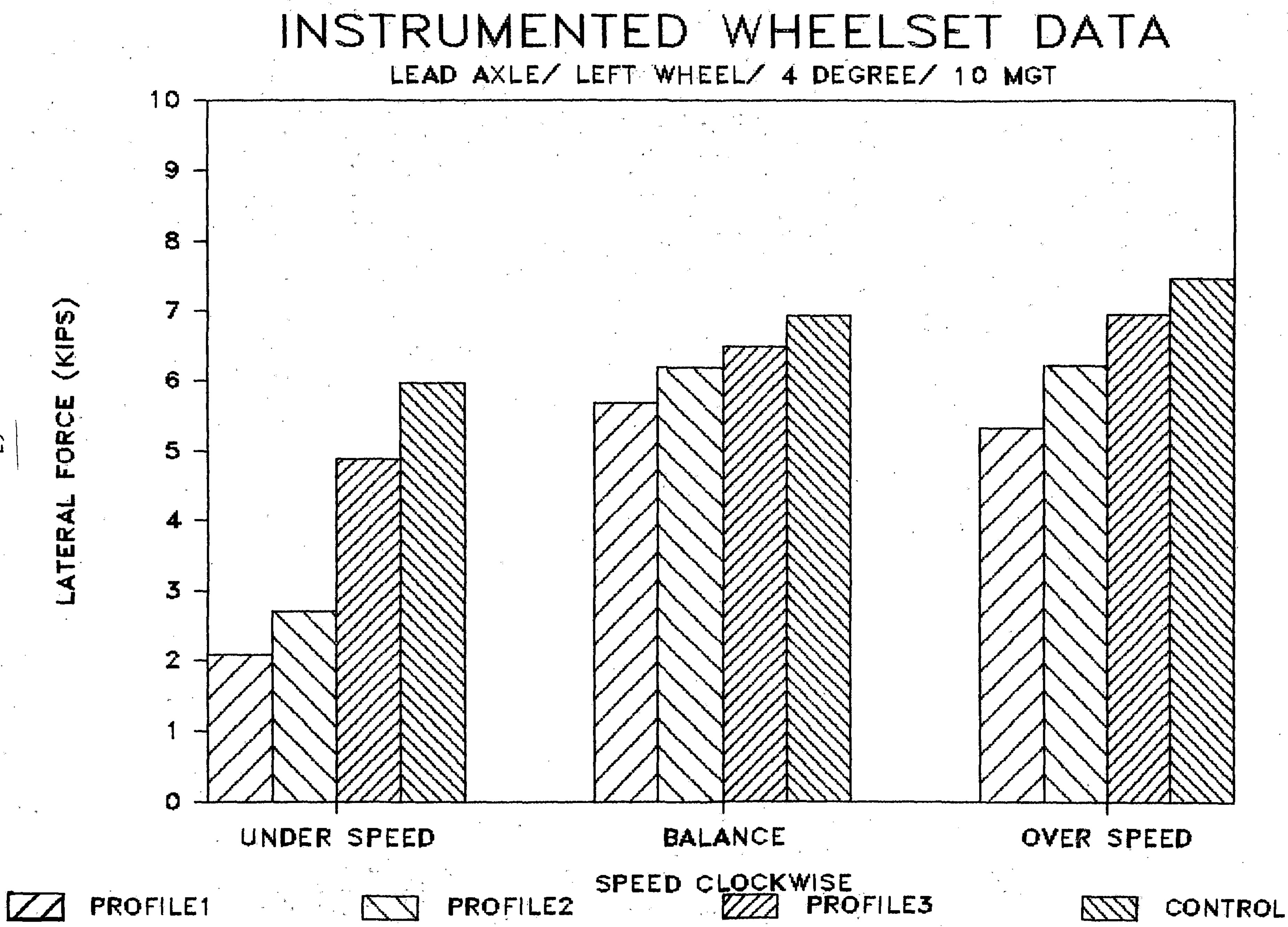


FIGURE 59. INSTRUMENTED WHEELSET DATA - 4.0° - 10 MGT.

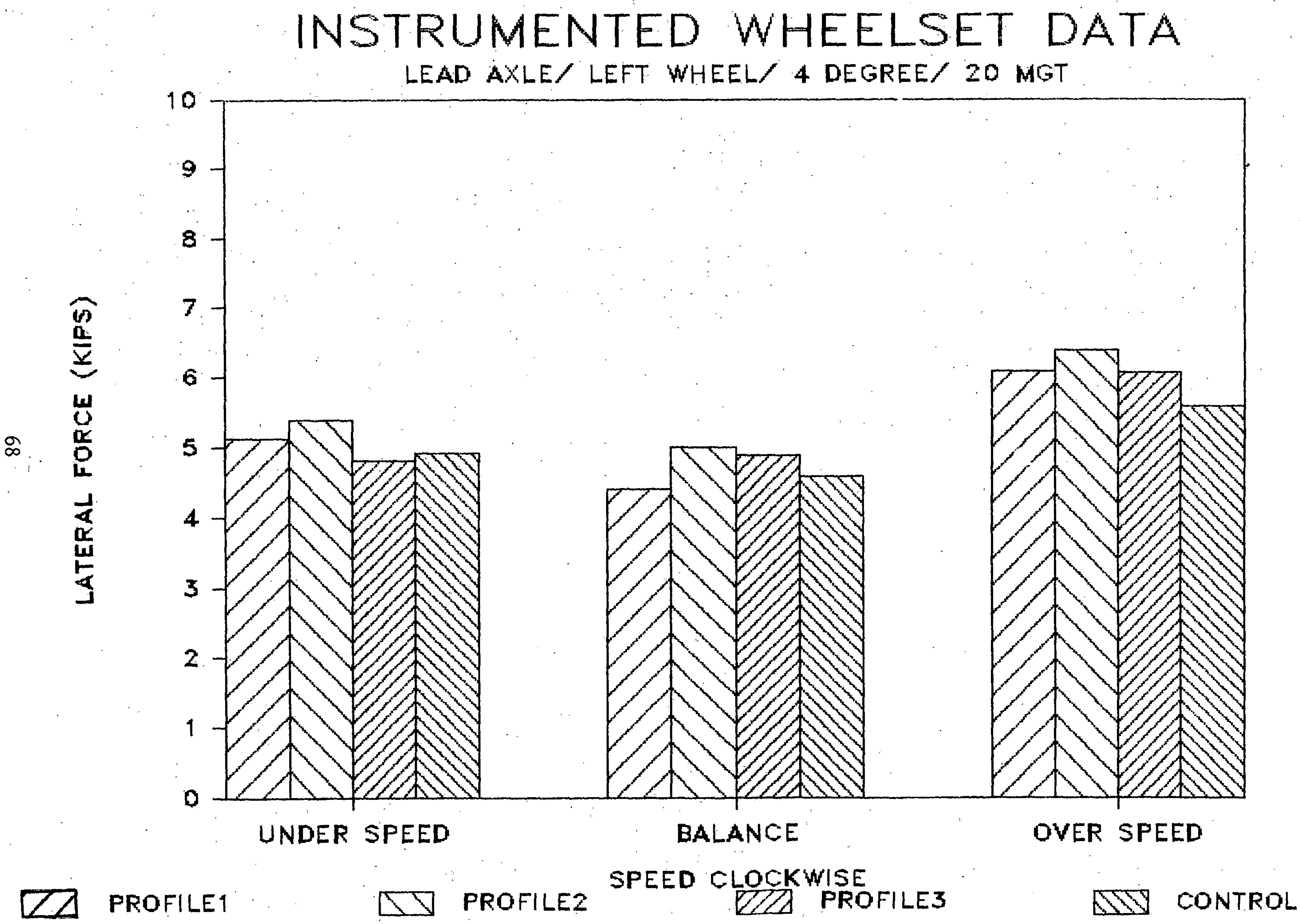


FIGURE 60. INSTRUMENTED WHEELSET DATA - 4.0° - 20 MGT.

8.0 CONCLUSIONS

Upon completion of the Rail Profile Variation experiment at the Transportation Test Center, the following observations can be made:

- Selected rail profile grinding can reduce lateral wheel/rail forces in curves of 1.5°, 3.0°, 4.0°, 5.0° and 7.5° curvature without lubrication.
- Except at the higher degrees of curvature, the longitudinal forces of the lead axle of a truck can also be reduced with a selected rail profile grinding, but to a lesser extent than the lateral forces.
- Profile 3, with the most severe grind pattern and grinds on the gage and field face, appear to have performed better at curvatures below 4.0°.
- The profiles with the lesser grinds, like Profile 2, perform better for curvatures above 4.0°.

- The rail profiles tested did not create corrugations on the inside rails during the 20 MGT on unlubricated track.
- Based upon the total rail head area loss, the profile grinding slightly reduced the wear on the inside rail in the 4.0° curve.
- Gage face wear on the outside rail of the 4.0° curve was also reduced slightly by rail profile grinding.
- The hardness of the field side of the head of the inside rail head showed a slight increase due to profile grinding.
- Metal flow for the 4.0° curve was evident on the field side of the inside rail head for the profile grinds. The flow was evident on the gage face of the inside unground control rail head.

9.0 RECOMMENDATIONS

The following recommendations are made based upon results of this Rail Profile Variation experiment:

- Upgrade the TTC rail grinder, with additional motors and capability of grinding both sides of each rail to a maximum of 60° from the horizontal.
- Investigate the possibility of rolling desired rail profiles at steel mill to eliminate initial rail profile grinding in the fields and/or investigate the feasibility of rolling desired rail profiles using wear resistant metallurgy to extend life of profiles.

- o Conduct long term wear tests of profiled rails with lubricated track conditions to investigate affect on rail defect occurrence.

10.0 ACKNOWLEDGEMENTS

The author wishes to express his appreciation to John A. Elkins and John F. Leary for their helpful insights as to procedure and validation of results, and to James W. Grebenc for the extensive graphics work required for presentation of this report.

11.0 REFERENCES

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2. Elkins and Gostling, "A General Quasi-Static Curving Theory for Railway Vehicles," Proceedings 5th VSD 2nd IUTAM Symposium Vienna, September 1977.

3. Elkins and Eickhoff, "Advances in Non-Linear Wheel/Rail Force Prediction Methods and Their Validation," Volume 104, Journal of Dynamic Systems, Measurement and Control, June 1982.

APPENDIX A

STEADY STATE CURVING MODEL INPUT PARAMETERS

Symbol	Title	Parameter
HKY	Primary Lateral Stiffness	2.8 MN/M
KPSI	Primary Yaw Stiffness	350.0 MN-M/RAD
KS	Cross-Braced Shear Stiffness	0.0 MN/M
KB	Cross-Braced Bending Stiffness	0.0 MN-M/RAD
M	Wheelset Mass	1.457 MG
MB	Truck Frame Mass ½ Carbody	56.73 MG
KTHETA	Roll Stiffness - Truck Axles	0.0 MN-M/RAD
KTHETAB	Roll Stiffness - Car Trucks	0.0 MN-M/RAD
AO	Semi-Wheel Base - Axles	0.888 M
AC	Semi-Wheel Base - Trucks	0.0 M
H	C.G. Height Above Rail	2.01 M
LO	Semi-Gage	0.760 M
WRL/WRR	Wheel Radius	0.457 M
CURV	Degree of Curvature (+ CW)	1.5 to 7.5 DEG
THETAD	Cant Deficiency	-3 to +3 DEG
MUL	Coefficient of Friction - Left Rail	0.40
MUR	Coefficient of Friction - Right Rail	0.40
MUF	Coefficient of Friction - Flange	0.40
NLC	Non-linear Curving Model	--
PY	Lateral Force Applied at Lead Axle	0.0 MN
QZB	External Yaw Torque on Truck	0.0 KN-M
QXA	Driving or Breaking Force	0.0 KN

APPENDIX A (CONTINUED)

STEADY STATE CURVING MODEL INPUT PARAMETERS

Symbol	Title	Parameter
TWISTB	Twist Between Axles	0.0
TWISTC	Twist Between Trucks	0.0
PSI10	Yaw Misalignment - Lead Axle	0.0 MRAD
PSI20	Yaw Misalignment - Trail Axle	0.0 MRAD
BO	Lateral Slim Spacing of Journals	0.0 M
MS	Mass of Sideframe	0.0 MG