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RAIL ROUGHNESS STUDY OF THE HOLLOMAN HIGH
SPEED ROCKET SLED TEST TRACK

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TEST TRACK DIVISION
6585TH TEST GROUP
HOLLOMAN AIR FORCE BASE, NEW MEXICO

1 SEPTEMBER 1981

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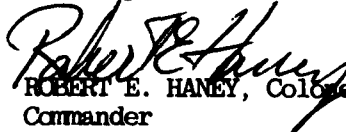


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PUBLICATION REVIEW

This report has been reviewed and is approved.


ROBERT E. HANEY, Colonel, USAF
Commander

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Data from a first order survey of the Holloman High Speed Rocket Sled Test Track was statistically analyzed to characterize the roughness of the rails. The rail roughness is a forcing function manifested as vibration in high speed sled tests conducted on the Track. Statistical methods in the space and frequency domain were developed and discussed and further data requirements were justified.		

FOREWORD

This report was prepared by the Test Track Division, Holloman Air Force Base, New Mexico, under System Development Plan entitled "Unified Sled Design Techniques."

The authors wish to express their appreciation to the many individuals who significantly contributed to completion of the final report, and in particular to Mr Bob Thede, Guidance Analysis Branch, for his timely preparation and adaptation of computer programs and accurate processing of the data. Special appreciation is also expressed to the Track Measurement Section that gathered the precise data through many hours of diligent surveying. Particular thanks are extended to Mrs Rosemary Phelps for typing the report.

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1. INTRODUCTION

1.1 Purpose

The purpose of this study was to define and determine the "roughness" of the Holloman High Speed Rocket Sled Test Track. Results of the study will be used to:

1.1.1 Provide forcing functions for Sledyne, a computer simulation program for structural analysis, and

1.1.2 Determine the effectiveness of rail grinding in reducing rail roughness, and hence reducing dynamic loads imparted to rocket sleds.

1.2 Background

The Holloman Test Track is a totally unique facility that offers a one-of-a-kind capability for testing aerospace equipment. The Holloman track is almost 10 miles long and has the smoothest and straightest rail surface in the free world. Each rail is continuously welded and under tension at temperatures less than 140°F. A sketch of the Holloman Test Track showing construction completion dates and track cross sections is shown in Figure 1.

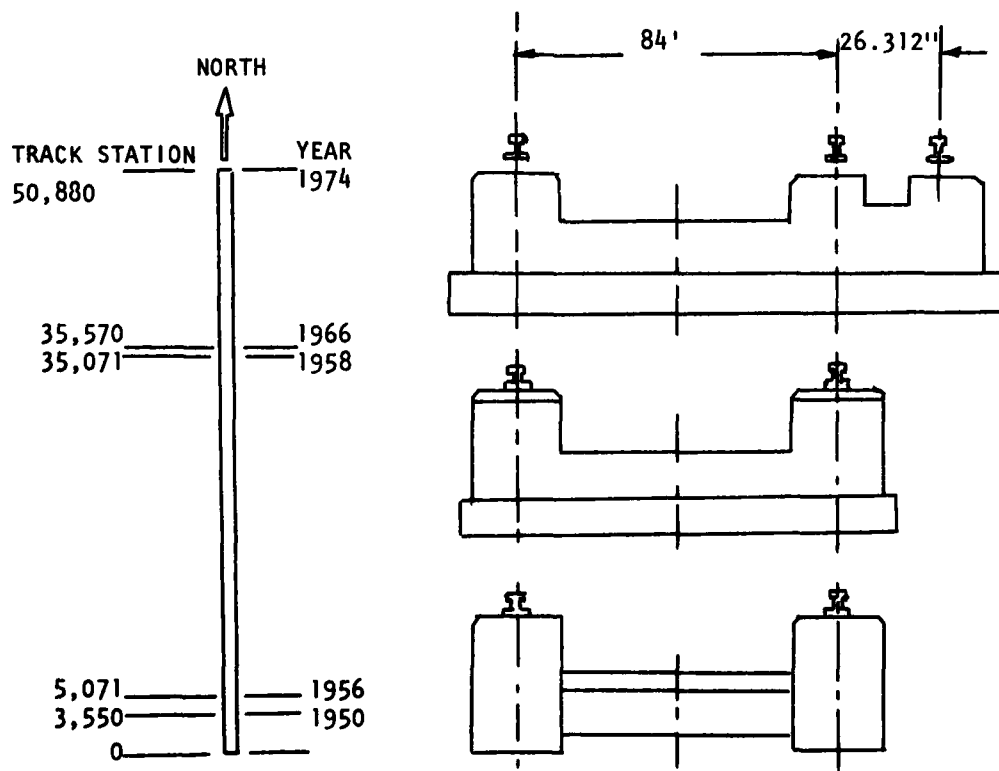


FIGURE 1. TRACK LAYOUT AND GIRDER CROSS SECTIONS

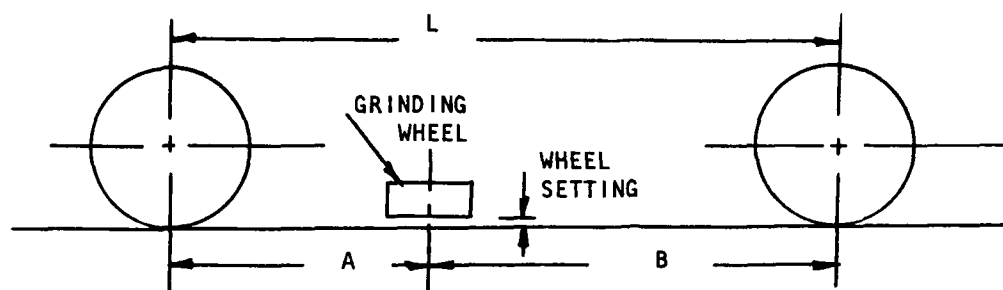
The original 3,550 foot facility, built in 1950, was extended to 5,071 feet in 1956 and is of a different girder cross-section from subsequent additions. In 1958 a major addition was completed which lengthened the facility to 35,071 feet. A short section was added in 1966 for a blast test program. The last extension was completed in 1974 and brought the total length to 50,880 feet; however, this last 15,310 feet was not fully operational until 1978 due to problems in a settlement area. As shown in the sketch, the original track was built on an 84-inch gage; the last 15,310 foot addition has a third rail 26.312 inches east of what was previously referred to as the east rail. This narrow gage capability allows for impact testing 3 foot diameter payloads in a Mach 4 velocity regime.

The purpose served by the Test Track is to provide a path which is as straight as is technically and economically feasible for a 10-mile outdoor facility; minor irregularities in the guiding surfaces can cause destructive dynamic forces and increase vibrations to unacceptable levels. Continuous surveys (and realignment) are conducted on the rails to insure rail alignment in both the vertical and lateral directions. Detailed procedures and tolerances are given in references 1 and 2. These references provide step-by-step descriptions of the procedures and in-depth appraisal on what the alignment and smoothness goals mean in actual application. For this study, the alignment goal is summarized as ± 0.005 inches to a fiducial (reference) line established by a U.S. Coast and Geodetic first order survey. This tolerance applies to the vertical and lateral direction for the west rail (master rail). The east rail and the third rail on the north 15,310 foot of track are aligned within ± 0.010 inches to the master rail by the means of fixtures.

1.3 Rail Grinding Technique

Separate from the alignment procedures, rail grinding is used to straighten the rails between the 52-inch space tie-downs. Grinding is accomplished after an initial rail bending procedure. As noted in Reference 2, "The entire process is, therefore, based on the premise that the points tied down by the alignment fixtures are located on a straight line, and that only the stretches between these fixtures should be affected by grinding." In actual practice, the grinding does have a smoothing effect over long distances as will be shown later in this study.

Two grinding machines have been developed over the past 25 years. The wheel bases and relative location of the grinding wheels are shown in the following sketch.



MACHINE	L (INCHES)	A (INCHES)	B (INCHES)
1	188	72.0	116.0
2	192	100.8	91.2

The principle of operation is defined as "profile averaging" method where the grinding machine is independent of external guideways and becomes self-aligning. Detail description of the evolution of these techniques are given in Reference 2. As previously described, the goal is to result in smooth rail surfaces that follow a straight line in the vertical and lateral planes.

1.4 Definition of Roughness

Before the study can progress, the definition of rail roughness must be determined and stated unambiguously. For purposes of this study, rail roughness was defined as the variations (or residuals) remaining after a best fit (least squares) straight line slope was removed from data surveyed at one foot intervals along the track. This rationale was justified by the fact that the slope would

provide only low frequency forcing functions to sleds, frequencies below the range of interest. The one foot interval was selected as a minimum interval which was economically feasible to obtain.

In this study residuals from various track stations are going to be compared as roughness. The validity of each set of residuals is dependent on the goodness-of-fit of each line. So, the coefficient of determination for each line was checked to insure it was different from zero. All were significantly different from zero. In addition, to compare residuals, the standard error of the estimate was utilized. This comparison is valid only if the coefficients of determination are not significantly different. Two of the 24 stations had coefficients of determination different from the rest. The two stations were at the north end, and each had a slope a magnitude smaller than the rest (and very nearly zero). Rigorously, the standard deviation rather than the standard error of the estimate (or conditional standard deviation) should be used. But for the sake of uniformity, the standard error of the estimate was used. In these two cases, since the slope was so small, there was little difference in the two parameters.

1.5 Sledyne

This rail roughness data will be used in the Sledyne computer program. Sledyne is a computer program used in sled design that takes the two rigid body modes of vibration and the first six (6) flexible modes of vibration in the pitch plane and, coupled with input parameters, calculates static G-forces at each finite mass point equivalent to the maximum dynamic response of the model. The six flexible modes of vibration are derived from another computer simulator, NASTRAN. NASTRAN uses an eigenvector/eigenvalue solution to a finite element model of the sled structures. The other input parameters are the stiffness of the supporting structure between the rail and the sled body, quasi-steady state forces such as lift, thrust, etc., velocity of the rocket sled and the non-linearity associated with the slipper gap. The velocity versus time data is used to modulate the rail roughness and results in a displacement versus time forcing function for the Sledyne simulation.

Sledyne was developed in 1974 and the only rail roughness data available was one 480 sample set taken along one 400 foot location on one rail in 1969. Data was taken every 10 inches at one point in the top center of the rail head. Additional discussion of this data will be provided later in the study.

Sledyne provides simulation only in the pitch plane and since only one line of rail roughness had been measured, the forcing function is started at a random point along the 400 ft sample and repeated in a continuous loop manner until the simulation is complete. The known length between front and aft slipper is used to insure that the aft slipper follows the front slipper in a physical sense. In the case of dual rail, each front slipper is started at different random points in the sample and repeated. The aft slippers longitudinal location is again specified.

Sledyne is obviously using a very small sample to derive a model of its forcing function. The original purpose of this study was to better characterize the track and toward that end the Sledyne forcing functions will be modified to include the results of this report.

1.6 Rail Grinding

A logical by-product of this report is to address a more basic question: Does required grinding result in significantly smoother rail surfaces? The two grinding machines were developed at a significant capital investment and the continued grinding is a constant drain on limited resources.

The data utilized in this study were obtained in early 1978. In March 1979 the status of rail grinding was as follows:

Track Station 0 to 35,570 ft

Top (1 & 2) 0.010"

Sides (1 & 2) 0.025" (one third ground to .010")

Bottom None

Track Station 35,570 to 50,880 (FY74 extension)

Top (1 & 2) 0.025" (3) .010"

Sides None

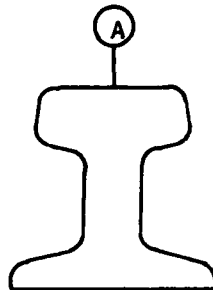
Bottom None

As of June 1981, the only additional grinding that has been accomplished on the master rail is the top from track station 35,570 to 50,880 which has been ground to 0.010" and the east side of the master rail from 35,510 to 50,880 has been ground to 0.025". Note the 1978 measurements were taken on the west side of the master rail.

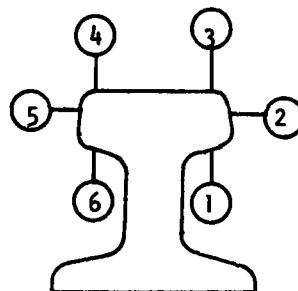
So the data from the south 35,000 feet can be compared with the north 15,000 feet to determine whether grinding has effected roughness. If the results of this study found no difference, a substantial savings could be realized.

1.7 Data Collection

In 1969 a first attempt was made to measure rail roughness. One set of data was measured for approximately 400 feet along the top of the west rail. Measurements were taken every 10 inches. This effort provided a 486 continuous sample; however, the measurement was taken only at one point of the rail cross-section, point A in the sketch.



This initial effort was less than desirable, since the monorail rocket sled rides on the following six (6) positions:



This observation can be verified by placing a monorail on the rail and positioning the sled in various conditions of roll. Dual rail, narrow gage sleds and outrigger rocket sleds ride on fewer surfaces since the roll movement is limited by the use of two rail heads.

In May 1978 a complete series of track roughness measurements were made much more extensive than the earlier 1969 set along one 400 foot section of rail. These new measurements were made in four phases. As shown in Table A, the plan was to take 25 sets of data every 2,000 feet along the track. Each set would contain 51 measurements of three roughness measurements at positions A, B and C in Figure 2. In actual practice rail side water trays were installed at track station 20,000, which obstructed any measurements at that station. Based on the earlier effort, measurements were made every one (1) foot in preference to 10 inches, since it had been demonstrated that the energy for periods of less than two (2) feet is small; i.e., two orders of magnitude smaller than the longer periods. A complete listing of this data is given in Appendix A.

The sampling philosophy was a compromise of varied and somewhat contradictory sampling requirements, survey techniques and economics. First, true sampling requires random samples which in this case would require n samples along the length of the track. However, survey techniques preclude accurate surveys over 250 to 300 feet for a single set. In addition, frequency domain analysis to meet the primary objective of the study required samples at regular, small intervals.

The sample size of 51 was derived by a trade-off between economics and confidence in derived statistics. In experiment design, the cost of data must be weighed against the probability of reaching incorrect conclusions. The two error types to be considered are the α or Type I error and the β or Type II. A Type I error is one in which a hypothesis that a sample statistic equal the population statistic is rejected when in fact they are equal. A Type II error is one in which the hypothesis is accepted when in fact it is false.

For this test, the basic hypothesis is that the standard deviation of the residuals of the samples is less than or equal to the standard deviation of the population residual. Or stated concisely;

$$H_0: s \leq \sigma$$

The alternative hypothesis is that s is greater than σ ;

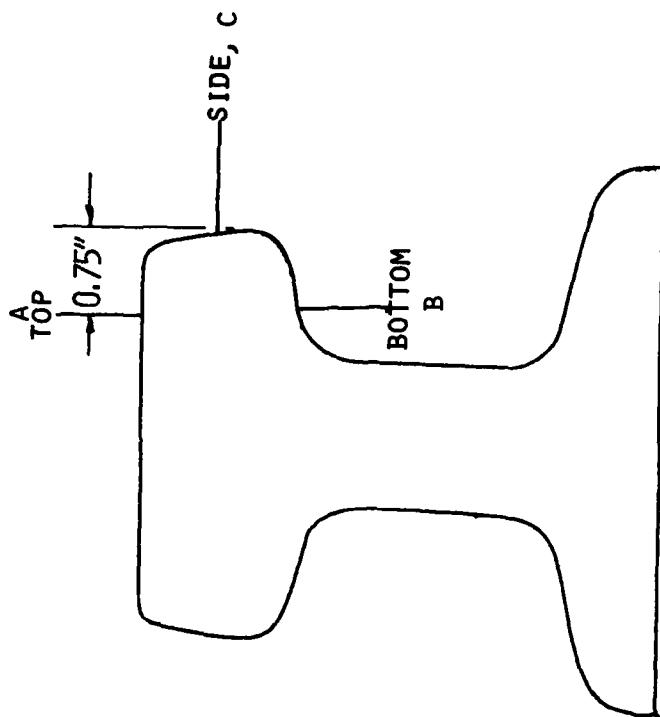
$$H_1: s > \sigma$$

TABLE A. PHASES FOR TRACK SURVEY OF RAIL ROUGHNESS.

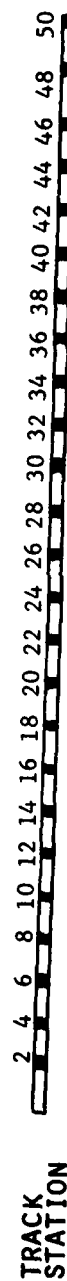
SAMPLE NO.	TRACK STATION	PHASE			
		I	II	III	IV
1	2,000	51 pts			
2	4,000			51 pts	
3	6,000		51 pts		
4	8,000				51 pts
5	10,000	51 pts			
6	12,000			51 pts	
7	14,000		51 pts		
8	16,000				51 pts
9	18,000	51 pts			
10 *	20,000			51 pts	
11	22,000		51 pts		
12	24,000				51 pts
13	26,000	51 pts			
14	28,000			51 pts	
15	30,000		51 pts		
16	32,000				51 pts
17	34,000	51 pts			
18	36,000			51 pts	
19	38,000		51 pts		
20	40,000				51 pts
21	42,000	51 pts			
22	44,000			51 pts	
23	46,000		51 pts		
24	48,000				51 pts
25	50,000	51 pts			

*Was not accomplished due to interference with rail side water braking trays.

MAY 1978 SURVEY



WEST (MASTER) RAIL LOOKING SOUTH



51 SAMPLES AT EACH LOCATION

FIGURE 2. RAIL CROSS-SECTION MEASUREMENT LOCATIONS

For this sample size, 51, and referring to a single tailed (upper tail) χ^2 operating characteristics curve for $\alpha = .05$ and $\beta = .05$, $s \leq 1.5\sigma$ (See Pg 302, Reference 3). A sample size of 100 would only decrease the uncertainty such that $s \leq 1.3\sigma$. Thus, a sample size of 51 appears to be a good compromise between confidence and economics for analysis in the amplitude domain. Analysis in the frequency domain will be discussed later.

The 24 sets of 51 measurements were made at three (3) points in the cross-section view of the west rail. See Figure 2. A total of 3,672 measurements were made of the possible 152,310 point population starting at even track stations. The track is orientated in the north-south direction and the furthest west rail was selected for the measurements. This rail is designated as the master rail and is aligned in the vertical and horizontal planes to the fiducial line which is marked on bench marks located every 99 foot 8 inches directly west of the west rail on the concrete girder. The fiducial line was established by the U.S. Coast and Geodetic Survey to a first order accuracy. These basic survey points are described in considerable detail in references 1 and 2.

The first step in the survey was to scribe marks on the rail at each of the predescribed 153 (A, B and C at 51 stations) measurement points. A paragon level was then attached to the east rail (7 foot to the east of the west rail) at a point midway from the first measurement and the 51st measurement. The distance from the horizontal plane defined by horizontal sweep plane of the paragon level to point A was measured at each of the 51 locations. After the 51st measurement the level instrument was returned to the first measurement and was required to repeat the original measurement to 0.005 inches. The same fixture used to locate point A was used to locate the point where point C was measured.

The next measurement was the side roughness. A K&E Gig Transit was referenced to each bench mark and sighted to the next bench mark 99 feet 8 inches down track. Using this reference, the distance B, Figure 2, was measured with a modified micrometer. A micrometer was modified so it would fit only in a pre-described position on the rail with respect to point A. In this manner, the cap thickness was measured to an accuracy of 0.001 inches. The rail bottom roughness is then the addition of measurement A and measurement B.

2. DATA PROCESSING (AMPLITUDE DOMAIN)

As mentioned above the first step in data processing was to calculate the slope and intercept of a best fit straight line for each set of data. (Throughout this report a set of data is 51 continuous samples from the rail top, bottom or side.) The slope and intercept were then removed from the data, leaving only the residuals which have been defined as rail roughness. Note that the bottom was not assumed to be parallel to the top, i.e., a slope was calculated for each.

Also calculated during this regression analysis was the standard error of the estimate or the conditional standard error. Mathematically, the standard error of the estimate is rigorously more correct to discuss after a regression line has been extracted. Practically the standard error of the estimate is nearly identical to the standard error of the residuals and the terms will be used interchangeably. Appendix A shows the collected raw data and the data after the regression line has been removed. A summary of the data is given in Table B.

Implicit in using the standard error is the assumption that the residuals would be normally distributed. In fact, the normality assumption significantly simplifies all statistical techniques used in the analysis, and this assumption is valid from two aspects: (1) The residuals after a least squares fit should be normal, and (2) the central limit theorem states that a large sample should be normally distributed about its average, even if the population is not normally distributed.

Running the risk of asking a question and receiving an unsatisfactory answer, 47 of the 72 sample populations were compared with a normal distribution using a χ^2 goodness-of-fit test. Of the 47, 6 failed to pass. The six were retested using a Yates correction for lack of continuity. None of the six passed with the Yates correction. As a final attempt, moments of the residuals were calculated and the skewness and kurtosis were calculated. One of the six was found to be normal. No explanation could be found for the contradiction, but calculation of moments is a more accurate test.

The five sets remaining were examined to determine why they were not normally distributed. Each set appeared to have several outliers; i.e., points that would be several standard errors from the mean of the data. To rigorously use those data, a Beta distribution would be required. Due to the significantly greater workload in using the Beta distribution, the five sets were assumed to be normal. If many more sets were found to be non-normal, the entire evaluation procedure would have to be changed.

TABLE B. SUMMARY OF SLOPES AND STANDARD ERROR OF
ESTIMATE VS TRACK STATION.

TRACK STATION	TOP OF RAIL		BOTTOM OF RAIL		SIDE OF RAIL	
	$MX10^{-3}$	$S_{Y/X}$	$M \times 10^{-3}$	$S_{Y/X}$	$MX10^{-3}$	$S_{Y/X}$
2,000	-12.30	8.88	-12.36	15.70	-.02	11.04
4,000	-11.63	11.47	-11.51	14.20	-.37	11.71
6,000	-13.75	10.47	-13.91	15.50	+.33	12.13
8,000	-21.29	9.95	-21.32	12.30	+.67	14.89
10,000	-18.00	12.21	-17.94	13.20	+.25	14.51
12,000	-18.32	17.36	-18.34	18.00	+.36	12.77
14,000	-21.73	9.03	-21.80	13.70	+.16	10.48
16,000	-18.10	9.67	-18.26	14.90	-.37	13.66
18,000	-15.66	9.40	-15.80	23.50	+.50	13.00
20,000	WATER TRAYS					
22,000	-10.73	14.21	-10.61	21.14	-.39	9.72
24,000	- 7.48	11.98	- 6.61	14.50	-1.27	9.68
26,000	- 6.17	12.09	- 6.09	16.30	+1.79	20.30
28,000	- 8.82	8.98	- 8.75	13.10	+.53	7.47
30,000	- 8.82	11.46	- 8.43	25.40	+.62	9.75
32,000	- 5.07	7.15	- 5.00	15.30	-.49	9.24
34,000	- 6.00	20.95	- 6.12	20.80	-.80	18.51
36,000	- 9.67	14.67	- 9.66	14.90	+1.22	16.62
38,000	- 9.81	12.34	- 9.06	17.11	+.08	17.97
40,000	-15.65	15.41	-15.30	17.60	+1.31	17.43
42,000	-10.65	15.80	- 9.66	29.000	+.34	20.70
44,000	-10.11	9.01	-10.10	10.00	+.16	12.05
46,000	- .86	23.87	- .83	26.00	+.29	26.61
48,000	- 1.81	16.91	- 1.83	16.80	-.27	31.26
50,000	+ .59	18.38	+ .63	19.30	-.04	14.99

M - Slope Removed (in/foot)

$S_{Y/X}$ - Standard Error of Estimate (thousandths of an inch)

3. CLASSIFICATION OF RAIL ROUGHNESS

Given the established or assumed normality of the data, a comparison can be made of rail roughness in several different groupings. First, each type of measurement, i.e., top, bottom, and side of rail, will be studied as a function of track station or distance down track. The purpose of these comparisons is to identify if any given location has irregularities significantly different from any other given location. This approach will permit an evaluation of rail grinding effectiveness in providing a significant smoothing of the rail surfaces. Second, a comparison will be made between the types of measurements, i.e., top compared to the bottom of the rail, and top compared to the side of the rail. This comparison again provides an evaluation of the effectiveness of rail grinding, since different degrees of grinding have been performed on the three different classification of surfaces. The top has received the most attention and the bottom surfaces have never been ground.

Figure 3 shows the Standard Error of Estimate (S_{yx}) for the top of the rail as a function of the 24 locations where the 51 sample size sets of data were measured. At the top of the figure is the standard error of three large ensembles which would separate the track into three spatial groups. The spatial groups are referred to as south (0-16K ft), central (18K - 34K) and north (36K - 50K).

A method was needed to statistically compare the groups of data. If the roughness changes significantly, the grouping of the data into classes of roughness would be beneficial in further discussion and recommendations. A procedure was found where any number of S_{yx}^2 values could be compared at once. This procedure is accomplished by means of the measure of L, sometimes referred to as the "criterion of likelihood" (reference 4). The equation is as follows:

$$L = \frac{\sqrt[n]{S_{yx1}^2 \times S_{yx2}^2 \dots \times S_{yxk}^2}}{\frac{1}{n} (S_{yx1}^2 + S_{yx2}^2 + \dots + S_{yxk}^2)}$$

where n = the number of samples under consideration. The numerator is the geometric mean of S_{yx}^2 's, while the denominator is the arithmetic mean of the S_{yx}^2 's. "If there are any differences between S_{yx}^2 's, the value of L will be less than 1.0, approaching 0 as its lower limit. L = 0 represents a condition of maximum

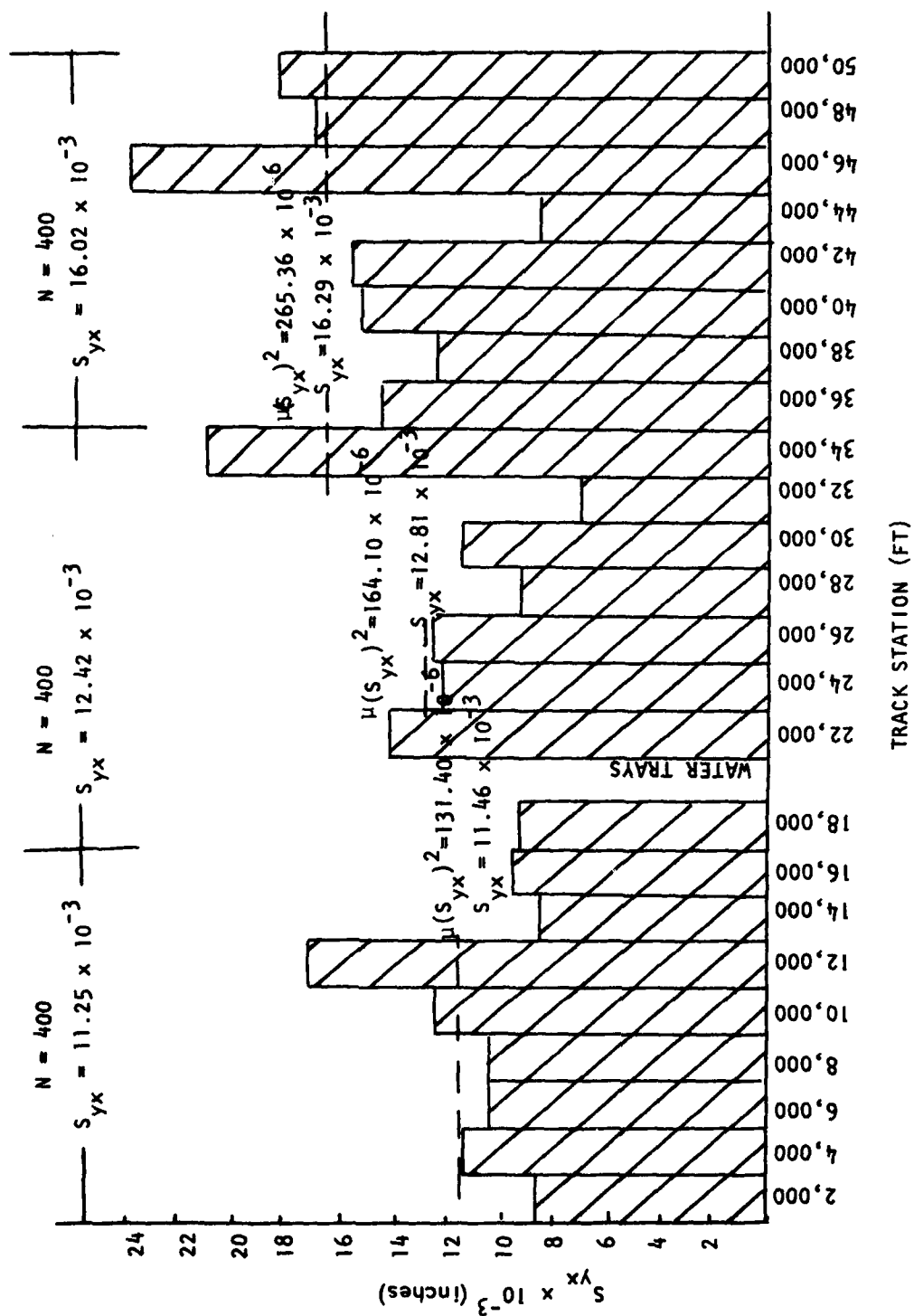


FIGURE 3. STANDARD ERROR OF ESTIMATE VS TRACK STATION
TOP OF RAIL

non-uniformity and is a theoretical limit which would not be approached in actual practice." The hypothesis to be tested is that the variances are from random samples of the same population in regard to S_{yx}^2 . A table is given in Appendix N of Reference 4 which lists the values of L at the 0.05 and 0.01 points for various different degrees of freedom.

The 0.05 confidence level and 60 degrees of freedom values were used in this test. Use of the 0.05 confidence level and a higher degree-of-freedom, i.e., 60 instead of 51, forces a tighter grouping of the variances.

3.1 Top of Rail

Table C gives a listing of the standard error of estimate and variances in rank order for the top of the rail. The procedure calls for taking the first n samples and conducting the L test, if the n samples failed, the last sample was dropped from consideration and the test repeated for the reduced population. A sample calculation for Class A is as follows:

$$\text{Let } n = 6 \quad L = \frac{\sqrt{6} \sqrt{568.22 \times 443.52 \times 337.46 \times 302.41 \times 289.68 \times 246.49}}{568.22 + 443.52 + 337.46 + 302.41 + 289.68 + 246.49}$$

6

$$L = 0.9608$$

From Table for $N_1 = 60$, $\alpha = 0.05$, $n = 6$

$L = 0.969$. Therefore, a set size of $n = 6$ fails the test. Now let $n = 5$.

$$L = \frac{\sqrt{5} \sqrt{568.22 \times 443.52 \times 337.46 \times 302.41 \times 289.68}}{568.22 + 443.52 + 337.46 + 302.41 + 289.68}$$

5

$$L = .9667.$$

From Table for $N_1 = 60$, $\alpha = 0.05$, $n = 5$, $L = 0.968$. Therefore, a set size of $n = 5$ passed the test. The bottom of the class will be assumed to be $S_{yx} = 17.02 \times 10^{-3}$ inches, and the maximum $S_{yx} = 23.85 \times 10^{-3}$ inches. The top of the next class will be assumed to start immediately below the next higher class, i.e., $S_{yx} = 17.01 \times 10^{-3}$ inches is assumed the top of Class B. Following this procedure the range of the standard error of estimate, S_{yx} , for each class is as follows.

TABLE C. TOP OF RAIL IN RANK ORDER.

TRACK STATION	$S_{yx} \times 10^{-3}$	$S_{yx}^2 \times 10^{-6}$	ROUGHNESS CLASS
46,000*	23.85	560.22	A
34,000	21.06	443.52	
50,000*	18.37	337.46	
12,000	17.39	302.41	
48,000*	17.02	289.68	B
42,000*	15.70	246.48	
40,000*	15.31	234.40	
36,000*	14.77	218.15	
22,000	14.32	205.06	C
10,000	12.59	158.51	
26,000	12.55	157.50	
38,000*	12.36	152.77	
24,000	12.21	149.08	D
30,000	11.63	135.26	
4,000	11.51	132.48	
8,000	10.44	108.99	
6,000	10.41	108.37	
16,000	9.68	93.70	
18,000	9.35	87.42	
28,000	9.29	86.30	
44,000	8.76	76.74	
2,000	8.73	76.21	
14,000	8.40	70.56	
32,000	7.03	49.42	

*North 15,000 Foot of Track.

	CLASS			
	A	B	C	D
S_{yx} (10^{-3} inches)	17.02 to 23.58	12.21 to 17.01	8.73 to 12.20	7.03 to 8.72
No. of Sets/Class	5	8	9	2

3.2 Bottom of Rail

The same analysis process was followed for the bottom of the rail as was conducted for the top of the rail. Figure 4 shows a bar graph of the Standard Error of Estimate (S_{yx}) for the 24 subsets of data as a function of track station. Again, for future analysis of power spectral density the data was also grouped into three sets of data for track stations 2,000 to 16,000, track stations 18,000 to 34,000, and 36,000 to 50,000, i.e., $N = 408$ per set. The criterion of likelihood can be used to establish if the mean, μ , of these three variances are of the same population as follows:

$$L = \sqrt[3]{\frac{218.45 \times 371.20 \times 387.03}{218.45 + 371.20 + 387.03}} = 0.968$$

From Appendix N, Reference 4, the value for L at $N_1 = 60$, $n = 3$, and $\alpha = 0.05$ is 0.967; consequently, these three can be considered from the same population. These results were verified by conducting a one way Analysis of Variance on the three sets of standard errors.

Bottom of the rail data is given in Table D in rank order. The criterion of likelihood, L , was calculated to establish which variances were of the same class in a statistical sense. Results are as follows.

	CLASS		
	A	B	C
S_{yx} (10^{-3} inches)	20.80 to 29.00	13.70 to 20.79	10.00 to 13.69
No. of Subsets/ Class	6	14	4

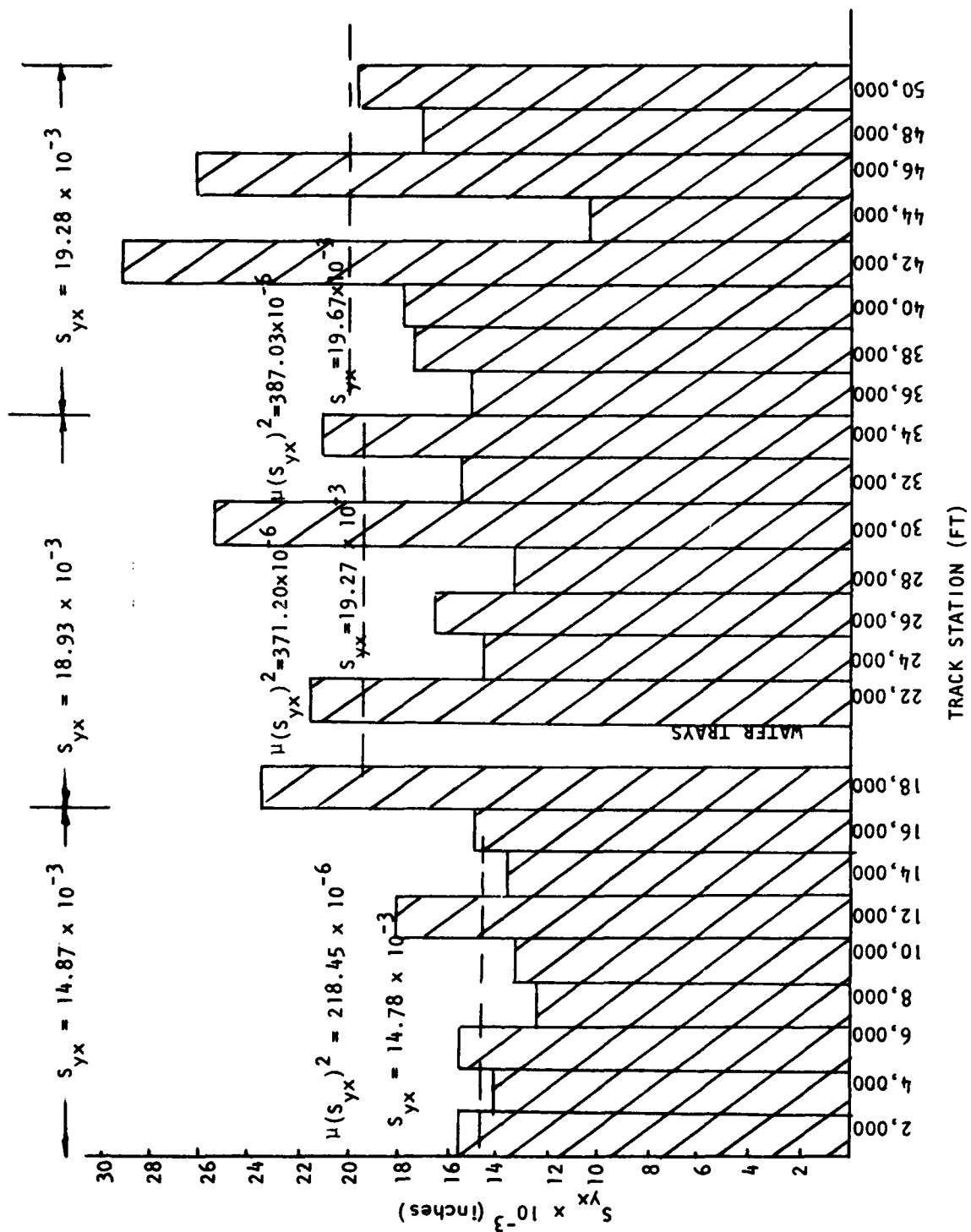


FIGURE 4. STANDARD ERROR OF ESTIMATE VS TRACK STATION BOTTOM OF RAIL

TABLE D. BOTTOM OF RAIL IN RANK ORDER

TRACK STATION	$S_{yx} \times 10^{-3}$	$S_{yx}^2 \times 10^{-3}$	ROUGHNESS CLASS
42,000*	29.0	841.00	A
46,000*	26.00	676.00	
30,000	25.40	645.16	
18,000	23.50	552.25	
22,000	21.14	457.96	
34,000	20.80	453.64	B
50,000*	19.30	372.49	
12,000	18.00	324.00	
40,000*	17.60	309.76	
38,000*	17.11	292.75	
48,000*	16.80	282.24	
26,000	16.30	265.69	
2,000	15.70	246.49	
6,000	15.50	240.25	
32,000	15.30	234.09	
36,000*	14.90	222.01	C
16,000	14.90	222.01	
24,000	14.50	210.25	
4,000	14.20	201.64	
14,000	13.70	187.69	
10,000	13.20	174.24	
28,000	13.10	171.61	
8,000	12.30	151.29	
44,000*	10.00	100.00	

*North 15,000 Foot of Track

By comparing the top of rail classes with bottom of rail classes, it is shown that the bottom of the rail is a significantly higher forcing function as shown in this table.

	CLASSES			
	A	B	C	D
Top of Rail S_{yx-3} (10^{-3} inches)	17.02 to 23.58	12.21 to 17.01	8.73 to 12.20	7.08 to 8.72
Bottom of Rail S_{yx-3} (10^{-3} inches)	20.80 to 29.00	13.70 to 20.79	10.00 to 13.79	Not Req'd

3.3 Side of Rail

This analysis approach was repeated for the third time for the side of the rail. Figure 5 shows a bar graph of the Standard Error of Estimate (S_{yx}) for the 24 subsets of data as a function of track station. At the top of this figure, the S_{yx} and S_{yx}^2 values are listed for the larger sets of data where eight subsets were added to provide a sample size of $N = 408$. A comparison of L values for the three sets shows that the two sets from the south 35,000 feet of track are probably from the same population and the north 15,000 is of a different population. These results were also verified with a one-way Analysis of Variance test. Also, comparison of the variances for the three sets shows good comparison with the means, μ 's, of the variances for the eight subsets which make up the larger samples, a further quality check of procedures.

Side of the rail data is given in Table E in rank order. The criterion of likelihood was calculated to divide the subset into statistical class if applicable. One different approach was necessarily from previous analyses. Due to the large difference between the second and third variance, the exact cut-off point had to be established. After several iterations, Class A extends down through $S_{yx} = 23.20 \times 10^{-3}$ inches. The same process was followed between Class B and C. Class B extends down through $S_{yx} = 15.50 \times 10^{-3}$ inches. The results can be summarized as follows:

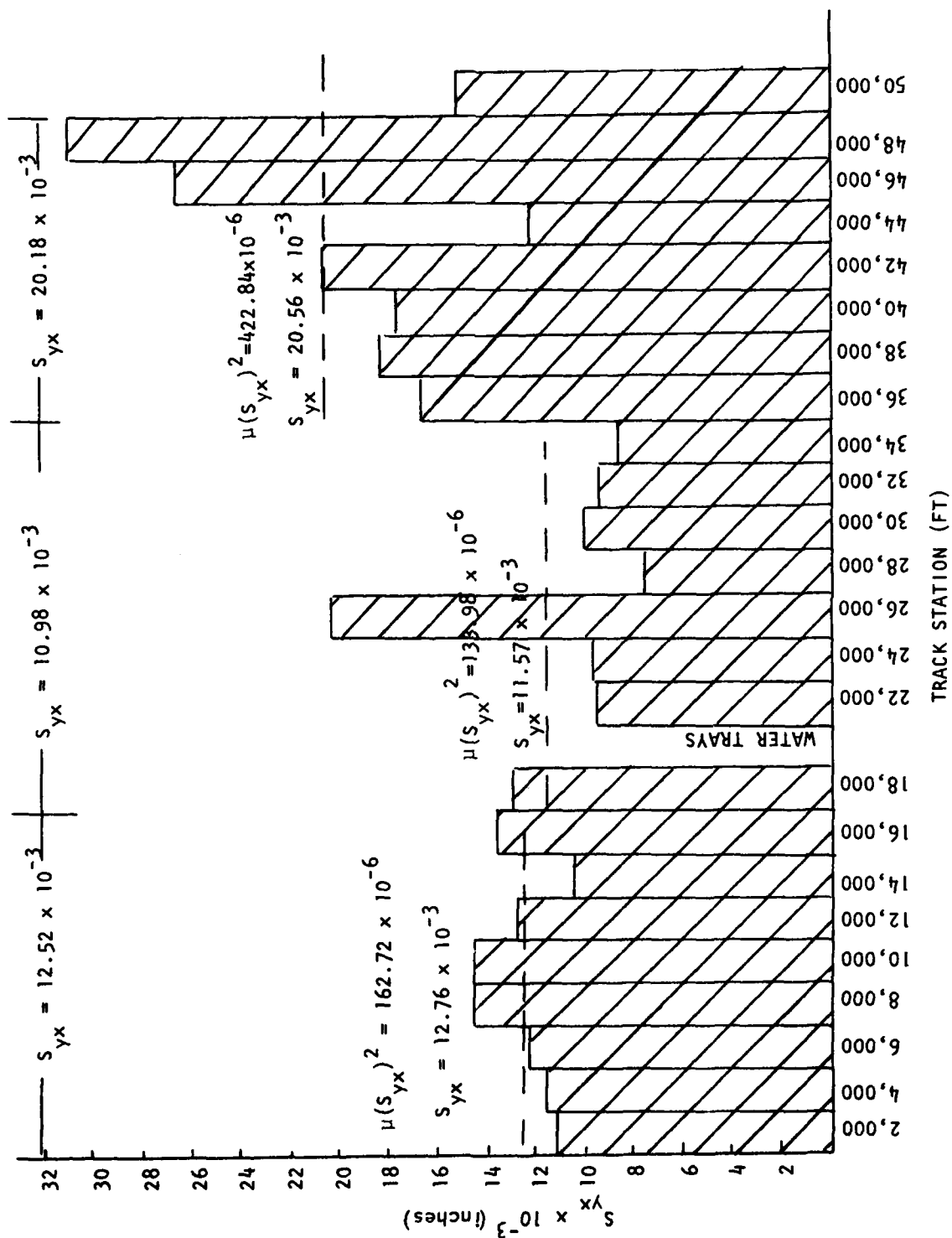


FIGURE 5. STANDARD ERROR OF ESTIMATE VS TRACK STATION SIDE OF RAIL

TABLE E. SIDE OF RAIL IN RANK ORDER

STATION	$S_{yx} \times 10^{-3}$	$S_{yx} \times 10^{-6}$	ROUGHNESS CLASS
48,000*	31.23	975.31	Ⓐ
46,000*	26.58	706.50	
42,000*	20.69	428.08	
26,000	20.26	410.47	Ⓑ
38,000*	18.03	325.08	
40,000*	17.40	302.76	
36,000*	16.68	278.22	Ⓒ
50,000*	14.99	224.70	
8,000	14.91	222.31	
10,000	14.58	212.58	Ⓓ
16,000	13.74	188.79	
18,000	12.90	166.41	
12,000	12.79	163.58	Ⓔ
6,000	12.17	148.11	
44,000*	11.92	142.09	
4,000	11.63	135.26	Ⓕ
2,000	11.05	122.10	
14,000	10.44	108.99	
30,000	9.81	96.24	Ⓖ
24,000	9.71	94.28	
22,000	9.69	93.90	
32,000	9.20	84.64	Ⓗ
34,000	8.52	72.59	
28,000	7.30	53.29	

*North 15,000 Foot of Track

	CLASS			
	A	B	C	D
S_{yx-3} (10^{-3} inches)	23.20 to 31.23	15.50 to 23.19	11.05 to 15.49	7.30 to 11.04
No. of Sub-sets/Class	2	5	10	7

This difference could have come from rail grinding or from rail alignment. The south 35,000 feet have been surveyed and aligned to the million foot radius repeatedly over the years and should be straighter than the relatively new north end. The variations due to grinding and alignment cannot be separated, but overall the north end obviously has larger residuals than the south 35,000 feet. Note that seven out of the top eight subsets are from the north end measurements.

A comparison of the top of the rail with the side by classes is as follows:

	CLASSES			
	A	B	C	D
Top of Rail S_{yx-3} (10^{-3} inches)	17.02 to 23.58	12.21 to 17.01	8.73 to 12.20	7.03 to 8.72
Side of Rail S_{yx-3} (10^{-3} inches)	23.20 to 31.23	15.50 to 23.19	11.05 to 15.49	7.03 to 11.04

Based on this comparison the side of the rail is significantly rougher surface than the top.

4. DATA PROCESSING (FREQUENCY DOMAIN)

In order to better characterize the data and study the effectiveness of rail grinding, the data was analyzed in the frequency domain. As in the amplitude domain, only the residuals (after removal of the regression line) were considered.

For frequency domain analysis, the data were grouped into larger ensembles as previously shown - south (2,000 - 16,000 feet), center (18,000 - 34,000 feet), and north (36,000 - 50,000 feet). The grouping was done by simply zeroing the first and last element of each 51 sample set, then aggregating eight adjacent samples. The net result is a larger sample size to study, increasing the confidence of the estimates of the power spectral densities (PSDs). See Appendix B for plots of the ensembles.

This grouping results in three ensembles of 408 samples each. The ratio of the mean squared value of a sample data set PSD to the population PSD is found by a ratio of χ^2 values for a given confidence level of Type I and Type II errors, or

$$d^2 = \frac{\chi^2_{n, \beta/2}}{\chi^2_{n, 1-\alpha/2}}$$

For $n = 400$, $\alpha = .05$ and $\beta = .05$, $d^2 = 1.32$ or d (standard deviation) = 1.09. Consequently, the root mean - squared value of PSD's should be within a factor of 1.1 of the population PSD. (For same analysis in time domain - see Reference 5). This uncertainty was accepted since no systematic errors were expected and larger groupings would not meet test objectives. In effect, this grouping was similar to averaging in the amplitude domain. Since no data with a period longer than 50 foot could exist in the original data, none could exist in the 408 sample ensemble.

To compare the roughness of the three sets, the PSD of each ensemble for a given rail surface was compared with the PSD's of the other ensembles (same surface) pair-wise. The units of the PSD's may seem rather unique. The measurements were taken at one foot intervals so the horizontal or frequency axis dimension is in cycles per foot. The parameter being analyzed is inches of residual so the "power" axis has units of inches squared per cycle per foot. Note that the vertical axis is a linear scale of logarithm data, rather than the normal log scale of linear data. So the vertical axis scale are powers of 10, e.g., 10^{-4} , $10^{-3.5}$, etc.

4.1 Top of Rail

Figure 6 is a plot of the rail top for the south and center sections. Each curve is annotated to aid in resolution. There are two peaks on the graph which are relatively constant for these PSD's and all other PSD's analyzed. The peak at 0.0256 cycles/foot corresponds to the period of 39 feet. The other peak at 0.23 cycles/foot corresponds to a period of 52 inches.

The 39 foot component arises from the standard length of a rail section as it is delivered from the factory. Apparently a slight change in slope was introduced as the different 39 foot sections were welded together.

The 52 inch component corresponds to the spacing of the rail tie-down/alignment fixtures, i.e., the rail apparently sags (or humps) between tie downs. The rail grinding machines were designed to minimize variation of 52 inches and less, but the component is still prevalent.

One conclusion to be drawn from Figure 6 is that there is very little difference between the south and center sections for top of rail.

Figures 7 and 8 are similar plots comparing south and center sections to the north section. Recall that when the data was collected, the south and center sections had been ground to a machine setting of 0.010 inches and the north section to 0.025 inches for top of rail.

In order to quantify the difference, the PSD's were integrated to arrive at mean squared residuals. Some points of interest for the three sections are:

CUMULATIVE "POWER"
(Inches Squared)

<u>f</u> <u>Cycles/Ft</u>	<u>L</u> <u>Ft</u>	<u>South</u>	<u>Center</u>	<u>North</u>
.02539	39.38	.0131	.0136	.0064
.0332	30.10	.0188	.0243	.0139
.0645	15.50	.0283	.0351	.0498
.2342	4.27	.0459	.0557	.0936

There are several noteworthy points in these data.

4.1.1 As shown in the plots, the North end 39 foot component is about half the magnitude of the South 35,000 feet.

4.1.2 The amount of "power" at frequencies above 0.03 cycles/ft is twice as great for the North section as the South 35,000 feet.

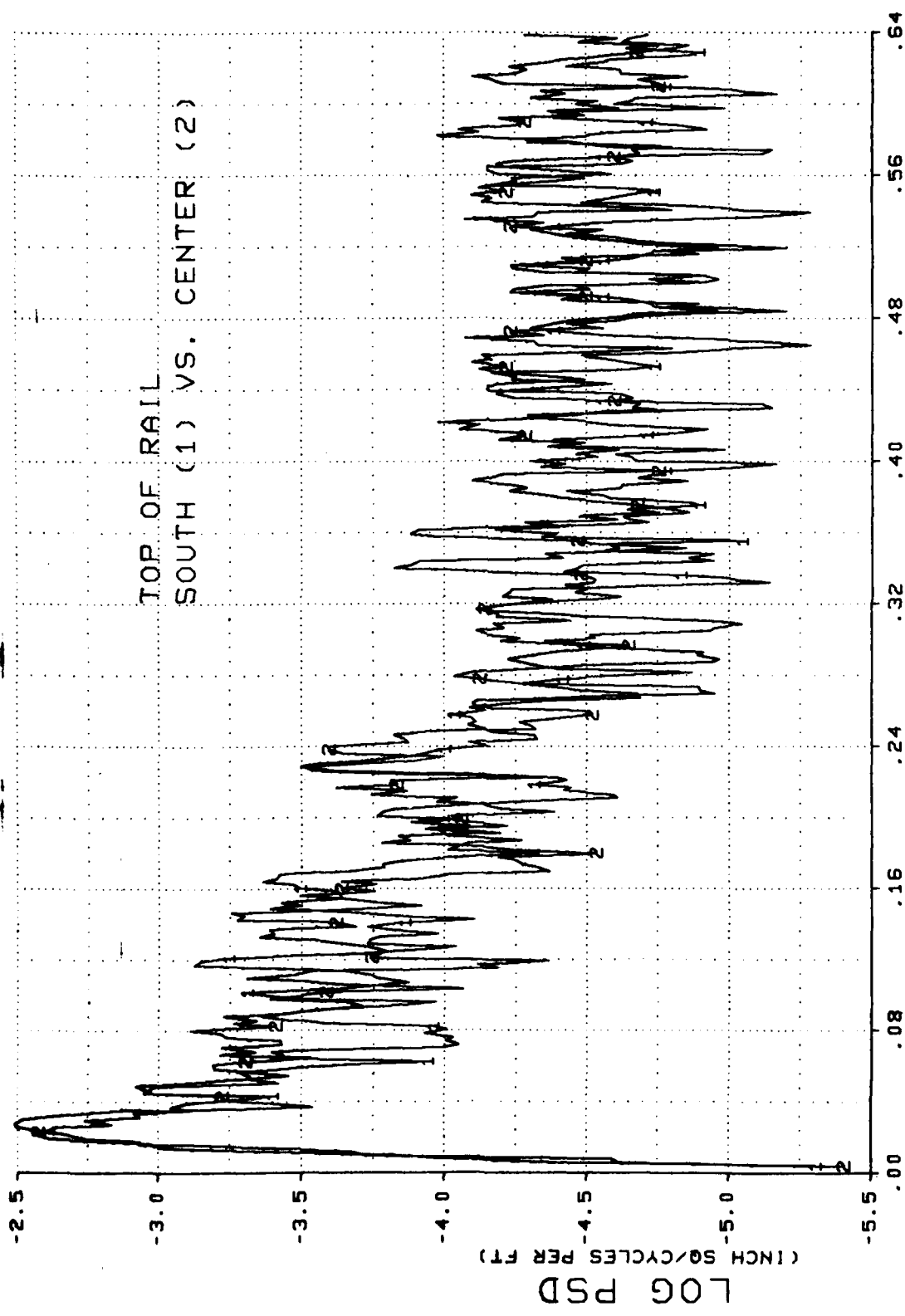


FIGURE 6

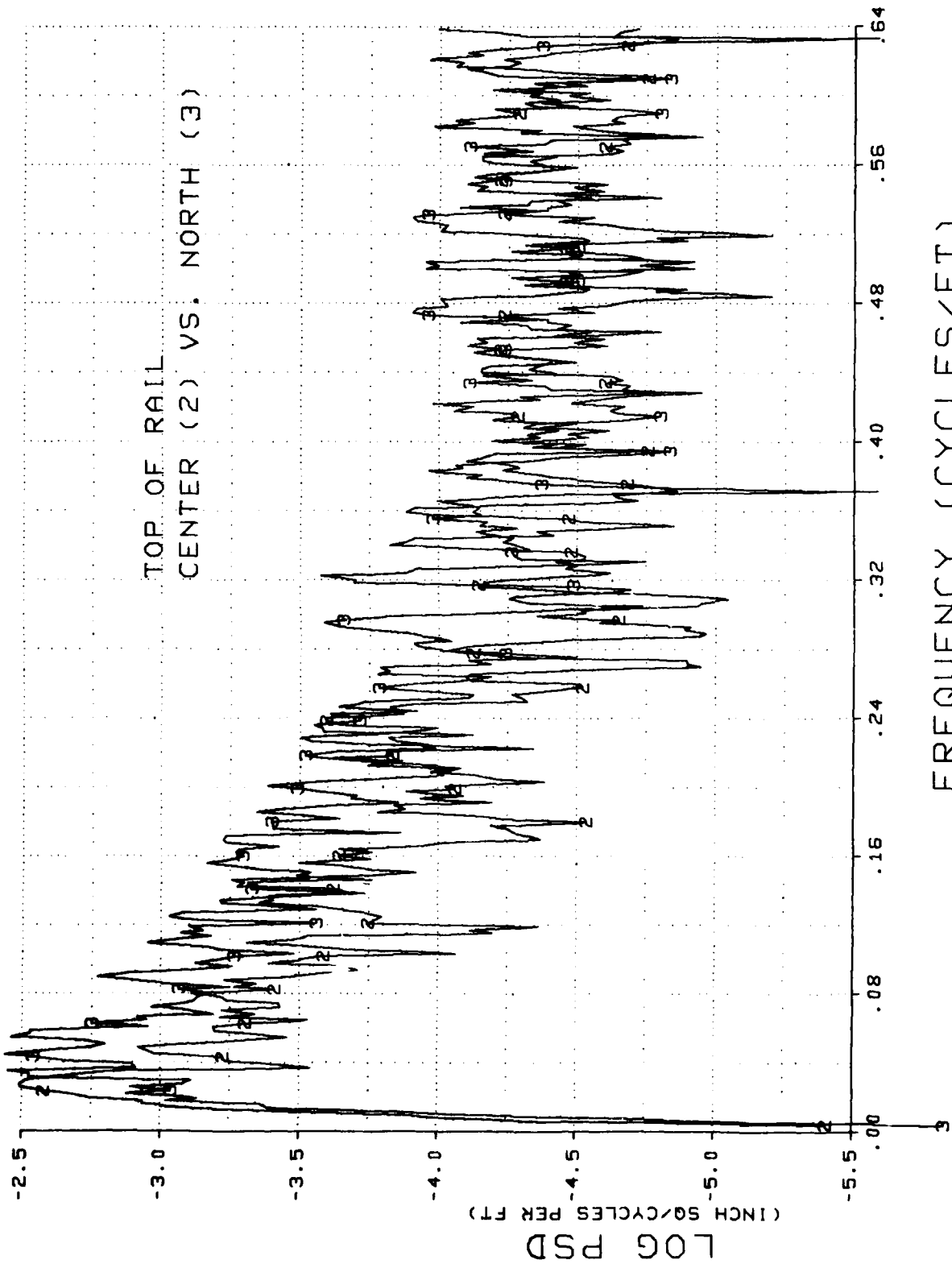


FIGURE 7

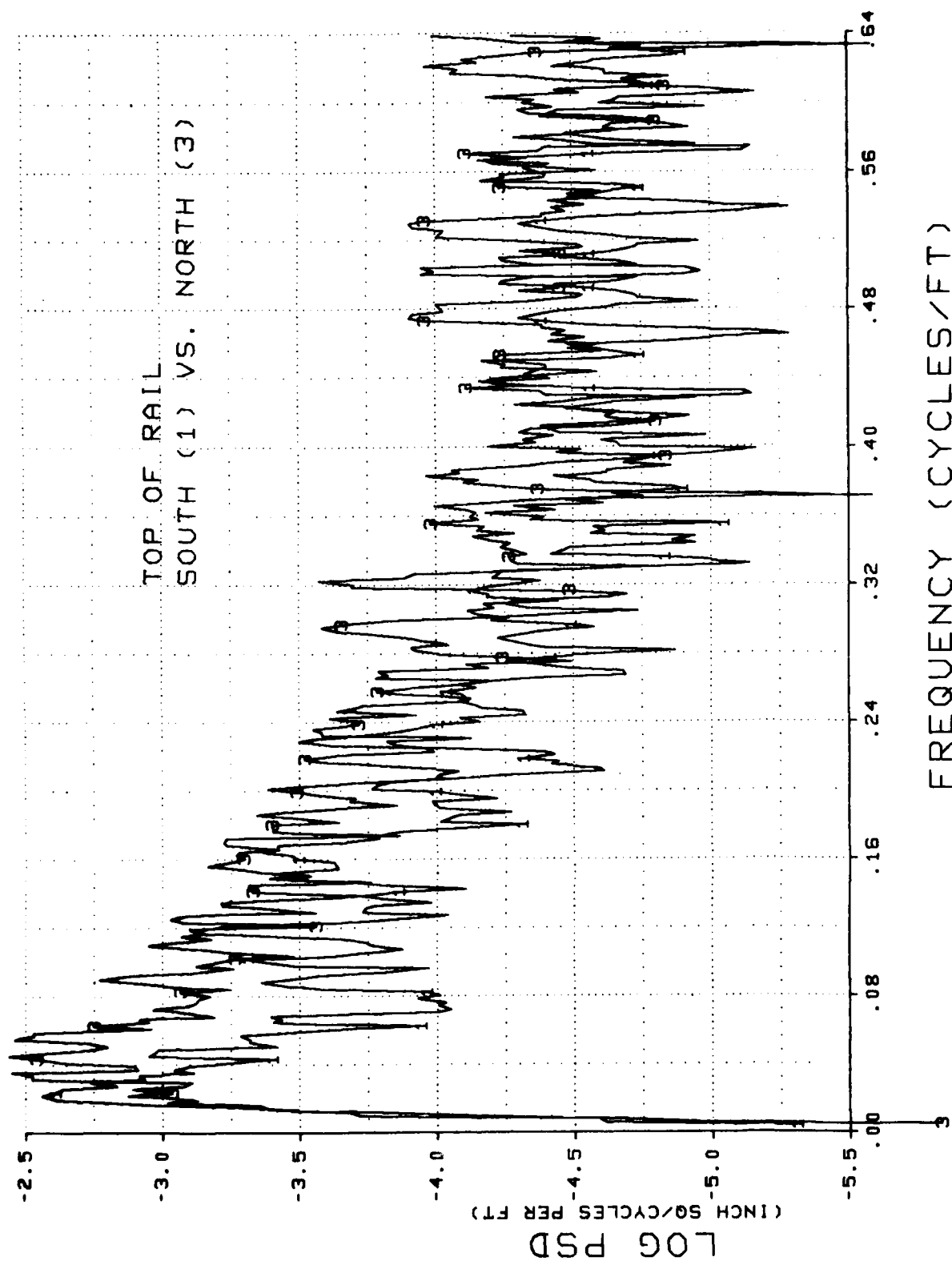


FIGURE 8

4.1.3 Overall, the "power" in the North end is significantly higher than the remainder of the track.

4.1.4 Even though the rail grinders were designed to improve roughness at distances of 52 inches and less, there is a significantly lower amount of "power" in the South 35,000 feet in the 0.03 to 0.23 cycle/ft (30 - 4.3 feet) frequency band than in the North 15,000 feet of track.

4.2 Bottom of Rail

Plots 9, 10 and 11 are the PSD's for the rail bottom. The lower lips or bottom of the rail have received no grinding and the differences in the amplitude domain are not as obvious as the rail top. The same points of interest were checked as for the rail top as follows:

CUMULATIVE "POWER" (Inches squared)

<u>f</u> <u>Cycles/Ft</u>	<u>L</u> <u>Ft</u>	<u>South</u>	<u>Center</u>	<u>North</u>
.02539	39.38	.0133	.0247	.0087
.0332	30.10	.0179	.0394	.0231
.0645	15.50	.0345	.0666	.0687
.2342	4.27	.0730	.1320	.1333

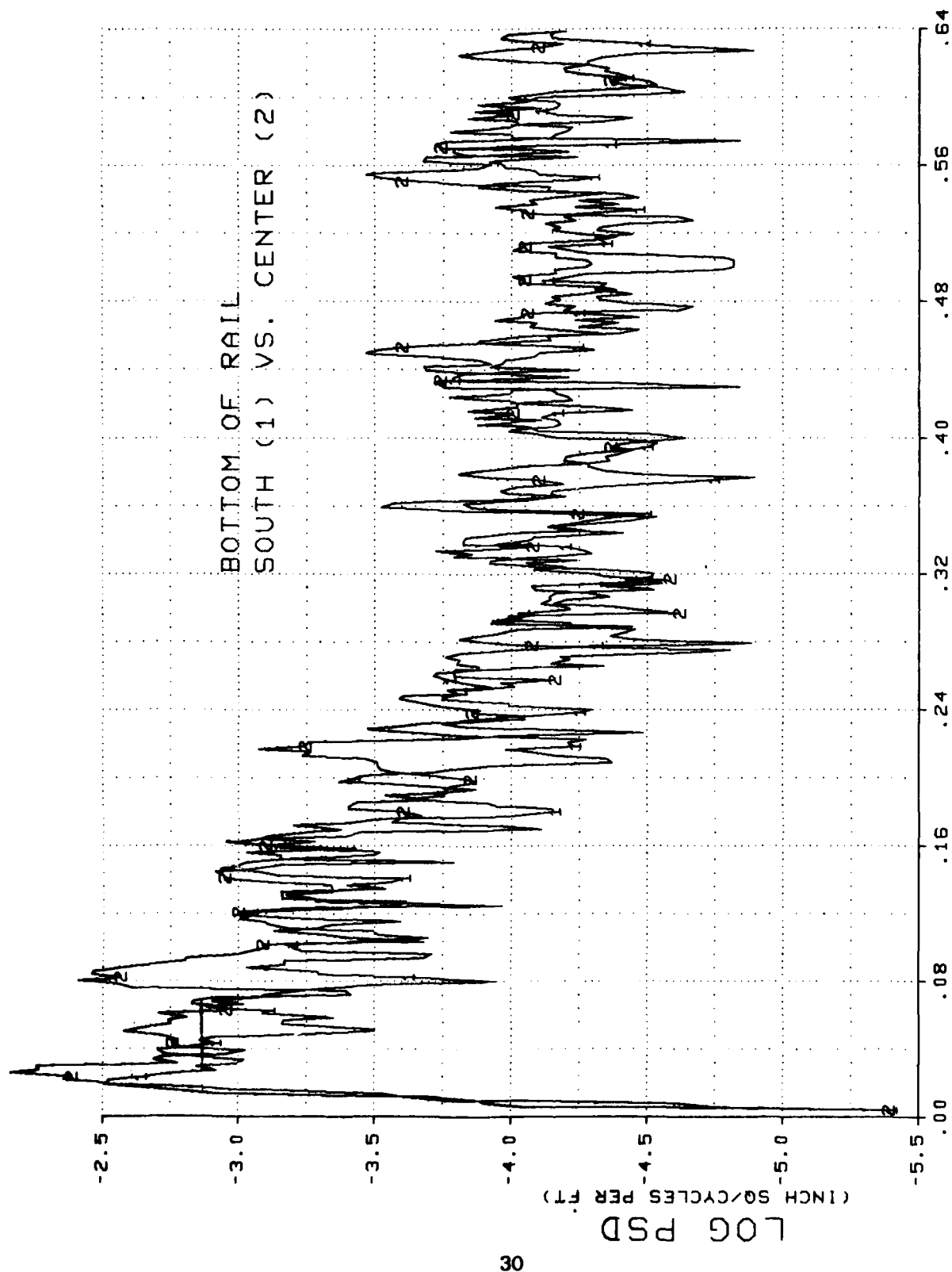
Noteworthy points are as follows:

4.2.1 Again the north end 39 foot component is significantly lower than the remainder of the track.

4.2.2 Overall the center and north sections are significantly rougher than the south 15,000 feet. One explanation could be is that the south end has had a significantly greater number of sled runs over the years. Wear from slipper loads tend to smooth the track surface the same as grinding. Also, there is a possibility that the lower surfaces were ground in the past and not documented.

4.3 Side of Rail

Plots 12, 13 and 14 are the PSD's for the side of the rail. The 39 foot component is again visible, especially in the north end. Also visible is the 52 inch period (.23 cycles/ft) in all plots.



FREQUENCY (CYCLES/FT)

FIGURE 9

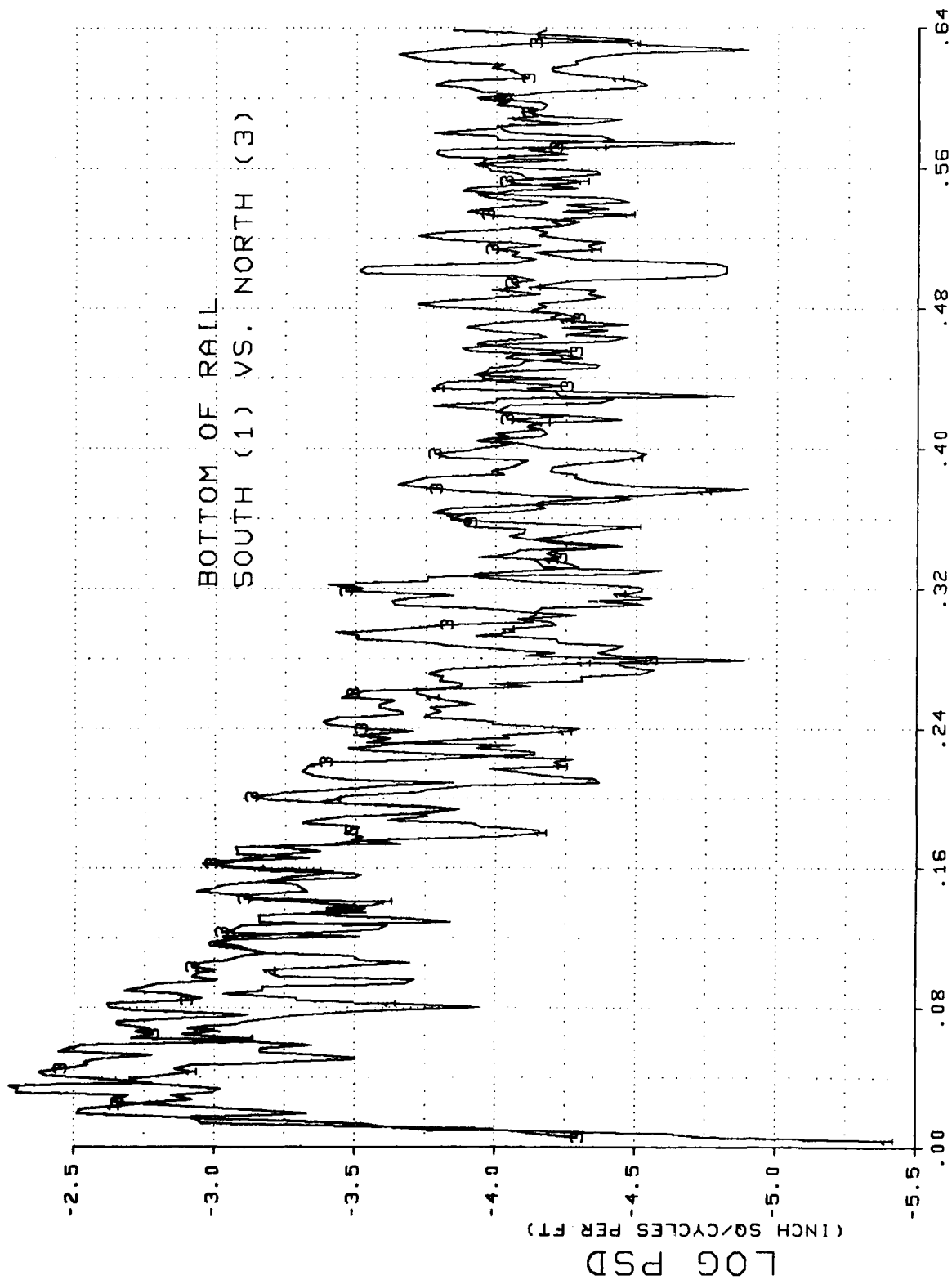


FIGURE 10

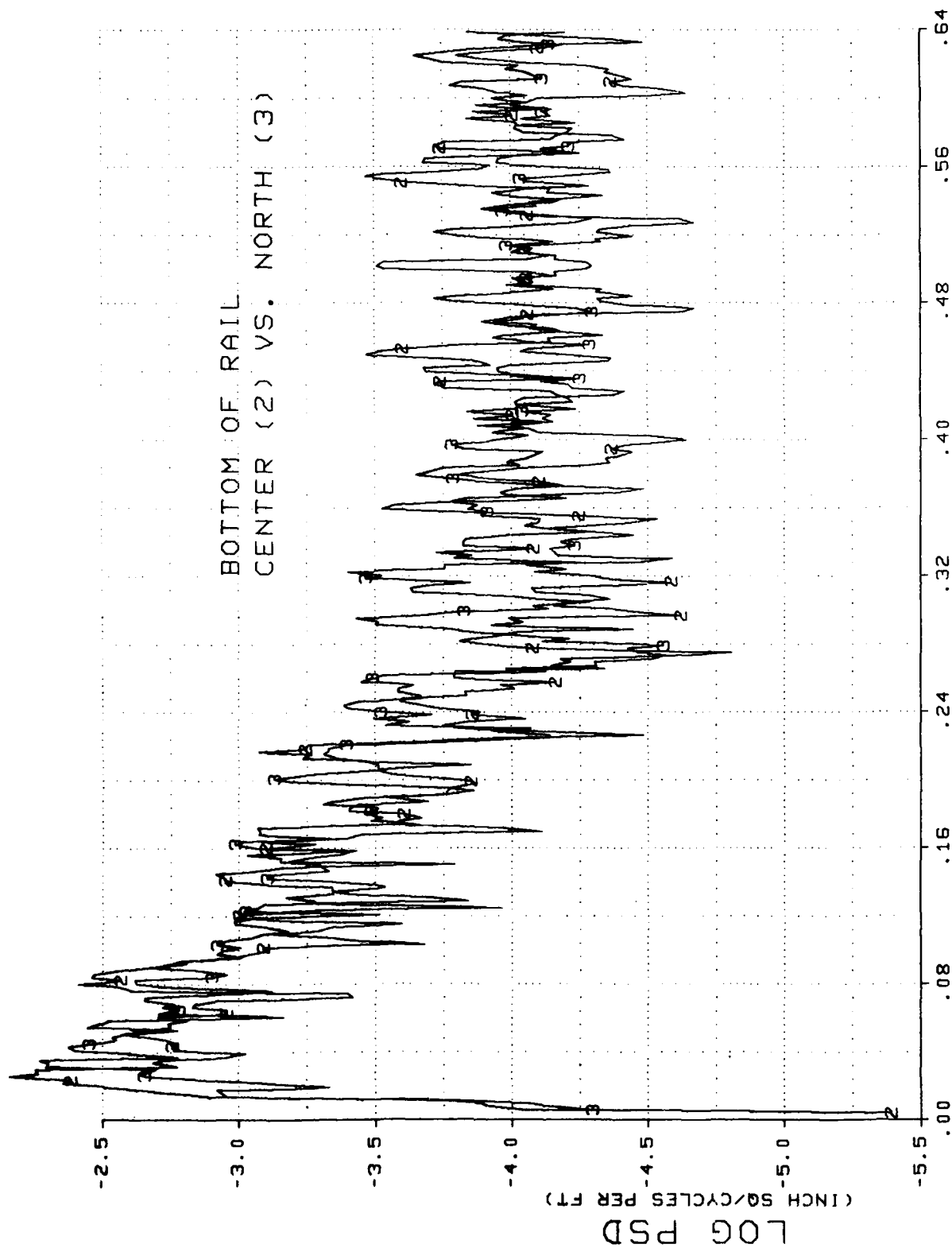


FIGURE 11

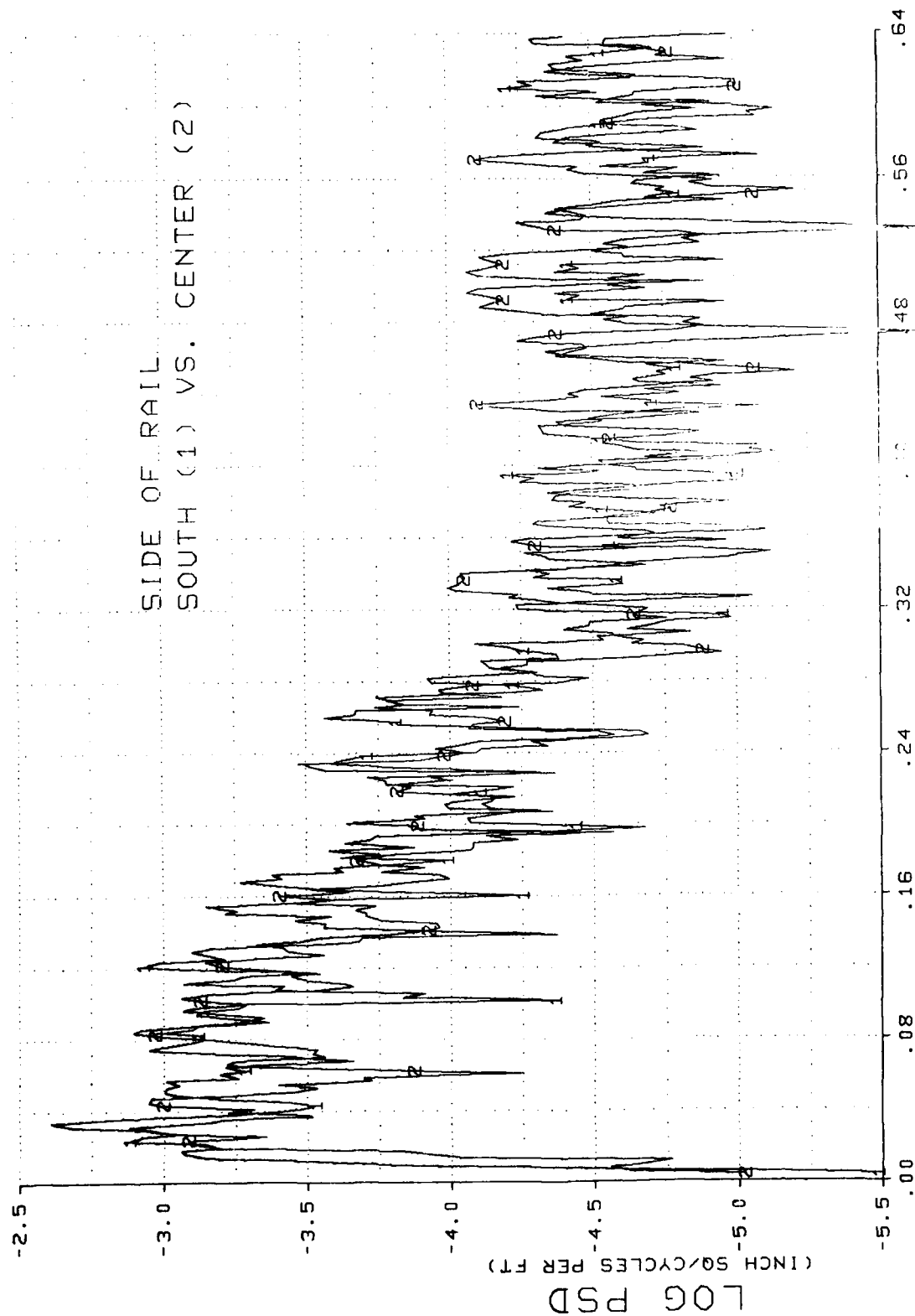
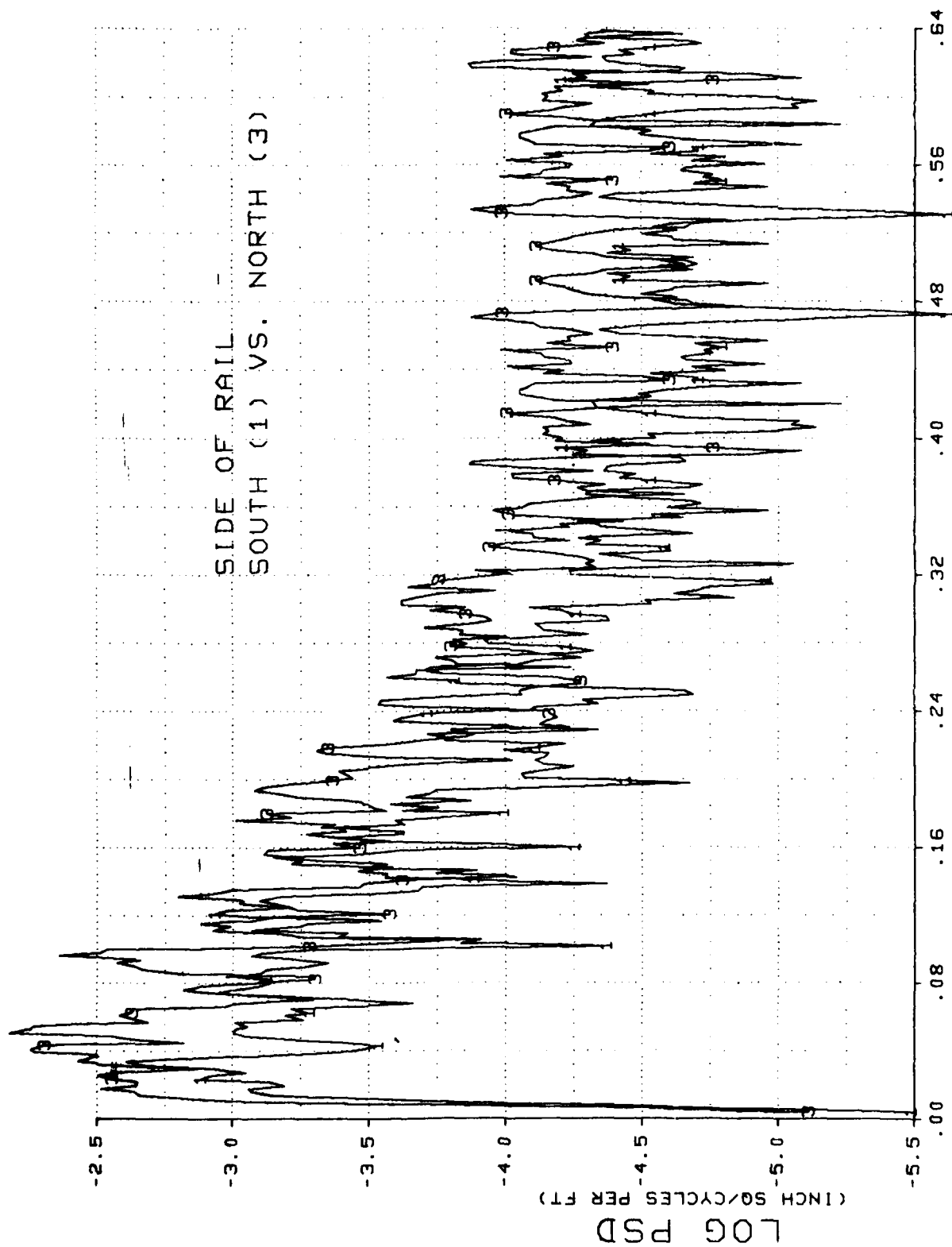


FIGURE 12



FREQUENCY (CYCLES/FT)

FIGURE 13

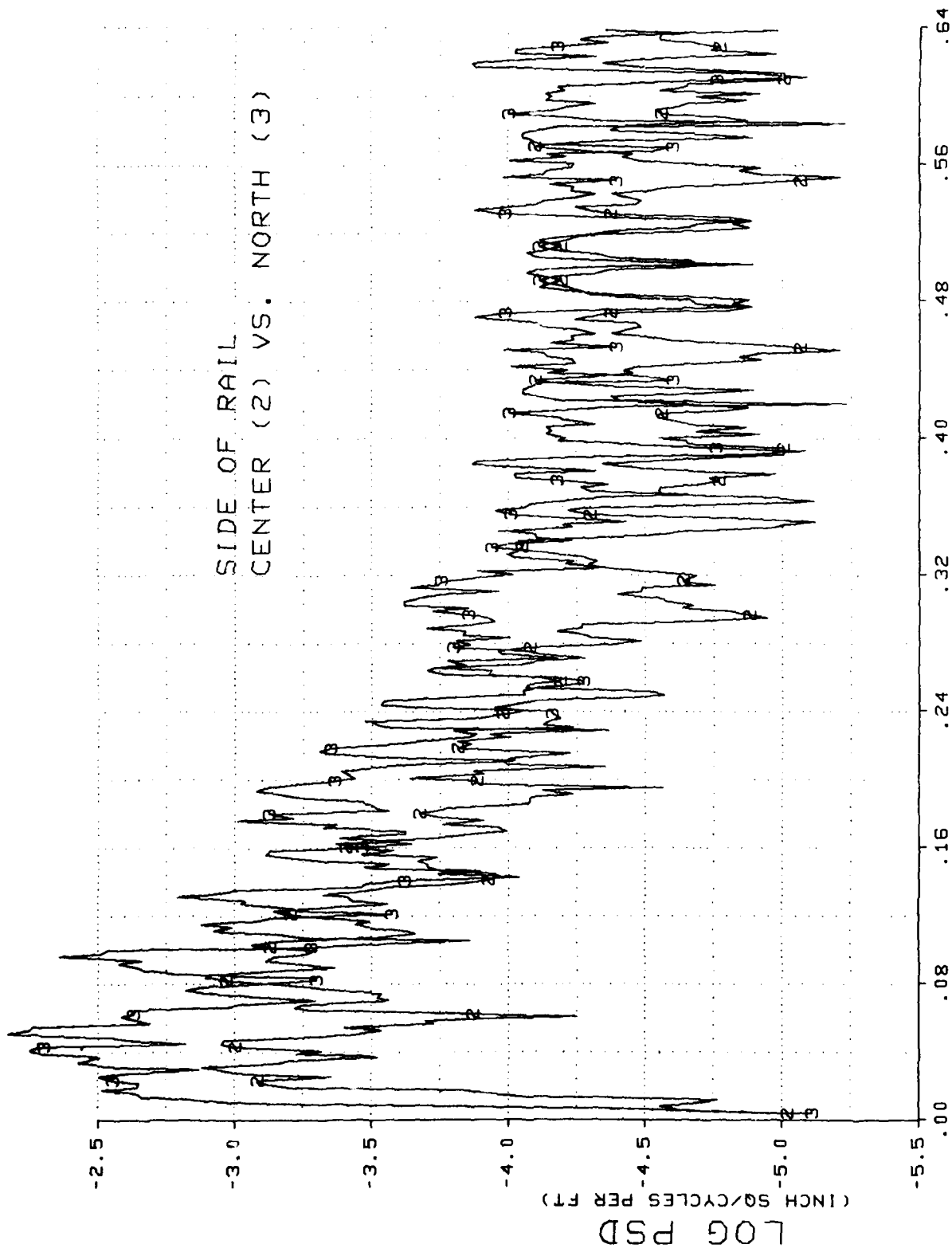


FIGURE 14
FREQUENCY (CYCLES/FT)

A check of the integrated "power" is as follows:

<u>f</u> Cycles/Ft	<u>L</u> Ft	<u>South</u>	<u>Center</u>	<u>North</u>
.02539	39.38	.0068	.0032	.0203
.0332	30.10	.0134	.0072	.0306
.0645	15.50	.0251	.0152	.0894
.2342	4.27	.0572	.0426	.1535

The following comments are offered for these comparisons:

4.3.1 A reversal in trend is noted for the 39 foot period. In the case of the side the north is significantly rougher than the remaining 35,000 feet of track. Evidently the fabrication techniques that assured straight welded joints in the vertical direction was not carried through to the lateral or cross track direction.

4.3.2 Overall, the rail is significantly rougher in the north 15,000 feet of track where no grinding had been accomplished. Note the South 35,000 feet of track sides of rail had been ground to 0.025 inches.

4.4 In paragraph 4 it was pointed out that no data with a period of greater than 50 feet could exist in the original data. To appreciate the full ramifications of this statement, consider the data from a structural dynamics perspective. As pointed out in reference 5, the acceptable level of Type I and Type II errors must be determined while considering the costs of measurements. If measurements are relatively cheap, then the experiment can be set with high levels of confidence and power (e.g., $\alpha = .01$, $\beta = .01$). In the case of track surveys, measurements cannot be considered cheap; therefore, lower confidence and power levels were investigated.

Three different combinations were considered - $\alpha = \beta = .01$; $\alpha = .01$ and $\beta = .05$ and $\alpha = \beta = .05$. The ratio d as defined earlier in this paragraph was calculated for $n = 1000, 400, 280, 200, 100$ and 50 for each of the three combinations. These results are presented graphically in plot 15 where d is plotted versus n , the number of samples. The top curve is for $\alpha = \beta = .01$ and the bottom is $\alpha = \beta = .05$. An observation is that going vertically up on the chart (holding n constant), d as a function of α & β varies greatly for small samples ($n = 50$) but varies little for large samples ($n = 1000$). Using the same criteria as found in reference 5 that $d = 1.2$, 280 samples would be required at $\alpha = \beta = .05$.

RATIO d vs. SAMPLE SIZE

Detectable difference in variance

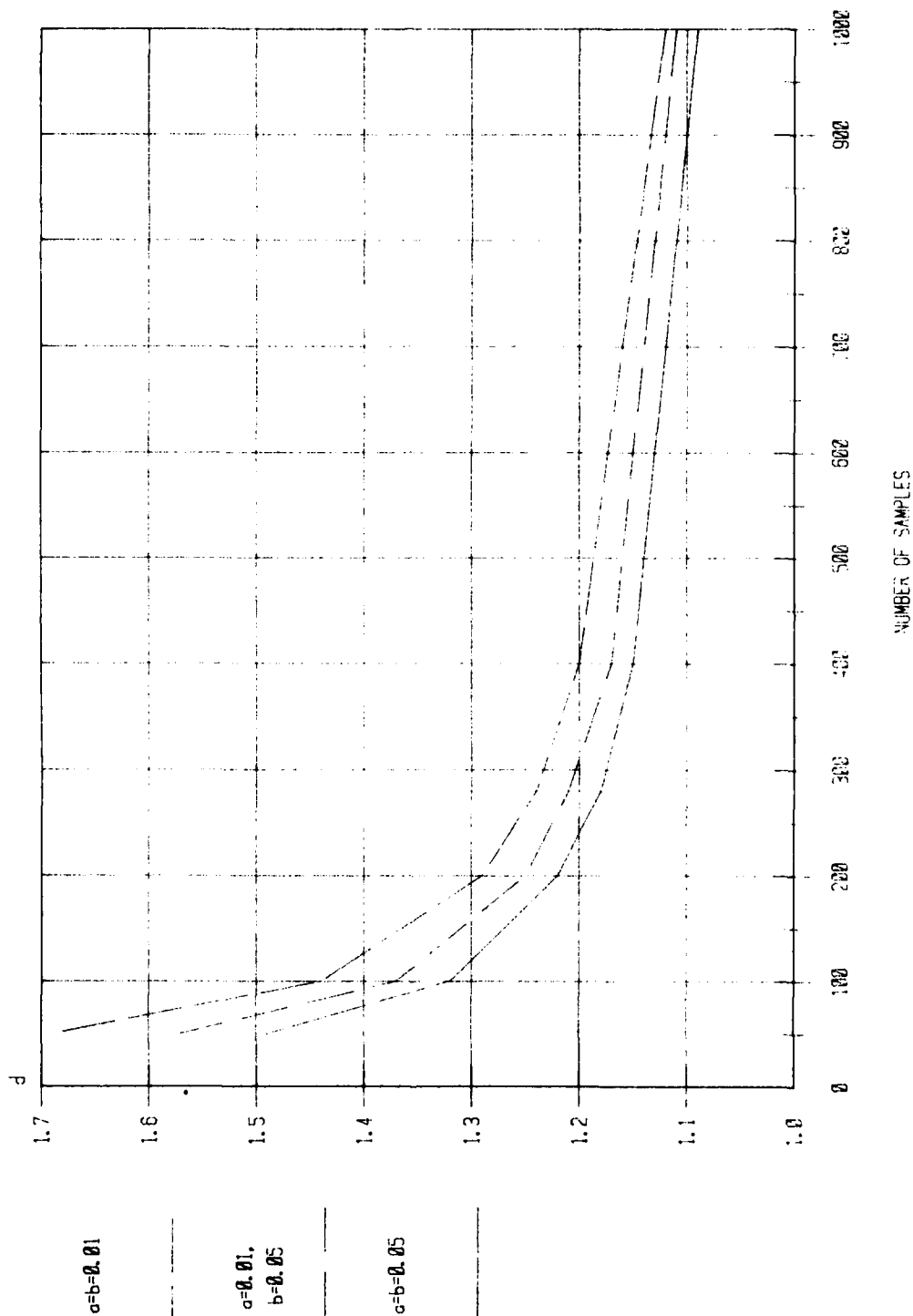


FIGURE 15

Now that theoretical limits have been defined for a recommended sample size; i.e., $n \approx 280$ at $\alpha = \beta = 0.05$, the adequacy can be addressed from a structural response viewpoint. Figure 6 shows one of the typical PSD estimates for the top of the rail and for combined data of eight 51 measurement sets from Track Stations 2,000 to 16,000. The size of the sample was 8×51 or 408 measurements. The reciprocal of any of the subdivisions of the ordinate represents some equivalent length; e.g., 0.1 cycles/ft equates to 10 ft length; 0.2 cycles/ft equates to a 5 ft distance, etc.

The more interesting portion of the PSD estimate is the low end of the spectrum where a natural frequency appears to occur at approximately 0.2 cycles per second, which is the reciprocal of 50 feet or the length of each survey section. As previously mentioned, a different set of measurements were made in 1969. The data measured in 1969 was for one position along the top center of the railhead. This data was recorded every 10 inches for 400 ft of the west rail. The slope and mean was then subtracted from the total sample. A log-linear plot of this data is shown in Figure 16. As shown by this plot, energy existed below the 0.0256 cycle per foot frequency. The next question is can this energy excite typical rocket sleds?

The previously described PSD estimates can be converted to the frequency domain multiplying both the abscissa and ordinate by a constant velocity. The constant velocity assumption should be emphasized since the velocity of rocket sleds seldom remains constant but is a quasi-steady state function. However, the time to traverse 400 feet of track varies from 0.05 sec to 8,000 feet per second (FPS) to 0.8 sec for 500 feet per second; consequently, the constant velocity assumption appears appropriate. Under the constant velocity assumption, the units of the PSD estimates become inches (RMS)/Hertz and Hertz. Using this concept, Table F was constructed. In addition to the points listed on the frequency axis; i.e., .1, .2, .3, .4, .5 cycles per foot, the frequencies of .0025, .00367, .005, .01, .0256 and .2308 cycles per foot were converted into the frequency domain because of the following special interest.

.0025 Cycles per Foot - Equates to a track period of 400 feet and requires minimum $n = 400$ each one (1) foot spaced measurements. Derived from theory $\alpha = \beta = .01$.

PSD OF TRACK DATA
OLD DATA 256 POINTS STARTING AT 100

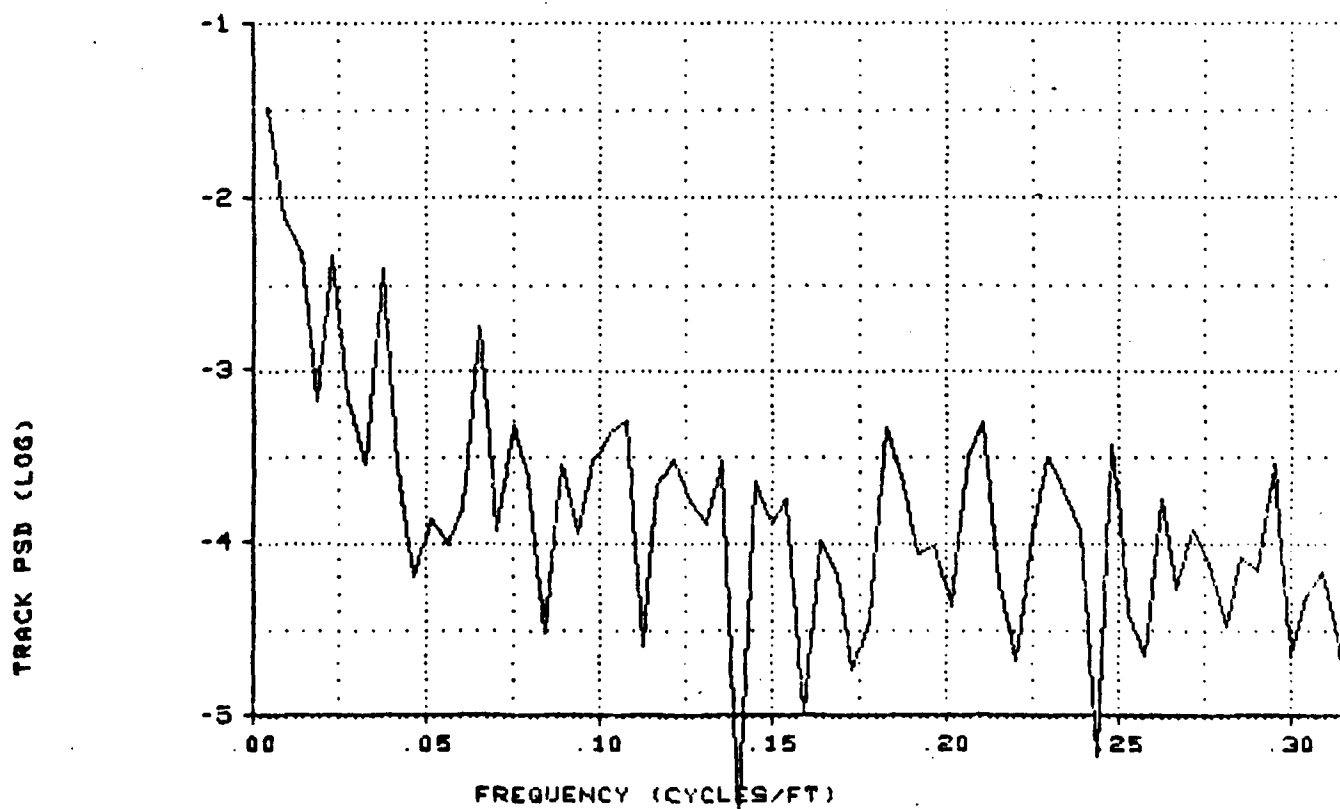


FIGURE 16

TABLE F. SAMPLE SIZE VERSUS VELOCITY/SLID FREQUENCY.

.00357 Cycles per Foot - Equates to a track period of 280 feet and requires minimum $n = 280$ each one (1) foot spaced measurements. Derived from theory $a = \beta = .05$.

.005 Cycles per Foot - Equates to a track period of 200 feet and requires minimum $n = 200$ each one (1) foot spaced measurements. Completes matrix.

.01 Cycles per Foot - Equates to a track period of 100 feet and requires minimum $n = 100$ each one (1) foot spaced measurements. Completes matrix.

.0256 Cycles per Foot - Equates to a track period of 39 feet and requires $n = 39$ each one (1) foot spaced measurements. Length of each rail section.

.2308 Cycles per Foot - Equates to a track period of 4.33 feet (52 inches) and requires a minimum of 4.33 one (1) foot spaced measurements. Distance between tie-downs and alignment points.

4.4.1 Criteria. Now that a frequency matrix has been derived, a criteria must be established in order to estimate the effect of the power at these frequencies will have on rocket sleds. Two classes of sleds will be considered.

4.4.2 Dual Rail Sleds. First, the lower frequency and lower velocity dual rail sled will be considered. Due to aerodynamic considerations, the velocities of dual rail sleds has been limited to approximately 3,000 feet per second. The structural frequency range is approximately 15 to 500 Hertz. The 15 Hz lower limit is associated with the lowest rigid body frequency observed on a dual rail sled. The 500 Hz upper limit is a conservative estimate of the highest frequency structural response that should be considered in design. Normally, the lower upper limit is used in design. This analysis does not infer that there are no vibrations above these frequencies; however, the displacement is small and need not be considered in the structural analysis process.

If these limits are applied to the previously derived frequency matrix, a band of frequencies are identified where probable response can be expected. See Table G. Based on these assumptions, the .005 cycles per foot should be measured. This requires a minimum sample size of $n = 200$.

4.4.3 Monorail Sleds. The monorail rocket sleds are basically higher frequency structures and are tested at much higher velocities. The maximum experimental test velocity for a monorail sled is 8,200 feet per second (FPS).

n REQUIRED TO IDENTIFY												
	280	200	140	100	50	39	10	5	4	3	2	
	FREQUENCY (CYCLES/FT)											
	.00357	.005	.0071	.01	.02	.0256	.1	.2	.3	.4	.5	
VELOCITY FT/SEC	FREQUENCY (CYCLES/SECOND)											
	1.8	2.5	3.6	5	10	12.8	50	100	150	200	250	
	3.6	5	7.1	10	20	25.6	100	200	300	400	500	
	5.4	7.5	10.7	15	30	38.4	150	300	450	600	750	
	7.1	10	14.2	20	40	51.2	200	400	600	800	1000	
	10.7	15	21.3	30	60	76.8	300	600	900	1200	1500	
	14.3	20	28.4	40	80	102.4	400	800	1200	1600	2000	
	17.9	25	35.5	50	100	128.0	500	1000	1500	2000	2500	
	21.4	30	42.6	60	120	153.6	600	1200	1800	2400	3000	
	25.0	35	49.7	70	140	179.2	700	1400	2100	2800	3500	
	28.6	40	56.8	80	160	204.8	800	1600	2400	3200	4000	

TABLE G. SAMPLE SIZE VS V/F DUAL RAIL SLEDS.

The lowest frequency that has been measured in the roll plane is approximately 50 Hz. An average lower limit in the pitch plane is approximately 100 Hz. On the upper limit, a conservative value of 1,000 Hz is established as the highest structural response to be of interest. Just as the case for dual rail sleds, higher frequency vibrations have been observed but not included in the design process due to the associated small displacements. These limits have been applied to Table H. On the lower end the 280 sample should suffice for monorails. The figure does indicate that measurements at a closer spacing than one (1) foot could be beneficial. However, the lower power and the fact that this interest would be at relative low velocities strongly suggest that one (1) foot spacing is adequate.

Based on this analysis and data recorded in 1969, a sample size of $n = 280$ is recommended on future measurements with one (1) foot spacing. The additional factor that falls out is that the data collected with 51 one foot samples are not sufficient to meet the prime objective of this study - to provide a forcing function for the sledyne simulator. This is not an indictment against the survey - those data were collected to estimate rail roughness, not to provide model parameters. This estimation of forcing functions was to be an additional benefit. The secondary objective of this study was the primary reason for the survey and previous discussions and conclusions toward that end are valid.

n REQUIRED TO IDENTIFY											
280	200	140	100	50	39	10	5	4	3	2	
FREQUENCY (CYCLES/FT)											
.00357	.005	.0071	.01	.02	.0256	.1	.2	.3	.4	.5	
FREQUENCY (CYCLES/SECOND)											
VELOCITY FT/SEC											
500	1.8	2.5	3.6	5	10	12.8	50	100	150	200	250
1000	3.6	5	7.1	10	20	25.6	100	200	300	400	500
1500	5.4	7.5	10.7	15	30	38.4	150	300	450	600	750
2000	7.1	10	14.2	20	40	51.2	200	400	600	800	1000
3000	10.7	15	21.3	30	60	76.8	300	600	900	1200	1500
4000	14.3	20	28.4	40	80	102.4	400	800	1200	1600	2000
5000	17.9	25	35.5	50	100	128.0	500	1000	1500	2000	2500
6000	21.4	30	42.6	60	120	153.6	600	1200	1800	2400	3000
7000	25.0	35	49.7	70	140	179.2	700	1400	2100	2800	3500
8000	28.6	40	56.8	80	160	204.8	800	1600	2400	3200	4000

TABLE H. SAMPLE SIZE VS V/F MONORAIL SLEDS.

5. CAP THICKNESS

An extra benefit which resulted from this measurement program was a study of the thickness of the rail cap. The Test Track had specified a 0.125 inch gap between slipper surfaces and the rail head for a number of years. This tolerance equates to a slipper dimension of 1.85 inches at the cross section of the measurement point (0.75 inches in from the edge of the rail). See Figure 2. This dimension will be called slipper depth. This clearance is intended to insure that the slipper will pass over any high spots that might exist and was established by trial and error. In the past, tighter slippers have been tested on the track and the slipper depth that resulted after the test was 1.85 inches. However, the question has been asked on numerous occasions: Can this dimension be reduced? The implication was that the dynamic loads might be reduced with a smaller slipper gap.

If the maximum and minimum cap thicknesses are extracted from the data and differences taken at each of the 24 sets of data, then the cap thickness can be studied as shown in Table I.

At about the same time as the measurement program in May 1978, the first attempts were being made to make the north section (15,000 feet) operational. During the trial and error periods, it was observed that the standard 1.85 inch slipper depth would hang up at certain locations. A direct approach was used where a slipper would be pulled along the track until one of the interference locations stopped motion. The rail would then be ground at that location. Consequently, this data is probably not representative of the north track extension. A verification measurement program is planned in the near future.

A graphical representation is presented in Figure 17. This bar graph shows the data to be consistent except at track station 42,000. The possibility exists that this rail section was not from the same mill run as required in the construction of the 15,000 ft track extension. See page 14, reference 2. In addition, a difference exists in cap thickness between opposite sides of the cap due to manufacturing techniques, and construction specifications required the ends to be matched. A possibility exists that this section of rail (39 ft) was reversed.

In order to better characterize the cap thickness for the entire population, the data of each set were fitted to various distributions. The beta distribution was required to actually fit the data rigorously, but the beta distribution is

TABLE I. CAP THICKNESS

TRACK STATION	MAXIMUM (IN)	MINIMUM (IN)	DELTA (IN)	$\bar{X}$	S
2,000	1.702	1.645	.057	1.681	.0117
4,000	1.683	1.645	.038	1.673	.0081
6,000	1.686	1.622	.064	1.670	.0115
8,000	1.689	1.654	.035	1.678	.0070
10,000	1.691	1.654	.040	1.678	.0083
12,000	1.691	1.663	.028	1.677	.0060
14,000	1.702	1.630	.072	1.679	.0123
16,000	1.689	1.633	.053	1.677	.0094
18,000	1.688	1.617	.071	1.666	.0183
20,000	Water Trays	--	--	--	--
22,000	1.702	1.626	.076	1.683	.0163
24,000	1.678	1.615**	.063	1.654	.0186
26,000	1.695	1.652	.043	1.678	.0103
28,000	1.697	1.650	.047	1.678	.0088
30,000	1.693	1.623	.070	1.663	.0201
32,000	1.690	1.636	.054	1.673	.0119
34,000	1.688	1.641	.025	1.676	.0085
36,000	1.720	1.703	.017	1.711	.0037
38,000	1.702	1.634	.065	1.675	.0172
40,000	1.720	1.687	.033	1.711	.0090
42,000	1.811*	1.706	.105	1.736	.0271
44,000	1.721	1.707	.014	1.713	.0033
46,000	1.721	1.682	.039	1.710	.0070
48,000	1.705	1.687	.018	1.694	.0049
50,000	1.720	1.703	.017	1.714	.0033

*Maximum 1.811

**Minimum 1.615

Delta 0.196 inches

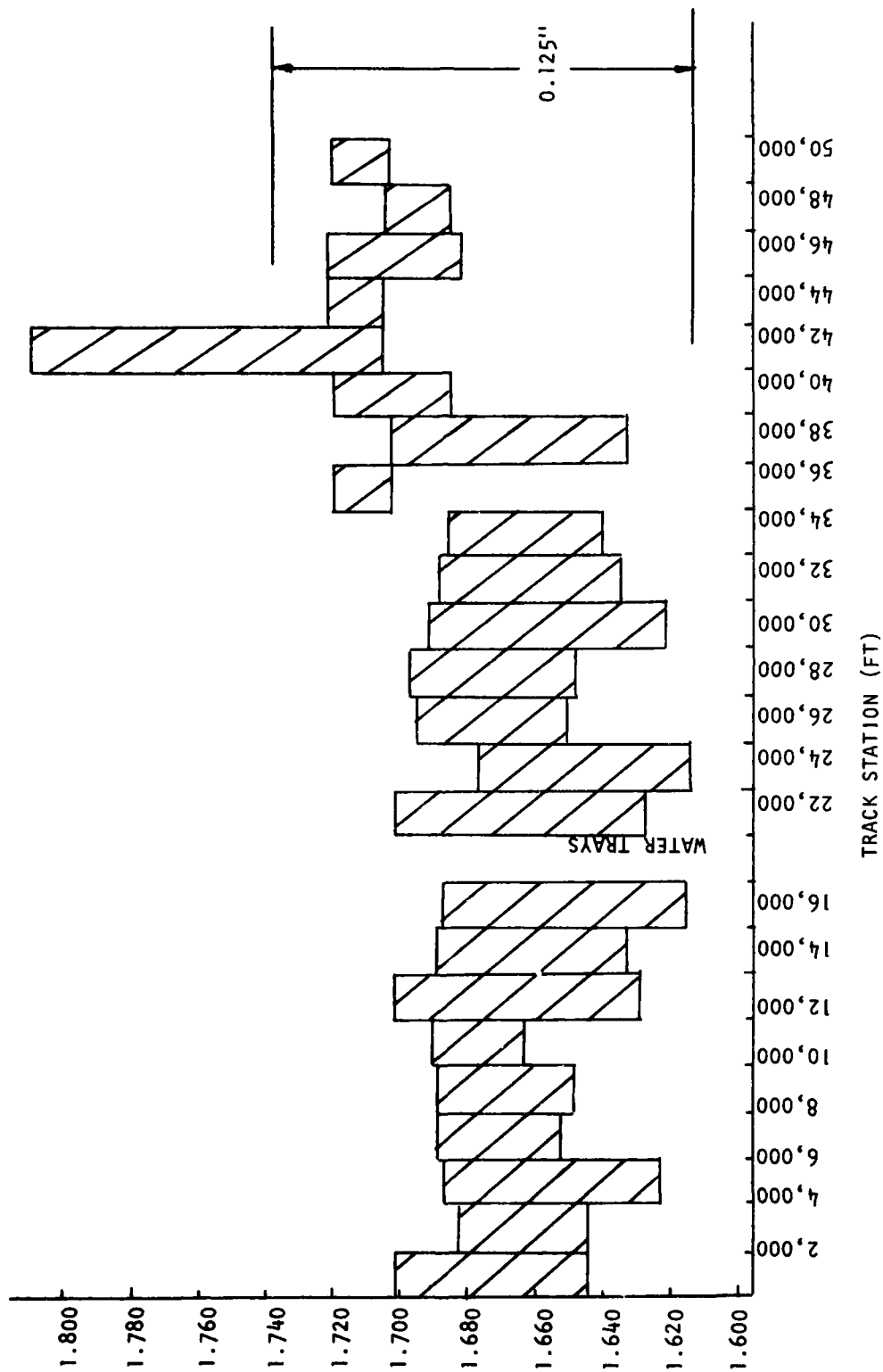


FIGURE 17. CAP THICKNESS

quite unwieldy to handle. Other distributions were also tried, and the log-normal was finally accepted as the distribution model which provided both a reasonable fit to the data and offered considerable convenience in operations.

The log-normal distribution has several desirable characteristics. For example, it lends itself to study using transformed normal data, and the overall distribution is log-normal if sets of log-normal distribution are combined by multiplication. In addition, there is a Central Limit Theorem which states that if a series of error measurements have resulted from a product of errors, the errors tend to be log-normal (reference 6). Also, typically mechanical systems do wear in a log-normal fashion. The only undesirable characteristic of the log-normal distribution is that, like the normal, it is unbounded on the upper end; i.e., it is continuous to infinity. This difficulty can be overcome by using a three parameter log-normal or Johnson S_L Distribution. The log-normal distribution uses a shape parameter, μ , and a scale parameter, σ^2 , for descriptions which are not to be confused with the mean, $\bar{x}$, and variance s^2 , used in description of normal distributions. The significance of μ and σ^2 are that they are the mean and variance of the natural logarithm of the parameters of interest; in this case, cap thickness. Thus, limits and confidence levels can easily be studied by taking logarithms and using standard normal table.

The log-normal parameters μ and σ^2 for each set are shown in Table J. One fact becomes clear when studying the log-normal characteristics--there are two distinct families of data: The north 15,000 feet and the south 35,000 feet. This observation was verified by analysis of variance.

Another fact was also verified--the data set from track station 42,000 appears to be an out-lier, even for the north 15,000 feet. As previously discussed, procedures were in effect in 1978 to correct these obvious anomalies; therefore, the data from 42,000 ft will be omitted from calculations. The task has been initiated to resurvey this area.

Given that the entire south 35,000 feet can be considered one population, the log-normal parameters would be $\mu = .5146$ and $\sigma^2 = 5.2668 \times 10^{-5}$. From reference 6 the probability that the data are within a given range of points is:

TABLE J. CAP THICKNESS LOG-NORMAL PARAMETERS

TRACK STATION	SHAPE PARAMETER μ	SCALE PARAMETER σ^2
2,000	.5192	4.8358
4,000	.5148	2.3520
6,000	.5127	4.8163
8,000	.5177	1.7433
10,000	.5176	2.4530
12,000	.5172	1.2833
14,000	.5182	5.4553
16,000	.5170	3.1532
18,000	.5105	12.6015
20,000	Water Trays —	--
22,000	.5106	3.8880
24,000	.5030	12.7107
26,000	.5174	3.7765
28,000	.5174	2.7856
30,000	.5088	14.7261
32,000	.5148	5.1041
34,000	.5164	2.5839
36,000	.5372	0.4697
38,000	.5260	5.0478
40,000	.5369	12.7611
42,000	.5515	23.9321
44,000	.5381	0.3714
46,000	.5365	1.7007
48,000	.5276	0.8474
50,000	.5388	0.3738

$$\begin{aligned}
P \quad 1.1. \leq T \leq \text{upper limit} &= \\
&= P \ln 1.1 \leq \ln T \leq \ln u.1. \\
&= \Phi \frac{\ln (u.1.) - \mu}{\sigma} - \Phi \frac{\ln (1.1.) - \mu}{\sigma}
\end{aligned}$$

where 1.1 = lower limit

u.1. = upper limit

Φ = standard normal operator

for 1.1 = 1.62

u.1. = 1.72

= .5146

$\sigma^2 = 5.2668 \times 10^{-5}$

$$\begin{aligned}
P &= \Phi \frac{\ln (1.72) - .5146}{.007257} - \Phi \frac{\ln (1.62) - .5146}{.007257} \\
&= \Phi 3.82 - \Phi - 4.43 \\
&= .999933 - .000005 = .999928 \text{ or } 99.993\%
\end{aligned}$$

In words the logarithm of 1.72 inches is 3.82 greater than the logarithm of the mean, and logarithm of 1.62 inches is over 4.4σ below the logarithm of the mean.

The same formula can be reversed such that $\pm 4\sigma$ points can be calculated; i.e., set the term within brackets to equal to plus or minus 4σ and solve for the upper or lower limit

$$\frac{\ln (u.1.) - \mu}{\sigma} = 4$$

$$u.1 = \exp = 1.72219 \text{ inches}$$

So, a slipper with this depth could pass 99.9968% of the points on south 34,000 ft of the track.

The significance of the lower limit is that it establishes the maximum required slipper gap size. This dimension is important during the design of sleds because it defines the limits of the shock loads that the structure will experience as a result of vertical and cross-track velocities. Additionally, for monorails, it defines the limits for the roll motion.

A similar process can be followed for the north end of the track (minus 42,000 ft data). For T.S. 36,000 to T.S. 5,000, the log-normal parameters are $\mu = .5345$, $\sigma^2 = 3.0817 \times 10^{-5}$. The $\pm 4\sigma$ values would be 1.745 inches and 1.669 inches. As previously mentioned, surveys have been initiated to ascertain the validity of omitting the data from T.S. 42,000.

From the calculations, it appears that the depth of the slipper could be reduced at least .100 inches, or as much as .130 inches for sleds confined to the south 35,000 feet; i.e., from 1.85 to 1.75 or 1.72 inches.

6. CONCLUSIONS

The prime objective of this study — to provide a statistical forcing function for Sledyne—could not be met due to small sample sizes. From a sample of size 51 the lowest frequency component that can be studied is at .02 cycles/ft. Previous studies indicate that appreciable energy exists at frequencies a magnitude lower. Characterization of frequencies as low as .005 cycles/ft are required to meet structural dynamics requirements.

Rail grinding does result in smoother rail surfaces. Whether the difference is significant from a structural dynamics standpoint is yet to be determined. Also, the surfaces that have received the most grinding, the top, is smoother than the side which in turn is smoother than the bottom, which has received the least attention.

Analysis techniques for studying rail roughness have been developed and verified. Analysis of residuals in the frequency domain has proven a simple and effective technique.

The depth of the sled slippers can be reduced as much as .100 inches, reducing the gap between the slipper and railhead. This will reduce the tendency of monorail sleds to roll and decrease dynamic loads on all sleds.

7. RECOMMENDATIONS

A follow-on study to address the Sledyne forcing function should be accomplished. Toward this end, the experiment has been designed and survey crews tasked to collect data in sets of 280 samples (or as large as possible up to 280). Other aspects of the experiment include measuring cap thickness on both side of the rail, surveying the east and west rails, and establishing an estimate of errors in the survey process.

The Sledyne computer simulator should be modified to allow the track parameters to be changed locally when data are available. The program should also be changed to provide a histogram output of dynamic loads.

The effects of smaller slipper gaps in dynamic load should be investigated using Sledyne.

The feasibility of selectively grinding the north 15,000 ft of the track to make the cap thickness more uniform should be investigated. This would permit use of small slipper gaps on high speed monorails in that area.

The data found in this study should be utilized to determine where to grind the rails. From the roughness classes, the roughest spots should be ground to attempt to make the track more homogeneous.

A feasibility study should be pursued on an automated measurement system for measuring the rail roughness, concentrating on multi-beam laser system(s).

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APPENDIX A

RAW DATA AND REGRESSION RESIDUALS

TRACK STATION 2000

RAW DATA

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
13.927	1.675	6.975
13.914	1.687	6.983
13.901	1.690	6.987
13.881	1.694	6.992
13.870	1.686	6.992
13.849	1.663	7.000
13.833	1.683	6.986
13.829	1.680	6.974
13.821	1.684	6.993
13.819	1.678	7.008
13.794	1.690	7.000
13.804	1.682	7.012
13.777	1.673	7.000
13.761	1.690	6.990
13.754	1.690	6.968
13.749	1.682	6.981
13.732	1.669	6.990
13.705	1.663	6.986
13.688	1.669	6.976
13.679	1.652	6.973
13.671	1.672	6.981
13.661	1.660	6.976
13.664	1.684	6.980
13.652	1.685	6.992
13.627	1.694	7.000
13.604	1.686	7.000
13.587	1.693	6.989
13.579	1.683	7.000
13.569	1.688	7.000
13.562	1.682	6.990
13.555	1.691	6.978
13.544	1.685	6.972
13.517	1.686	6.977
13.508	1.696	6.989
13.508	1.688	6.995
13.493	1.677	7.001
13.478	1.682	7.009
13.463	1.702	7.000
13.454	1.685	6.985
13.442	1.682	6.983
13.435	1.679	6.982
13.421	1.681	6.997
13.407	1.695	7.008
13.413	1.699	7.000
13.392	1.677	6.980
13.372	1.675	6.974
13.362	1.660	6.974
13.353	1.645	6.984
13.318	1.669	6.984
13.303	1.675	6.986
13.292	1.677	6.987

DATA WITH LINE REMOVED

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
.005912	-.001326	-.014201
.005212	.010038	-.006177
.004512	.012401	-.002153
-.003188	.008765	.002871
-.001888	.002129	.002894
-.010588	-.029508	.010918
-.014288	-.013144	-.003058
-.005988	-.007780	-.015035
-.001688	.000583	.003989
.008612	.004947	.019013
-.004088	.004310	.011037
.018212	.018674	.023060
.003512	-.004962	.011084
-.000188	.008401	.001108
.005112	.013765	-.020869
.012412	.013129	-.007845
.007712	-.004508	.001179
-.006988	-.025144	-.002798
-.011688	-.023781	-.012774
-.008388	-.037417	-.015750
-.004088	-.013053	-.007726
-.001788	-.022690	-.012703
.013512	.016674	-.008679
.013812	.018037	.003345
.001112	.014401	.011368
-.009588	-.004235	.011392
-.014288	-.001872	.000416
-.009988	-.007508	.011440
-.007688	-.000144	.011463
-.002388	-.000781	.001487
.002912	.013583	-.010489
.004212	.008946	-.016466
-.010488	-.004690	-.011442
-.007188	.008674	.000582
.005112	.013037	.006606
.002412	-.000599	.012629
-.000288	.001765	.020653
-.002988	.019128	.011677
.000312	.005492	-.003300
.000612	.002855	-.005276
.005912	.005219	-.006252
.004212	.005583	.008772
.002512	.017946	.019795
.020812	.040310	.011819
.012112	.009673	-.008157
.004412	.000037	-.014134
.006712	-.012599	-.014110
.010012	-.024236	-.004086
-.012688	-.022872	-.004063
-.015388	-.019508	-.002039
-.014088	-.016145	-.001015

TRACK STATION 4000

RAW DATA

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
6.067	1.679	5.625
6.047	1.660	5.630
6.049	1.645	5.607
6.033	1.652	5.594
6.005	1.675	5.600
6.010	1.676	5.608
6.005	1.671	5.617
6.000	1.682	5.626
5.990	1.683	5.644
5.972	1.678	5.627
5.953	1.675	5.613
5.940	1.676	5.609
5.928	1.672	5.625
5.921	1.673	5.642
5.907	1.681	5.628
5.895	1.673	5.628
5.877	1.680	5.614
5.871	1.673	5.622
5.859	1.676	5.628
5.847	1.675	5.627
5.827	1.670	5.614
5.819	1.661	5.614
5.815	1.668	5.612
5.785	1.678	5.607
5.776	1.677	5.605
5.768	1.678	5.602
5.773	1.674	5.602
5.767	1.676	5.605
5.750	1.679	5.605
5.739	1.664	5.612
5.738	1.652	5.605
5.721	1.670	5.602
5.707	1.677	5.606
5.707	1.673	5.600
5.706	1.683	5.592
5.672	1.682	5.598
5.648	1.671	5.605
5.634	1.663	5.611
5.637	1.675	5.602
5.639	1.672	5.635
5.624	1.677	5.635
5.605	1.681	5.609
5.584	1.681	5.598
5.571	1.676	5.596
5.548	1.677	5.605
5.530	1.674	5.603
5.520	1.673	5.605
5.511	1.676	5.608
5.495	1.683	5.612
5.486	1.678	5.600
5.479	1.666	5.599

DATA WITH LINE REMOVED

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
-.003225	.005319	.003676
-.011598	-.022169	.009045
.002029	-.023657	-.013587
-.002344	-.021145	-.026219
-.018717	-.014633	-.019851
-.002090	.002879	-.011482
.004537	.004391	-.002114
.011164	.021903	.007254
.012791	.024415	.025622
.006418	.012927	.008991
-.000955	.002438	-.004641
-.002328	.001950	-.008273
-.002701	-.002538	.008095
.001926	.002974	.025464
-.000447	.008486	.011832
-.000820	-.000002	.012200
-.007193	.000510	-.001432
-.001565	-.000978	.006936
-.001938	.001534	.013305
-.002311	.000046	.012673
-.010684	-.013442	.000041
-.007057	-.018930	.000409
.000570	-.004418	-.001222
-.017803	-.012906	-.005854
-.015176	-.011394	-.007486
-.011549	-.006882	-.010118
.005078	.005630	-.009749
.010705	.013142	-.006381
.005332	.010653	-.006013
.005959	-.003835	.001355
.016586	-.005323	-.005276
.011213	.007189	-.007908
.008840	.011701	-.003540
.020467	.019213	-.009172
.031095	.039725	-.016804
.008722	.016237	-.010435
-.003651	-.007251	-.003067
-.006024	-.017739	.003301
.008603	.008773	-.005331
.022230	.019285	.028038
.018857	.020797	.028406
.011484	.017309	.002774
.002111	.007821	-.007858
.000738	.001333	-.009489
-.010635	-.009155	-.000121
-.017008	-.018643	-.001753
-.015381	-.018131	.000615
-.012754	-.012620	.003984
-.017127	-.010108	.008352
-.014500	-.012596	-.003280
-.009873	-.020084	-.003912

TRACK STATION 6000

RAW DATA

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
14.246	1.645	6.434
14.252	1.658	6.419
14.243	1.668	6.405
14.225	1.685	6.428
14.205	1.676	6.435
14.175	1.665	6.416
14.165	1.669	6.412
14.152	1.679	6.402
14.152	1.678	6.413
14.143	1.676	6.406
14.127	1.686	6.409
14.102	1.679	6.404
14.089	1.668	6.409
14.068	1.671	6.407
14.062	1.671	6.412
14.053	1.678	6.405
14.035	1.667	6.404
14.021	1.677	6.399
14.010	1.674	6.404
13.993	1.681	6.402
13.979	1.678	6.405
13.969	1.680	6.412
13.956	1.673	6.415
13.943	1.668	6.415
13.916	1.675	6.417
13.889	1.678	6.422
13.882	1.668	6.434
13.861	1.678	6.430
13.854	1.664	6.421
13.846	1.655	6.428
13.835	1.663	6.423
13.812	1.653	6.434
13.800	1.667	6.426
13.782	1.684	6.441
13.778	1.675	6.458
13.768	1.673	6.455
13.759	1.673	6.440
13.738	1.669	6.440
13.719	1.681	6.448
13.710	1.663	6.445
13.701	1.670	6.438
13.687	1.675	6.441
13.682	1.651	6.436
13.674	1.622	6.453
13.652	1.644	6.449
13.638	1.668	6.426
13.624	1.674	6.425
13.625	1.676	6.435
13.614	1.673	6.425
13.598	1.671	6.439
13.579	1.668	6.444

DATA WITH LINE REMOVED

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
-.007333	-.036182	.027717
.012417	-.003270	.011992
.017168	.011641	-.002733
.012918	.024553	.019542
.006669	.009465	.025817
-.009580	-.017624	.006091
-.005830	-.009712	.001366
-.005079	.001199	-.009359
.008671	.014111	.000916
.013422	.017023	-.006809
.011173	.024934	-.004534
-.000077	.006846	-.010260
.000674	-.003243	-.005985
-.006576	-.007331	-.008710
.001175	.000580	-.004435
.005925	.012492	-.012160
.001676	-.002596	-.013885
.001427	.007315	-.019610
.004177	.007227	-.015336
.000928	.011138	-.018061
.000678	.008050	-.015786
.004429	.013962	-.009511
.005180	.007873	-.007236
.005930	.003785	-.007961
-.007319	-.002304	-.006687
-.020569	-.012392	-.002412
-.013818	-.015481	.008863
-.021067	-.012569	.004138
-.014317	-.019657	-.005587
-.008566	-.022746	.000688
-.005816	-.011834	-.005038
-.015065	-.030923	.005237
-.013315	-.015011	-.003488
-.017564	-.002099	.010787
-.007813	-.001188	.027062
-.004063	.000724	.023337
.000688	.005635	.007611
-.006562	-.005453	.006886
-.011811	.001458	.014161
-.007060	-.011630	.010436
-.002310	.000282	.002711
-.002559	.005193	.004986
.006191	-.009895	-.000739
.011942	-.032984	.015535
.003693	-.019072	.010810
.003443	.004840	-.012915
.003194	.010751	-.014640
.017944	.027663	-.005365
.020695	.027574	-.016090
.018445	.023486	-.002816
.013196	.015397	.001459

TRACK STATION 8000

RAW DATA

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
13.981	1.654	6.975
13.960	1.678	6.968
13.932	1.677	6.945
13.907	1.675	6.945
13.883	1.677	6.945
13.856	1.678	6.945
13.840	1.678	6.945
13.814	1.680	6.945
13.800	1.683	6.950
13.771	1.677	6.968
13.749	1.671	6.968
13.721	1.667	6.976
13.707	1.680	6.950
13.674	1.685	6.941
13.669	1.689	6.932
13.667	1.686	6.932
13.627	1.685	6.938
13.611	1.678	6.951
13.590	1.672	6.955
13.571	1.678	6.955
13.562	1.683	6.955
13.539	1.688	6.955
13.513	1.682	6.955
13.486	1.688	6.955
13.467	1.686	6.955
13.448	1.678	6.955
13.421	1.676	6.955
13.396	1.676	6.950
13.380	1.675	6.940
13.346	1.684	6.940
13.322	1.683	6.952
13.307	1.684	6.965
13.296	1.688	6.965
13.277	1.675	6.965
13.248	1.678	6.963
13.230	1.674	6.963
13.203	1.683	6.954
13.182	1.684	6.954
13.169	1.683	6.954
13.147	1.680	6.957
13.139	1.675	6.961
13.099	1.678	6.966
13.088	1.663	6.983
13.060	1.682	7.000
13.044	1.674	7.012
13.022	1.675	7.008
12.995	1.667	6.999
12.954	1.675	6.985
12.921	1.686	6.971
12.915	1.670	6.971
12.894	1.665	6.971

DATA WITH LINE REMOVED

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
.009531	-.015239	.031597
.009821	.009076	.023931
.003111	.001390	.000265
-.000599	-.004295	-.000401
-.003309	-.004980	-.001068
-.009018	-.009666	-.001734
-.003728	-.004351	-.002400
-.008438	-.007036	-.003066
-.001148	.003278	.001267
-.008858	-.010407	.018601
-.009568	-.017092	.017935
-.016278	-.027778	.025269
-.008987	-.007463	-.001398
-.020697	-.014148	-.011064
-.004407	.006166	-.020730
.014883	.022481	-.021396
-.003827	.002796	-.016063
.001463	.001110	-.003729
.001753	-.004575	-.000395
.004043	.003739	-.001061
.016334	.021054	-.001728
.014624	.024369	-.002394
.009914	.013683	-.003060
.004204	.013998	-.003726
.006494	.014313	-.004393
.008784	.008627	-.005059
.003074	.000942	-.005725
-.000635	-.002743	-.011391
.004655	.001571	-.022058
-.008055	-.002114	-.022724
-.010765	-.005799	-.011390
-.004475	.001515	.000944
.005815	.015830	.000277
.008105	.005145	-.000389
.000396	.000459	-.003055
.003686	-.000226	-.003721
-.002024	.003089	-.013388
-.001734	.004403	-.014054
.006556	.011718	-.014720
.005846	.008033	-.012386
.019136	.016347	-.009052
.000426	.000662	-.004719
.010717	-.004023	.011615
.004007	.008291	.027949
.009297	.005606	.039283
.008587	.005921	.034616
.002877	-.007765	.024950
-.016833	-.019450	.010284
-.028543	-.020135	-.004382
-.013252	-.020821	-.005049
-.012962	-.025506	-.005715

TRACK STATION 10000

RAW DATA

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
14.253	1.677	7.516
14.227	1.681	7.536
14.198	1.682	7.539
14.186	1.682	7.532
14.178	1.687	7.534
14.166	1.670	7.531
14.142	1.665	7.530
14.132	1.678	7.520
14.113	1.679	7.528
14.086	1.672	7.541
14.066	1.680	7.545
14.049	1.666	7.530
14.039	1.679	7.529
14.026	1.682	7.530
14.008	1.682	7.530
13.972	1.680	7.531
13.961	1.674	7.538
13.949	1.686	7.556
13.936	1.686	7.556
13.922	1.686	7.552
13.898	1.681	7.552
13.882	1.681	7.564
13.865	1.683	7.567
13.858	1.680	7.558
13.844	1.687	7.548
13.833	1.678	7.550
13.815	1.672	7.555
13.784	1.672	7.567
13.764	1.679	7.556
13.752	1.663	7.548
13.734	1.654	7.544
13.705	1.679	7.549
13.682	1.686	7.568
13.668	1.690	7.575
13.651	1.680	7.576
13.626	1.678	7.569
13.609	1.683	7.564
13.588	1.684	7.557
13.573	1.686	7.543
13.552	1.666	7.543
13.545	1.655	7.543
13.512	1.669	7.540
13.494	1.680	7.535
13.484	1.679	7.545
13.476	1.674	7.554
13.433	1.684	7.546
13.406	1.679	7.539
13.387	1.689	7.527
13.370	1.691	7.524
13.352	1.690	7.526
13.353	1.673	7.525

DATA WITH LINE REMOVED

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
-.002945	-.002399	-.021989
-.010946	-.006462	-.002243
-.021946	-.016525	.000503
-.015947	-.010589	-.006751
-.005947	-.015652	-.005004
.000052	-.006715	-.008258
-.005949	-.017778	-.009512
.002051	.003158	-.019766
.001050	.003095	-.012019
-.007951	-.012968	.000727
-.009951	-.007032	.004473
-.008952	-.020095	-.010781
-.000953	.000842	-.012035
.004047	.008779	-.011288
.004046	.008715	-.011542
-.013954	-.011348	-.010796
-.006955	-.010411	-.004050
-.000956	.007526	.013697
.004044	.012462	.013443
.008043	.016399	.009189
.002042	.005336	.008935
.004042	.007273	.020682
.005041	.010209	.023428
.016040	.018146	.014174
.020040	.029083	.003920
.027039	.027020	.005667
.027039	.020956	.010413
.014038	.007893	.022159
.012037	.012830	.010905
.018037	.002767	.002652
.018036	-.006297	-.001602
.007035	.007640	.003144
.002035	.009577	.021890
.006034	.017514	.028637
.007034	.008450	.029383
.000033	-.000613	.022129
.001032	.005324	.016875
-.001968	.003261	.009622
.001031	.008197	-.004632
-.001970	-.014866	-.004886
.009030	-.014929	-.005140
-.005971	-.015993	-.008393
-.005972	-.005056	-.013647
.002028	.001881	-.003901
.012027	.006818	.004845
-.012973	-.008246	-.003408
-.021974	-.022309	-.010662
-.022975	-.013372	-.022916
-.021975	-.010435	-.026170
-.021976	-.011499	-.024423
-.002977	-.009562	-.025677

TRACK STATION 12000

RAW DATA

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
5.713	1.675	7.345
5.694	1.682	7.337
5.684	1.686	7.329
5.674	1.678	7.326
5.650	1.678	7.333
5.638	1.673	7.343
5.619	1.676	7.368
5.599	1.671	7.376
5.581	1.677	7.363
5.565	1.682	7.336
5.550	1.680	7.318
5.535	1.676	7.325
5.515	1.673	7.336
5.498	1.676	7.332
5.482	1.687	7.334
5.470	1.681	7.330
5.455	1.686	7.338
5.427	1.678	7.334
5.410	1.682	7.325
5.385	1.675	7.340
5.367	1.677	7.337
5.360	1.675	7.334
5.349	1.669	7.339
5.334	1.672	7.338
5.310	1.663	7.352
5.305	1.669	7.350
5.284	1.674	7.350
5.279	1.682	7.347
5.274	1.682	7.347
5.236	1.685	7.338
5.206	1.679	7.344
5.187	1.675	7.330
5.168	1.674	7.324
5.146	1.689	7.337
5.130	1.676	7.349
5.105	1.668	7.356
5.095	1.674	7.336
5.076	1.675	7.335
5.045	1.678	7.338
5.014	1.667	7.353
4.986	1.673	7.368
4.971	1.675	7.371
4.951	1.681	7.372
4.938	1.682	7.365
4.918	1.677	7.342
4.897	1.687	7.347
4.881	1.684	7.354
4.851	1.691	7.342
4.837	1.676	7.357
4.812	1.672	7.358
4.806	1.667	7.355

DATA WITH LINE REMOVED

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
-.024525	-.027219	.010096
-.025210	-.020886	.001741
-.016895	-.008553	-.006615
-.008580	-.008221	-.009970
-.014264	-.013888	-.003325
-.007949	-.012555	.006320
-.008634	-.010223	.030965
-.010319	-.016890	.038609
-.010004	-.010557	.025254
-.007689	-.003225	-.002101
-.004374	-.001892	-.020456
-.001059	-.002559	-.013811
-.002744	-.007227	-.003167
-.001428	-.002894	-.007522
.000887	.010439	-.005877
.007202	.010771	-.010232
.010517	.019104	-.002587
.000832	.001437	-.006943
.002147	.006769	-.016298
-.004538	-.006898	-.001653
-.004223	-.004565	-.005008
.007092	.004767	-.008363
.014408	.006100	-.003719
.017723	.012433	-.005074
.012038	-.002235	.008571
.025353	.017098	.006216
.022668	.019431	.005860
.035983	.040763	.002505
.049298	.054096	.002150
.029613	.037429	-.007205
.017929	.019761	-.001560
.017244	.015094	-.015916
.016559	.013427	-.022271
.012874	.024759	-.009626
.015189	.014092	.002019
.008504	-.000575	.008664
.016819	.013757	-.011692
.016134	.014090	-.013047
.003449	.004423	-.010402
-.009235	-.019245	.004243
-.018920	-.022912	.018888
-.015605	-.017579	.021532
-.017290	-.013247	.022177
-.011975	-.006914	.014822
-.013660	-.013581	-.008533
-.016345	-.006249	-.003888
-.014030	-.006916	.002756
-.025715	-.011587	-.009599
-.021399	-.022251	.005046
-.028084	-.032918	.005691
-.015769	-.025585	.002336

TRACK STATION 14000

RAW DATA

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
12.985	1.691	6.861
12.961	1.685	6.863
12.940	1.689	6.860
12.917	1.678	6.862
12.891	1.679	6.857
12.864	1.672	6.860
12.840	1.678	6.854
12.825	1.691	6.850
12.807	1.679	6.856
12.781	1.682	6.861
12.748	1.674	6.863
12.731	1.674	6.857
12.713	1.687	6.853
12.691	1.678	6.850
12.655	1.681	6.856
12.645	1.675	6.891
12.632	1.670	6.887
12.615	1.682	6.874
12.579	1.682	6.865
12.560	1.679	6.851
12.526	1.659	6.851
12.518	1.650	6.849
12.502	1.664	6.852
12.464	1.680	6.852
12.451	1.691	6.852
12.433	1.684	6.860
12.418	1.683	6.861
12.393	1.677	6.861
12.362	1.681	6.853
12.329	1.680	6.854
12.313	1.680	6.860
12.293	1.686	6.854
12.271	1.687	6.855
12.269	1.692	6.857
12.252	1.682	6.859
12.235	1.684	6.859
12.200	1.683	6.856
12.161	1.690	6.847
12.140	1.702	6.842
12.113	1.698	6.846
12.103	1.683	6.851
12.083	1.668	6.859
12.065	1.657	6.868
12.058	1.630	6.875
12.035	1.653	6.874
11.999	1.684	6.876
11.975	1.685	6.879
11.957	1.687	6.876
11.940	1.676	6.871
11.910	1.683	6.871
11.873	1.684	6.879

DATA WITH LINE REMOVED

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
.009854	.020315	.004505
.007588	.012111	.006341
.008323	.016907	.003177
.007057	.004703	.005013
.002792	.001499	-.000150
-.002474	-.010705	.002686
-.004739	-.006909	-.003478
.001995	.012887	-.007641
.005730	.004683	-.001805
.001464	.003479	.003031
-.009802	-.015725	.004867
-.005067	-.010929	-.001296
-.001333	.005867	-.005460
-.001598	-.003337	-.008624
-.015864	-.014541	-.002787
-.004129	-.008744	.032049
.004605	-.004948	.027885
.009340	.011848	.014721
-.004926	-.002356	.005558
-.002191	-.002560	-.008606
-.014457	-.034764	-.008770
-.000722	-.029968	-.010933
.005012	-.010172	-.008097
-.011253	-.010376	-.008261
-.002519	.009420	-.008425
.001216	.006216	-.000588
.007950	.012012	.000248
.004685	.002808	.000084
-.004581	-.002396	-.008079
-.015846	-.014600	-.007243
-.010112	-.008804	-.001407
-.008377	-.001008	-.007570
-.008643	-.000212	-.006734
.011092	.024584	-.004898
.015826	.019380	-.003062
.020560	.026176	-.003225
.007295	.011972	-.006389
-.009971	.001768	-.015553
-.009236	.014564	-.020716
-.014502	.005360	-.016880
-.002767	.002156	-.012044
-.001033	-.011048	-.004208
.002702	-.018252	.004629
.017436	-.030456	.011465
.016171	-.008660	.010301
.001905	.008136	.012138
-.000360	.006932	.014974
.003374	.012728	.011810
.008109	.006524	.006646
-.000157	.005320	.006483
-.015422	-.008884	.014319

TRACK STATION 16000

RAW DATA

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
5.618	1.687	7.122
5.616	1.686	7.122
5.603	1.687	7.140
5.556	1.673	7.144
5.535	1.673	7.144
5.514	1.677	7.144
5.500	1.675	7.144
5.470	1.680	7.140
5.469	1.684	7.140
5.455	1.688	7.140
5.432	1.677	7.140
5.407	1.678	7.140
5.404	1.676	7.140
5.383	1.673	7.135
5.367	1.689	7.135
5.339	1.685	7.135
5.312	1.686	7.135
5.306	1.670	7.143
5.299	1.679	7.153
5.279	1.674	7.150
5.253	1.675	7.139
5.231	1.683	7.132
5.215	1.668	7.132
5.200	1.672	7.121
5.182	1.675	7.121
5.167	1.680	7.121
5.163	1.679	7.118
5.139	1.687	7.118
5.121	1.685	7.116
5.104	1.685	7.128
5.082	1.683	7.142
5.062	1.679	7.142
5.039	1.673	7.138
5.021	1.674	7.121
5.003	1.675	7.108
4.992	1.665	7.104
4.983	1.665	7.102
4.955	1.664	7.102
4.924	1.674	7.108
4.902	1.675	7.112
4.876	1.633	7.115
4.866	1.657	7.110
4.857	1.677	7.110
4.844	1.687	7.110
4.820	1.681	7.120
4.811	1.682	7.122
4.796	1.674	7.128
4.760	1.678	7.137
4.739	1.676	7.155
4.717	1.681	7.155
4.698	1.686	7.146

DATA WITH LINE REMOVED

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
.001071	.007065	-.016972
.017171	.022327	-.016605
.022271	.028588	.001763
-.006629	-.014150	.006130
-.009529	-.016888	.006498
-.012430	-.015627	.006865
-.008330	-.013365	.007233
-.020230	-.020103	.003600
-.003130	.001159	.003968
.000970	.009420	.004336
-.003930	-.006318	.004703
-.010830	-.012056	.005071
.004270	.001205	.005438
.001370	-.004533	.000806
.003470	.013729	.001173
-.006430	-.000009	.001541
-.015331	-.007748	.001908
-.003231	-.011486	.010276
.007869	.008776	.020643
.005969	.002038	.018011
-.001931	-.004701	.007378
-.005831	-.000439	.000746
-.003731	-.013177	.001113
-.000631	-.005916	-.009519
-.000531	-.002654	-.009152
.002569	.005608	-.008784
.016669	.018870	-.011417
.010768	.021131	-.011049
.010868	.019393	-.012682
.011968	.020655	-.000314
.008068	.014916	.014053
.006168	.009178	.014421
.001268	-.001560	.010788
.001368	-.000298	-.005844
.001468	.000963	-.018477
.008568	-.001775	-.022109
.017668	.007487	-.023742
.007768	-.003252	-.023374
-.005133	-.005990	-.017007
-.009033	-.008728	-.012639
-.016933	-.058466	-.009272
-.008833	-.026205	-.013904
.000267	.003057	-.013537
.005367	.018319	-.013169
-.000533	.006581	-.002802
.008567	.016842	-.000434
.011667	.012104	.005933
-.006233	-.001634	.015301
-.009133	-.006373	.033668
-.013034	-.005111	.034036
-.013934	-.000849	.025403

TRACK STATION 18000

RAW DATA

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
13.881	1.680	6.855
13.866	1.677	6.865
13.848	1.680	6.884
13.832	1.676	6.876
13.808	1.681	6.878
13.802	1.681	6.876
13.754	1.676	6.865
13.769	1.688	6.851
13.757	1.685	6.848
13.740	1.677	6.847
13.717	1.677	6.853
13.685	1.681	6.855
13.681	1.680	6.860
13.665	1.672	6.862
13.644	1.669	6.860
13.632	1.659	6.854
13.617	1.650	6.858
13.600	1.644	6.858
13.579	1.655	6.858
13.567	1.668	6.870
13.557	1.668	6.893
13.534	1.681	6.886
13.522	1.675	6.861
13.486	1.657	6.858
13.479	1.626	6.862
13.475	1.631	6.862
13.457	1.632	6.860
13.443	1.648	6.860
13.427	1.647	6.870
13.415	1.636	6.868
13.403	1.617	6.875
13.375	1.621	6.866
13.353	1.656	6.861
13.345	1.650	6.866
13.340	1.686	6.878
13.318	1.683	6.880
13.300	1.679	6.868
13.284	1.660	6.863
13.271	1.673	6.860
13.252	1.678	6.862
13.240	1.678	6.869
13.227	1.683	6.883
13.213	1.681	6.891
13.192	1.674	6.900
13.178	1.657	6.881
13.164	1.670	6.873
13.158	1.678	6.898
13.143	1.667	6.920
13.135	1.673	6.896
13.118	1.673	6.873
13.107	1.683	6.872

DATA WITH LINE REMOVED

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
.012039	.022217	-.002080
.012696	.020018	.007421
.010352	.020819	.025921
.010009	.016619	.017421
.001665	.013420	.018922
.011322	.023221	.016422
-.021022	-.013978	.004923
.009635	.028822	-.009577
.013291	.029623	-.013076
.011947	.020424	-.014576
.004604	.013224	-.009075
-.011740	.001025	-.007575
-.000083	.011826	-.003075
-.000427	.003627	-.001574
-.005770	-.004573	-.004074
-.002114	-.010772	-.010573
-.001457	-.018971	-.007073
-.002801	-.026170	-.007572
-.008144	-.020370	-.008072
-.004488	-.003569	.003429
.001169	.002232	.025929
-.006175	.008032	.018430
-.002518	.005833	-.007070
-.022862	-.032366	-.010570
-.014205	-.054565	-.007069
-.002549	-.037765	-.007569
-.004893	-.038964	-.010068
-.003236	-.021163	-.010568
-.003580	-.022363	-.001067
.000077	-.029562	-.003567
.003733	-.044761	.002934
-.008610	-.052960	-.006566
-.014954	-.024160	-.012065
-.007297	-.022359	-.007565
.003359	.024442	.003935
-.002984	.015243	.005436
-.005328	.009043	-.007064
-.005671	-.010156	-.012563
-.003015	.005645	-.016063
-.006358	.007445	-.014562
-.002702	.011246	-.008062
-.000045	.019047	.005439
.001611	.018848	.012939
-.003733	.006648	.021440
-.002076	-.008551	.001940
-.000420	.006250	-.006560
.009237	.024050	.017941
.009893	.013851	.039441
.017550	.027652	.014942
.016206	.026453	-.008558
.020863	.041253	-.010057

TRACK STATION 22000

RAW DATA

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
12.707	1.674	7.018
12.686	1.667	7.009
12.675	1.649	7.004
12.676	1.676	6.994
12.661	1.653	6.996
12.655	1.674	6.982
12.658	1.678	6.976
12.657	1.674	6.994
12.632	1.678	6.991
12.609	1.662	6.995
12.583	1.670	6.982
12.581	1.663	6.988
12.567	1.661	6.984
12.546	1.665	6.985
12.537	1.651	6.987
12.533	1.647	6.978
12.522	1.660	6.973
12.511	1.666	6.976
12.492	1.659	6.980
12.483	1.660	6.986
12.482	1.673	6.996
12.480	1.674	6.992
12.451	1.680	6.983
12.428	1.673	6.974
12.416	1.653	6.970
12.409	1.652	6.974
12.405	1.656	6.982
12.399	1.662	6.988
12.389	1.664	6.995
12.381	1.662	7.002
12.374	1.649	7.010
12.353	1.678	6.990
12.348	1.681	6.978
12.353	1.672	6.973
12.333	1.676	6.988
12.321	1.669	6.989
12.300	1.656	6.987
12.283	1.654	6.986
12.266	1.664	6.979
12.260	1.668	6.979
12.260	1.665	6.978
12.260	1.652	6.979
12.247	1.654	6.990
12.241	1.662	6.984
12.233	1.675	6.977
12.216	1.686	6.970
12.216	1.673	6.981
12.206	1.669	6.978
12.200	1.679	6.971
12.200	1.679	6.967
12.198	1.687	6.965

DATA WITH LINE REMOVED

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
.009787	.020520	.023413
-.000484	.003125	.014798
-.000756	-.015270	.010183
.010973	.023336	.000568
.006701	-.004059	.002953
.011430	.021546	-.010662
.025158	.039151	-.016277
.034887	.044756	.002108
.020615	.034361	-.000507
.008344	.005966	.003878
-.006928	-.001429	-.008737
.001801	.000176	-.002352
-.001471	-.005219	-.005967
-.011742	-.011614	-.004582
-.010014	-.024009	-.002197
-.003285	-.021404	-.010811
-.003557	-.008799	-.015426
-.003828	-.003193	-.012041
-.012100	-.018588	-.007656
-.010371	-.015983	-.001271
-.000643	.006622	.009114
.008086	.016227	.005499
-.010186	.003832	-.003116
-.022457	-.015563	-.011731
-.023729	-.036958	-.015346
-.020000	-.034353	-.010961
-.013271	-.023748	-.002576
-.008543	-.013143	.003809
-.007814	-.010538	.011194
-.005086	-.009933	.018579
-.001357	-.019328	.026965
-.011629	-.000723	.007350
-.005900	.007883	-.004265
.009828	.014488	-.008880
.000557	.009093	.006505
-.000715	.000698	.007890
-.010936	-.022697	.006275
-.017258	-.031092	.005660
-.023529	-.027487	-.000955
-.018801	-.018882	-.000570
-.008072	-.011277	-.001185
.002656	-.013672	.000200
.000385	-.014067	.011585
.005113	-.001462	.005970
.007842	.014143	-.000644
.001570	.018748	-.007259
.012299	.016353	.004126
.013027	.012959	.001511
.017756	.027564	-.005104
.028484	.038169	-.008719
.037213	.054774	-.010334

TRACK STATION 24000

RAW DATA

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
9.270	1.619	6.996
9.267	1.631	6.991
9.261	1.643	6.987
9.252	1.647	6.987
9.249	1.641	6.991
9.239	1.628	6.991
9.223	1.626	6.983
9.206	1.618	6.981
9.204	1.621	6.993
9.183	1.628	7.010
9.182	1.635	6.991
9.175	1.626	6.983
9.180	1.616	6.974
9.171	1.615	6.976
9.146	1.631	6.976
9.132	1.643	6.976
9.127	1.659	6.978
9.133	1.670	6.980
9.118	1.678	6.980
9.108	1.677	6.979
9.103	1.661	6.955
9.102	1.659	6.950
9.079	1.668	6.946
9.074	1.676	6.945
9.068	1.669	6.950
9.072	1.672	6.960
9.076	1.665	6.960
9.059	1.657	6.960
9.042	1.658	6.961
9.044	1.659	6.956
9.050	1.661	6.948
9.023	1.660	6.949
9.015	1.667	6.946
9.005	1.668	6.946
9.002	1.671	6.946
8.995	1.665	6.943
8.996	1.653	6.943
8.999	1.657	6.943
8.995	1.662	6.943
8.998	1.660	6.952
8.987	1.659	6.960
8.982	1.665	6.962
8.950	1.672	6.958
8.941	1.661	6.948
8.938	1.663	6.942
8.924	1.654	6.940
8.932	1.661	6.923
8.900	1.668	6.925
8.890	1.677	6.925
8.892	1.670	6.942
8.877	1.674	6.931

DATA WITH LINE REMOVED

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
.007725	-.005196	.002187
.012208	.010411	-.001540
.013690	.023018	-.004266
.012173	.024625	-.002993
.016655	.022232	.002280
.014137	.005839	.003554
.005620	-.005554	-.003173
-.003898	-.023947	-.003900
.001584	-.016340	.009373
-.011933	-.023733	.027647
-.005451	-.011125	.009920
-.004969	-.020518	.003193
.007514	-.018911	-.004533
.005996	-.022304	-.001260
-.011522	-.024697	.000013
-.018039	-.020090	.001287
-.015557	-.002483	.004560
-.002075	.021124	.007833
-.009592	.020731	.009106
-.012110	.016338	.009380
-.009627	.001945	-.013347
-.003145	.005552	-.017074
-.018663	-.001841	-.019800
-.016180	.007766	-.019527
-.014698	.001373	-.013254
-.003216	.014980	-.001980
.008267	.018587	-.000707
-.001251	.000195	.000566
-.010769	-.009198	.002840
-.001286	.000409	-.000887
.012196	.015016	-.007614
-.007322	-.006377	-.005341
-.007839	-.000770	-.007067
-.010357	-.003163	-.005794
-.005875	.003444	-.004521
-.005392	-.002949	-.006247
.003090	-.007342	-.004974
.013573	.006265	-.003701
.017055	.013872	-.002427
.027537	.021479	.007846
.024020	.016086	.017119
.026502	.023693	.020392
.001984	.005300	.017666
.000467	-.008093	.008939
.004949	-.002485	.004212
-.001569	-.018878	.003486
.013914	.002729	-.012241
-.010604	-.015664	-.008968
-.013122	-.010057	-.007694
-.003639	-.008450	.010579
-.011157	-.012843	.000852

TRACK STATION 26000

RAW DATA

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
15.556	1.679	6.639
15.545	1.683	6.635
15.536	1.683	6.638
15.526	1.666	6.636
15.526	1.671	6.632
15.524	1.673	6.638
15.521	1.682	6.640
15.518	1.683	6.635
15.518	1.686	6.631
15.510	1.684	6.631
15.501	1.684	6.629
15.490	1.683	6.625
15.478	1.679	6.628
15.468	1.677	6.631
15.474	1.671	6.642
15.474	1.668	6.657
15.469	1.649	6.641
15.459	1.651	6.629
15.441	1.671	6.622
15.437	1.679	6.619
15.448	1.685	6.611
15.451	1.674	6.617
15.439	1.682	6.631
15.445	1.678	6.653
15.446	1.684	6.665
15.437	1.692	6.672
15.418	1.689	6.672
15.401	1.688	6.674
15.395	1.682	6.681
15.399	1.672	6.672
15.388	1.672	6.673
15.381	1.682	6.668
15.374	1.652	6.668
15.360	1.655	6.696
15.347	1.678	6.686
15.324	1.679	6.688
15.331	1.676	6.709
15.330	1.679	6.733
15.320	1.674	6.745
15.308	1.690	6.720
15.301	1.693	6.688
15.298	1.686	6.678
15.289	1.681	6.662
15.289	1.679	6.663
15.275	1.679	6.676
15.284	1.662	6.695
15.283	1.672	6.700
15.269	1.676	6.714
15.268	1.688	6.716
15.252	1.685	6.706
15.255	1.695	6.690

DATA WITH LINE REMOVED

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
-.005538	-.002193	.021090
-.010371	-.003107	.015296
-.013204	-.006021	.016503
-.017038	-.026935	.012710
-.010871	-.015848	.006916
-.006705	-.009762	.011123
-.003538	.002324	.011329
-.000371	.006410	.004536
.005795	.015496	-.001257
.003962	.011582	-.003051
.001128	.008668	-.006844
-.003705	.002755	-.012638
-.009538	-.007159	-.011431
-.013372	-.013073	-.010224
-.001205	-.006987	-.001018
.004961	-.003901	.012189
.006128	-.021815	-.005605
.002295	-.023728	-.019398
-.009539	-.015642	-.028191
-.007372	-.005556	-.032985
.009794	.017530	-.042778
.018961	.015616	-.038572
.013128	.017702	-.026365
.025294	.025788	-.006158
.032461	.038875	.004048
.029627	.043961	.009255
.016794	.028047	.007462
.005961	.016133	.007668
.006127	.010219	.012875
.016294	.010305	.002081
.011460	.005392	.001288
.010627	.014478	-.005505
.009794	-.016436	-.007299
.001960	-.021350	.018908
-.004873	-.005264	.007114
-.021706	-.021178	.007321
-.008540	-.011092	.026528
-.003373	-.003005	.048734
-.007207	-.011919	.058941
-.013040	-.001833	.032147
-.013873	.000253	-.001646
-.010707	-.003661	-.013439
-.013540	-.011575	-.031233
-.007374	-.007488	-.032026
-.015207	-.015402	-.020820
-.000040	-.017316	-.003613
.005126	-.002230	-.000406
-.002707	-.006144	.011800
.002459	.010942	.012007
-.007374	-.001972	.000213
.001793	.017115	-.017580

TRACK STATION 28000

RAW DATA

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
11.132	1.671	6.665
11.121	1.684	6.662
11.108	1.685	6.657
11.100	1.686	6.651
11.087	1.679	6.652
11.079	1.678	6.647
11.070	1.678	6.649
11.058	1.678	6.645
11.047	1.686	6.646
11.036	1.683	6.645
11.028	1.685	6.645
11.018	1.679	6.641
11.008	1.680	6.650
10.993	1.678	6.649
10.983	1.675	6.657
10.980	1.685	6.663
10.964	1.684	6.663
10.964	1.672	6.657
10.964	1.670	6.656
10.960	1.674	6.653
10.942	1.673	6.651
10.933	1.660	6.664
10.922	1.655	6.660
10.922	1.671	6.660
10.910	1.672	6.662
10.893	1.669	6.664
10.893	1.650	6.658
10.893	1.668	6.664
10.870	1.675	6.664
10.870	1.672	6.663
10.859	1.678	6.662
10.846	1.683	6.666
10.820	1.688	6.665
10.806	1.679	6.669
10.805	1.678	6.666
10.805	1.664	6.654
10.809	1.668	6.648
10.783	1.677	6.662
10.781	1.675	6.664
10.781	1.686	6.669
10.785	1.685	6.673
10.780	1.697	6.671
10.763	1.689	6.667
10.740	1.677	6.659
10.736	1.678	6.660
10.721	1.675	6.667
10.708	1.686	6.677
10.708	1.681	6.682
10.705	1.685	6.681
10.678	1.687	6.682
10.673	1.690	6.691

DATA WITH LINE REMOVED

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
.012597	.007745	.017411
.010420	.018496	.013885
.006244	.015246	.008359
.007067	.016997	.001832
.002890	.005747	.002306
.003713	.005498	-.003220
.003536	.005249	-.001746
.000359	.001999	-.006273
-.001817	.007750	-.005799
-.003994	.002500	-.007325
-.003171	.005251	-.007851
-.004348	-.001998	-.012378
-.005525	-.002248	-.003904
-.011702	-.010497	-.005430
-.012878	-.014747	.002044
-.007055	.001004	.007517
-.014232	-.007245	.006991
-.005409	-.010495	.000465
.003414	-.003744	-.001061
.008237	.005006	-.004588
-.000939	-.005243	-.007114
-.001116	-.018493	.005360
-.003293	-.025742	.000834
.005530	-.000991	.000307
.002353	-.003241	.001781
-.005824	-.014490	.003255
.003000	-.024740	-.003271
.011823	.002011	.002202
-.002354	-.005238	.001676
.006469	.000512	.000150
.004292	.004263	-.001376
.000115	.005013	.002097
-.017061	-.007236	.000571
-.022238	-.021485	.004045
-.014415	-.014735	.000519
-.005592	-.019984	-.012008
.007231	-.003234	-.018534
-.009946	-.011483	-.005060
-.003122	-.006733	-.003586
.005701	.013018	.000887
.018524	.024769	.004361
.022347	.040519	.001835
.014170	.024270	-.002691
-.000007	-.001980	-.011217
.004817	.003771	-.010744
-.001360	-.005478	-.004270
-.005537	.001272	.005204
.003286	.005023	.009678
.009109	.014773	.008151
-.009068	-.001476	.008625
-.005244	.005275	.017099

TRACK STATION 30000

RAW DATA

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
13.322	1.688	6.632
13.328	1.671	6.631
13.331	1.662	6.637
13.309	1.680	6.647
13.290	1.672	6.652
13.278	1.655	6.652
13.272	1.628	6.637
13.267	1.633	6.640
13.253	1.630	6.644
13.250	1.625	6.639
13.249	1.625	6.642
13.248	1.623	6.647
13.232	1.639	6.643
13.210	1.674	6.639
13.223	1.689	6.635
13.219	1.685	6.638
13.204	1.677	6.646
13.190	1.664	6.644
13.169	1.655	6.647
13.177	1.641	6.638
13.151	1.625	6.650
13.144	1.651	6.656
13.133	1.674	6.676
13.139	1.672	6.672
13.123	1.689	6.661
13.114	1.679	6.670
13.100	1.673	6.656
13.104	1.671	6.646
13.095	1.685	6.642
13.092	1.678	6.654
13.071	1.677	6.664
13.021	1.658	6.659
13.043	1.650	6.655
13.029	1.653	6.659
13.022	1.649	6.652
13.015	1.649	6.653
13.000	1.643	6.647
13.004	1.660	6.641
13.005	1.686	6.645
12.995	1.693	6.648
13.003	1.663	6.667
12.997	1.677	6.682
12.974	1.679	6.674
12.959	1.674	6.669
12.949	1.662	6.685
12.922	1.646	6.668
12.921	1.679	6.662
12.909	1.680	6.658
12.908	1.685	6.664
12.894	1.687	6.666
12.888	1.668	6.671

DATA WITH LINE REMOVED

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
-.012011	.023192	-.005551
.002843	.020625	-.007168
.014698	.023057	-.001785
.001552	.027489	.007598
-.008593	.008922	.011981
-.011738	-.011646	.011363
-.008884	-.036214	-.004254
-.005029	-.027782	-.001871
-.010175	-.036349	.001512
-.004320	-.035917	-.004105
.003534	-.028485	-.001722
.011389	-.023052	.002660
.004244	-.014620	-.001957
-.008902	.006812	-.006574
.012953	.043245	-.011191
.017807	.043677	-.008808
.011662	.029109	-.001426
.006516	.010542	-.004043
-.005629	-.011026	-.001660
.011226	-.008594	-.011277
-.005920	-.042162	.000106
-.004065	-.014729	.005488
-.006211	.005703	.024871
.008644	.018135	.020254
.001498	.027568	.008637
.001353	.017000	.017020
-.003792	.005432	.002402
.009062	.015865	-.008215
.008917	.029297	-.012832
.014771	.027729	-.001449
.002626	.014162	.007934
-.038520	-.046406	.002316
-.007665	-.023974	-.002301
-.012810	-.026542	.001082
-.010956	-.029109	-.006535
-.009101	-.027677	-.006152
-.015247	-.040245	-.012770
-.002392	-.010812	-.019387
.007462	.024620	-.016004
.006317	.030052	-.013621
.023171	.016485	.004762
.026026	.032917	.019144
.011881	.020349	.010527
.005735	.008782	.004910
.004590	-.004786	.020293
-.013556	-.039354	.002676
-.005701	.001078	-.003941
-.008847	-.001489	-.008559
-.000992	.010943	-.003176
-.006137	.007375	-.001793
-.003283	-.009192	.002590

TRACK STATION 32000

RAW DATA

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
10.030	1.681	6.645
10.016	1.671	6.644
10.018	1.655	6.636
10.012	1.636	6.636
10.013	1.648	6.642
10.000	1.652	6.636
9.989	1.676	6.624
9.995	1.682	6.621
9.996	1.682	6.623
9.991	1.690	6.635
9.982	1.687	6.631
9.974	1.679	6.614
9.965	1.667	6.613
9.966	1.672	6.621
9.956	1.678	6.640
9.968	1.682	6.640
9.950	1.689	6.631
9.940	1.670	6.623
9.936	1.667	6.613
9.940	1.675	6.624
9.929	1.678	6.616
9.922	1.689	6.616
9.922	1.676	6.624
9.916	1.663	6.621
9.913	1.676	6.618
9.908	1.685	6.606
9.905	1.684	6.607
9.908	1.679	6.615
9.908	1.684	6.625
9.900	1.683	6.636
9.882	1.688	6.636
9.885	1.677	6.628
9.867	1.681	6.624
9.862	1.669	6.624
9.855	1.666	6.639
9.857	1.669	6.635
9.855	1.646	6.620
9.854	1.664	6.615
9.838	1.671	6.612
9.839	1.671	6.608
9.834	1.678	6.612
9.818	1.669	6.624
9.812	1.665	6.620
9.824	1.668	6.618
9.802	1.661	6.615
9.790	1.661	6.610
9.793	1.673	6.606
9.782	1.669	6.610
9.785	1.686	6.605
9.774	1.690	6.605
9.774	1.684	6.601

DATA WITH LINE REMOVED

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
-.001556	.007712	.010299
-.010490	-.011288	.009790
-.003423	-.020287	.002282
-.004357	-.040286	.002773
.001709	-.022286	.009265
-.006225	-.026285	.003757
-.012159	-.008285	-.007752
-.001093	.008716	-.010260
.004973	.014716	-.007769
.005040	.022717	.004723
.001106	.015717	.001214
-.001828	.004718	-.015294
-.005762	-.011282	-.015802
.000304	-.000281	-.007311
-.004630	.000720	.012181
.012437	.021720	.012672
-.000497	.015721	.004164
-.005431	-.008279	-.003344
-.004365	-.010278	-.012853
.004701	.006722	-.001361
-.001233	.003723	-.008870
-.003167	.012723	-.008378
.001900	.004724	.000113
.000966	-.009276	-.002395
.003032	.005725	-.004903
.003098	.014725	-.016412
.005164	.015726	-.014920
.013230	.018727	-.006429
.018297	.028727	.004063
.015363	.024728	.015555
.002429	.016728	.016046
.010495	.013729	.008538
-.002439	.004729	.005029
-.002373	-.007270	.005521
-.004307	-.012270	.021012
.002760	-.002269	.017504
.005826	-.022269	.002996
.009892	-.000268	-.001513
-.001042	-.004267	-.004021
.005024	.001733	-.007530
.005090	.008734	-.003038
-.005843	-.011266	.009454
-.006777	-.016265	.005945
.010289	.003735	.004437
-.006645	-.020264	.001928
-.013579	-.027264	-.002580
-.005513	-.007263	-.006089
-.011447	-.017263	-.001597
-.003380	.007738	-.006105
-.009314	.005739	-.005614
-.004248	.004739	-.009122

TRACK STATION 34000

RAW DATA

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
15.106	1.676	6.546
15.106	1.675	6.561
15.096	1.661	6.575
15.088	1.641	6.566
15.076	1.673	6.561
15.067	1.684	6.559
15.064	1.677	6.560
15.053	1.680	6.554
15.045	1.675	6.553
15.050	1.678	6.550
15.045	1.689	6.545
15.038	1.684	6.536
15.026	1.685	6.545
15.026	1.679	6.549
15.022	1.682	6.556
15.015	1.681	6.556
15.000	1.682	6.546
14.982	1.684	6.546
14.973	1.672	6.543
14.956	1.675	6.533
14.950	1.682	6.533
14.945	1.680	6.528
14.949	1.679	6.528
14.952	1.681	6.535
14.941	1.688	6.540
14.929	1.687	6.544
14.911	1.679	6.537
14.869	1.674	6.528
14.899	1.677	6.529
14.903	1.677	6.529
14.908	1.686	6.528
14.902	1.684	6.538
14.887	1.685	6.544
14.875	1.675	6.552
14.858	1.681	6.542
14.851	1.668	6.531
14.832	1.667	6.523
14.844	1.673	6.515
14.844	1.674	6.515
14.853	1.673	6.516
14.844	1.676	6.519
14.848	1.666	6.520
14.853	1.663	6.520
14.859	1.671	6.529
14.859	1.677	6.532
14.864	1.677	6.532
14.846	1.676	6.530
14.832	1.670	6.528
14.830	1.667	6.519
14.822	1.663	6.522
14.814	1.663	6.524

DATA WITH LINE REMOVED

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
.014668	.011833	-.012351
.020669	.016950	.003454
.016670	-.000933	.018259
.014670	-.022816	.010063
.008671	.003302	.005868
.005672	.011419	.004672
.008673	.007536	.006477
.003673	.005654	.001282
.001674	-.001229	.001086
.012675	.012888	-.001109
.013675	.025005	-.005305
.012676	.019123	-.013500
.006677	.014240	-.003695
.012678	.014357	.001109
.014678	.019475	.008914
.013679	.017592	.009719
.004680	.009709	.000523
-.007320	-.000174	.001328
-.010319	-.015056	-.000868
-.021318	-.022939	-.010063
-.021317	-.015822	-.009258
-.020317	-.016704	-.013454
-.010316	-.007587	-.012649
-.001315	.003530	-.004845
-.006314	.005647	.000960
-.012314	-.001235	.005765
-.024313	-.021118	-.000431
-.060312	-.062001	-.008626
-.024312	-.022883	-.006821
-.014311	-.012766	-.006017
-.003310	.007351	-.006212
-.003309	.005468	.004592
-.012309	-.002414	.011397
-.018308	-.018297	.020202
-.029307	-.023180	.011006
-.030306	-.037062	.000811
-.043306	-.050945	-.006385
-.025305	-.026828	-.013580
-.019304	-.019711	-.012775
-.004304	-.005593	-.010971
-.007303	-.005476	-.007166
.002698	-.005359	-.005361
.013699	.002759	-.004557
.025699	.022876	.005248
.031700	.034993	.009052
.042701	.046110	.009857
.030701	.033228	.008662
.022702	.019345	.007466
.026703	.020462	-.000729
.024704	.014580	.003075
.022704	.012697	.005880

TRACK STATION 36000

RAW DATA

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
12.432	1.709	6.815
12.417	1.707	6.818
12.394	1.703	6.840
12.367	1.709	6.830
12.344	1.710	6.831
12.340	1.720	6.884
12.330	1.712	6.840
12.318	1.709	6.848
12.302	1.710	6.860
12.295	1.708	6.859
12.281	1.708	6.865
12.287	1.712	6.871
12.277	1.716	6.850
12.266	1.713	6.830
12.266	1.715	6.839
12.244	1.720	6.848
12.220	1.718	6.856
12.220	1.716	6.857
12.220	1.714	6.856
12.200	1.711	6.847
12.200	1.709	6.834
12.190	1.703	6.832
12.172	1.708	6.838
12.172	1.710	6.837
12.162	1.712	6.836
12.152	1.710	6.836
12.140	1.711	6.837
12.132	1.709	6.864
12.117	1.705	6.870
12.093	1.709	6.872
12.087	1.712	6.872
12.079	1.717	6.861
12.079	1.713	6.867
12.022	1.712	6.867
12.068	1.708	6.872
12.057	1.710	6.885
12.065	1.713	6.887
12.056	1.715	6.889
12.043	1.717	6.884
12.040	1.712	6.883
12.021	1.710	6.880
11.983	1.708	6.860
11.983	1.712	6.861
11.972	1.712	6.859
11.969	1.714	6.871
11.949	1.712	6.900
11.954	1.713	6.909
11.938	1.707	6.896
11.938	1.708	6.886
11.925	1.711	6.900
11.905	1.713	6.930

DATA WITH LINE REMOVED

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
.039090	.037211	-.015709
.033765	.029870	-.013927
.020439	.012529	.006855
.003114	.001188	-.004363
-.010211	-.011153	-.004581
-.004536	.004506	.047202
-.004861	-.003835	.001984
-.007186	-.009176	.008766
-.013512	-.014517	.019548
-.010837	-.013858	.017330
-.015162	-.018199	.022112
.000513	.001460	.026894
.000188	.005119	.004676
-.001137	.000778	-.016542
.008538	.012437	-.008760
-.003788	.005096	-.000978
-.018113	-.011245	.005804
-.008438	-.003586	.005586
.001237	.004073	.003369
-.009088	-.009268	-.006849
.000587	-.001609	-.021067
.000261	-.007950	-.024285
-.008064	-.011291	-.019503
.001611	.000368	-.021721
.001286	.002027	-.023939
.000961	-.000314	-.025157
-.001364	-.001655	-.025375
.000310	-.001996	.000407
-.005015	-.011337	.005189
-.019340	-.021678	.005971
-.015665	-.015019	.004754
-.013990	-.008360	-.007464
-.004315	-.002701	-.002682
-.051640	-.051042	-.003900
.004034	.000617	-.000118
.002709	.001276	.011664
.020384	.021935	.012446
.021059	.024594	.013228
.017734	.023253	.007010
.024409	.024912	.004792
.015083	.013571	.000574
-.013242	-.016770	-.020644
-.003567	-.003111	-.020861
-.004892	-.004452	-.024079
.001783	.004207	-.013297
.011458	.011866	.014485
.006132	.007525	.022267
-.000193	-.004816	.008049
.009482	.005843	-.003169
.006157	.005502	.009613
-.004168	-.002839	.038395

TRACK STATION 38000

RAW DATA

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
12.399	1.677	6.882
12.386	1.658	6.880
12.371	1.634	6.882
12.357	1.668	6.882
12.356	1.688	6.900
12.358	1.694	6.901
12.357	1.698	6.890
12.347	1.701	6.881
12.331	1.702	6.905
12.311	1.698	6.915
12.305	1.697	6.913
12.307	1.691	6.898
12.292	1.699	6.883
12.287	1.701	6.881
12.278	1.698	6.882
12.251	1.702	6.900
12.243	1.698	6.901
12.243	1.692	6.901
12.228	1.692	6.895
12.221	1.695	6.894
12.217	1.697	6.896
12.205	1.670	6.895
12.177	1.695	6.885
12.172	1.698	6.886
12.157	1.697	6.900
12.159	1.697	6.900
12.132	1.696	6.906
12.126	1.699	6.906
12.125	1.702	6.914
12.119	1.700	6.910
12.115	1.696	6.909
12.096	1.689	6.905
12.080	1.696	6.905
12.066	1.699	6.893
12.066	1.696	6.870
12.061	1.700	6.851
12.064	1.697	6.848
12.048	1.693	6.848
12.055	1.688	6.876
12.029	1.688	6.908
12.035	1.694	6.927
12.049	1.692	6.927
12.035	1.691	6.907
12.007	1.689	6.878
11.985	1.694	6.870
11.991	1.694	6.873
11.983	1.697	6.894
11.963	1.696	6.914
11.942	1.695	6.910
11.936	1.693	6.909
11.925	1.695	6.911

DATA WITH LINE REMOVED

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
.002651	-.006440	-.009966
-.001043	-.029381	-.012050
-.006736	-.059322	-.010133
-.011430	-.030263	-.010217
-.003123	-.002204	.007699
.008183	.014856	.008615
.016490	.026915	-.002468
.015796	.028974	-.011552
.009103	.023033	.012364
-.001591	.008092	.022281
.001716	.010151	.020197
.013023	.015211	.005113
.007329	.017270	-.009971
.011636	.023329	-.012054
.011942	.020388	-.011138
-.005751	.006447	.006778
-.004445	.003507	.007695
.004862	.006566	.007611
-.000832	.000625	.001527
.001475	.005684	.000443
.006781	.012743	.002360
.004088	-.017198	.001276
-.014606	-.011138	-.008808
-.010299	-.004079	-.007891
-.015993	-.011020	.006025
-.004686	.000039	.005941
-.022380	-.018902	.011857
-.019073	-.012842	.011774
-.010767	-.001783	.019690
-.007460	-.000724	.015606
-.002154	.000335	.014523
-.011847	-.016606	.010439
-.018541	-.016546	.010355
-.023234	-.018487	-.001729
-.013928	-.012428	-.024812
-.009621	-.004369	-.043896
.002685	.004690	-.046980
-.004008	-.006251	-.047063
.012298	.004809	-.019147
-.004395	-.012132	.012769
.010911	.008927	.031686
.034218	.029986	.031602
.029524	.024045	.011518
.010831	.003105	-.017566
-.001862	-.004836	-.025649
.013444	.010223	-.022733
.014751	.014282	-.001817
.004057	.002341	.018100
-.007636	-.010600	.014016
-.004330	-.009540	.012932
-.006023	-.009481	.014848

TRACK STATION 40000

RAW DATA

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
14.520	1.696	6.873
14.495	1.695	6.876
14.464	1.696	6.859
14.440	1.696	6.857
14.422	1.695	6.860
14.408	1.690	6.860
14.410	1.689	6.863
14.393	1.699	6.865
14.360	1.687	6.867
14.339	1.713	6.867
14.340	1.720	6.888
14.330	1.720	6.900
14.317	1.717	6.906
14.298	1.708	6.922
14.275	1.708	6.914
14.250	1.710	6.898
14.230	1.713	6.894
14.191	1.710	6.885
14.200	1.714	6.885
14.208	1.714	6.878
14.205	1.712	6.890
14.192	1.713	6.904
14.159	1.715	6.908
14.142	1.720	6.908
14.120	1.719	6.917
14.110	1.716	6.917
14.100	1.717	6.916
14.090	1.715	6.923
14.087	1.716	6.940
14.060	1.714	6.954
14.029	1.717	6.948
14.008	1.713	6.939
13.970	1.713	6.925
13.940	1.711	6.920
13.945	1.714	6.923
13.945	1.718	6.929
13.930	1.715	6.929
13.915	1.720	6.929
13.887	1.709	6.921
13.882	1.720	6.921
13.873	1.713	6.921
13.852	1.715	6.927
13.830	1.716	6.916
13.800	1.717	6.902
13.798	1.715	6.900
13.795	1.713	6.911
13.787	1.701	6.927
13.780	1.706	6.905
13.775	1.718	6.912
13.733	1.720	6.935
13.713	1.716	6.950

DATA WITH LINE REMOVED

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
.023925	.017957	.000037
.014578	.007260	.001729
-.000769	-.007437	-.016579
-.009116	-.016134	-.019887
-.011463	-.019831	-.018196
-.009809	-.023529	-.019504
.007844	-.007226	-.012812
.006497	.001077	-.017120
-.010850	-.028620	-.016428
-.016197	-.008317	-.017736
.000457	.014986	.001956
.006110	.020289	.012647
.008763	.019592	.017339
.005416	.006895	.032031
-.001930	-.000802	.022723
-.011277	-.008500	.005415
-.015624	-.010197	.000107
-.038971	-.036894	-.010202
-.014318	-.008591	-.011510
.009336	.014712	-.019818
.021989	.025015	-.009126
.024642	.028318	.003566
.007295	.012621	.006258
.005948	.015924	.004950
-.000398	.008227	.012641
.005255	.010529	.011333
.010908	.016832	.009025
.016561	.020135	.014717
.029215	.033438	.030409
.017868	.019741	.043101
.002521	.007044	.035793
-.002826	-.002653	.025484
-.025173	-.025350	.010176
-.039519	-.042047	.003868
-.018866	-.018745	.005560
-.003213	.000558	.010252
-.002560	-.002139	.008944
-.001907	.003164	.007636
-.014253	-.020533	-.001673
-.003600	.000770	-.002981
.003053	.000073	-.004289
-.002294	-.003624	.000403
-.008640	-.009321	-.011905
-.022987	-.023018	-.027213
-.009334	-.011716	-.030521
.003319	-.001413	-.020830
.010972	-.006110	-.006138
.019626	.007193	-.029446
.030279	.029496	-.023754
.003932	.004799	-.002062
-.000415	-.003898	.011630

TRACK STATION 42000

RAW DATA

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
10.552	1.706	6.883
10.548	1.715	6.905
10.558	1.713	6.903
10.552	1.715	6.886
10.542	1.721	6.898
10.519	1.718	6.912
10.509	1.720	6.918
10.515	1.719	6.913
10.512	1.729	6.919
10.509	1.746	6.928
10.500	1.756	6.917
10.474	1.761	6.908
10.443	1.730	6.902
10.412	1.735	6.904
10.410	1.741	6.905
10.407	1.720	6.918
10.401	1.715	6.926
10.384	1.720	6.923
10.361	1.716	6.917
10.347	1.712	6.916
10.344	1.721	6.919
10.345	1.717	6.902
10.342	1.711	6.902
10.332	1.712	6.892
10.320	1.711	6.896
10.306	1.714	6.925
10.287	1.721	6.916
10.262	1.721	6.902
10.262	1.720	6.910
10.263	1.713	6.919
10.241	1.738	6.965
10.212	1.730	6.968
10.216	1.727	6.943
10.229	1.730	6.917
10.223	1.763	6.936
10.192	1.775	6.954
10.183	1.775	6.948
10.171	1.778	6.944
10.156	1.779	6.930
10.172	1.804	6.941
10.182	1.731	6.950
10.170	1.725	6.949
10.144	1.715	6.932
10.116	1.722	6.921
10.112	1.720	6.925
10.102	1.763	6.917
10.086	1.761	6.910
10.069	1.774	6.881
10.055	1.743	6.881
10.047	1.811	6.886
10.032	1.802	6.887

DATA WITH LINE REMOVED

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
-.020791	-.025801	-.025564
-.014137	-.011145	-.003903
.006518	.006510	-.006242
.011172	.012166	-.023581
.011826	.017821	-.011920
-.000519	.001477	.001741
.000135	.003132	.007402
.016790	.017788	.002063
.024444	.034444	.007724
.032098	.058099	.016385
.033753	.068755	.005046
.018407	.057410	-.004293
-.001938	.005066	-.010632
-.022284	-.011279	-.008971
-.013630	.002377	-.008310
-.005975	-.011967	.004351
-.001321	-.013312	.012012
-.007666	-.015656	.008673
-.020012	-.033001	.002334
-.023358	-.041345	.000995
-.015703	-.025690	.003656
-.004049	-.019034	-.013683
.003605	-.018378	-.014022
.004260	-.017723	-.024361
.002914	-.021067	-.020700
-.000431	-.022412	.007961
-.008777	-.024756	-.001378
-.023123	-.040101	-.015717
-.012468	-.031445	-.008056
-.000814	-.027790	.000605
-.012159	-.015134	.046266
-.030505	-.042478	.048927
-.015851	-.031823	.023588
.007804	-.006167	-.002751
.012458	.030488	.015910
-.007887	.021144	.033571
-.006233	.021799	.027232
-.007579	.022455	.022893
-.011924	.018111	.008554
.014730	.068766	.019215
.035384	.015422	.027876
.034039	.007077	.026537
.018693	-.019267	.009198
.001348	-.030612	-.002141
.008002	-.026956	.001520
.008656	.015700	-.006819
.003311	.007355	-.014158
-.003035	.013011	-.043497
-.006380	-.022334	-.043836
-.003726	.047322	-.039175
-.008072	.032977	-.038514

TRACK STATION 44000

RAW DATA

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
13.017	1.711	6.923
13.013	1.716	6.923
13.008	1.713	6.920
13.003	1.712	6.927
12.992	1.707	6.920
12.970	1.708	6.940
12.968	1.712	6.943
12.960	1.716	6.946
12.960	1.713	6.945
12.933	1.713	6.945
12.920	1.709	6.945
12.914	1.709	6.968
12.918	1.713	6.974
12.895	1.712	6.952
12.890	1.715	6.940
12.890	1.715	6.940
12.876	1.715	6.949
12.874	1.714	6.949
12.865	1.709	6.958
12.841	1.716	6.939
12.826	1.721	6.931
12.806	1.716	6.932
12.806	1.715	6.926
12.784	1.709	6.926
12.776	1.710	6.922
12.768	1.709	6.922
12.760	1.709	6.931
12.750	1.717	6.935
12.737	1.713	6.932
12.732	1.712	6.944
12.728	1.710	6.944
12.722	1.713	6.948
12.715	1.714	6.934
12.715	1.719	6.940
12.693	1.717	6.943
12.675	1.711	6.934
12.655	1.712	6.929
12.655	1.710	6.928
12.648	1.714	6.935
12.638	1.716	6.935
12.635	1.720	6.941
12.618	1.713	6.946
12.599	1.715	6.946
12.591	1.709	6.942
12.573	1.710	6.938
12.550	1.713	6.936
12.562	1.713	6.952
12.552	1.717	6.952
12.544	1.710	6.948
12.549	1.709	6.952
12.530	1.707	6.964

DATA WITH LINE REMOVED

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
-.012127	-.013754	-.012826
-.006020	-.002653	-.012988
-.000913	-.000551	-.016150
.004194	.003550	-.009313
.003301	-.002348	-.016475
-.008592	-.013246	.003363
-.000485	-.001145	.006201
.001622	.004957	.009038
.011729	.012058	.007876
-.005164	-.004840	.007714
-.008057	-.011739	.007552
-.003950	-.007637	.030389
.010157	.010464	.036227
-.002736	-.003434	.014065
.002371	.004667	.001903
.012478	.014769	.001740
.008585	.010870	.010578
.016693	.017972	.010416
.017800	.014074	.019253
.003907	.007175	.000091
-.000986	.007277	-.008071
-.010879	-.007622	-.007233
-.000772	.001480	-.013396
-.012665	-.016419	-.013558
-.010558	-.013317	-.017720
-.008451	-.012216	-.017882
-.006344	-.010114	-.009045
-.006237	-.002013	-.005207
-.009130	-.008911	-.008369
-.004023	-.004810	.003469
.002084	-.000708	.003306
.006191	.006394	.007144
.009298	.010495	-.007018
.019405	.025597	-.001180
.007513	.011698	.001657
-.000380	-.002200	-.007505
-.010273	-.011099	-.012667
-.000166	-.002997	-.013830
.002941	.004104	-.006992
.003048	.006206	-.007154
.010155	.017307	-.001316
.003262	.003409	.003521
-.005631	-.003490	.003359
-.003524	-.007388	-.000803
-.011417	-.014286	-.004965
-.024310	-.024185	-.007128
-.002203	-.002083	.008710
-.002096	.002018	.008548
.000011	-.002880	.004386
.015118	.011221	.008223
.006225	.000323	.020061

TRACK STATION 46000

RAW DATA

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
.666	1.703	6.922
.694	1.705	6.934
.698	1.708	6.921
.709	1.711	6.914
.710	1.710	6.914
.706	1.711	6.926
.695	1.710	6.943
.715	1.706	6.966
.709	1.709	6.980
.702	1.711	6.978
.690	1.712	6.987
.692	1.715	6.987
.705	1.707	7.009
.715	1.711	6.961
.707	1.721	6.948
.685	1.717	6.936
.690	1.718	6.936
.689	1.710	6.942
.690	1.710	6.950
.699	1.711	6.950
.717	1.709	6.943
.709	1.716	6.961
.709	1.713	6.973
.701	1.709	6.958
.700	1.709	6.950
.691	1.707	6.950
.677	1.714	6.941
.671	1.706	6.941
.686	1.682	6.937
.695	1.686	6.937
.685	1.696	6.937
.686	1.712	6.964
.700	1.714	6.990
.706	1.715	6.999
.714	1.718	6.999
.735	1.717	6.994
.740	1.716	6.981
.729	1.713	6.966
.713	1.707	6.978
.715	1.713	6.981
.707	1.712	6.979
.674	1.718	6.970
.661	1.711	6.965
.657	1.711	6.971
.660	1.710	6.994
.653	1.703	6.984
.635	1.706	6.949
.633	1.713	6.909
.634	1.714	6.914
.636	1.718	6.915
.622	1.708	6.914

DATA WITH LINE REMOVED

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
-.046149	-.052403	-.026716
-.017285	-.021570	-.015002
-.012420	-.013737	-.028287
-.000555	.001097	-.035572
.001310	.001930	-.035857
-.001825	-.000237	-.024142
-.011961	-.011403	-.007427
.008904	.005430	.015288
.003769	.003264	.029003
-.002366	-.000903	.026718
-.013501	-.011070	.035433
-.010637	-.005236	.035148
.003228	.000597	.056863
.014093	.015431	.008578
.006958	.018264	-.004707
-.014177	-.006903	-.016992
-.008313	-.000069	-.017278
-.008448	-.008236	-.011563
-.006583	-.006402	-.003848
.003282	.004431	-.004133
.022147	.021264	-.011418
.015011	.021098	.006297
.015876	.018931	.018012
.008741	.007765	.002727
.008606	.007598	-.005558
.000471	-.002569	-.005843
-.012665	-.008735	-.015128
-.017800	-.021902	-.015413
-.001935	-.030068	-.019698
.007930	-.016235	-.019983
-.001205	-.015402	-.020268
.000659	.002432	.006446
.015524	.019265	.032161
.022389	.027099	.040876
.031254	.038932	.040591
.053119	.059765	.035306
.058983	.064599	.022021
.048848	.051432	.006736
.033713	.030265	.018451
.036578	.039099	.021166
.029443	.030932	.018881
-.002693	.004766	.009596
-.014828	-.014401	.004311
-.017963	-.017568	.010026
-.014098	-.014734	.032741
-.020233	-.027901	.022456
-.037369	-.042067	-.012830
-.038504	-.036234	-.053115
-.036639	-.033401	-.048400
-.033774	-.026567	-.047685
-.046910	-.049734	-.048970

TRACK STATION 48000

RAW DATA

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
10.983	1.701	7.175
10.989	1.700	7.180
10.981	1.698	7.185
10.982	1.696	7.185
10.982	1.697	7.190
10.990	1.694	7.190
11.005	1.698	7.210
11.000	1.678	7.215
11.003	1.697	7.200
11.000	1.695	7.190
11.023	1.703	7.191
11.008	1.693	7.150
11.004	1.697	7.175
11.000	1.696	7.177
10.975	1.692	7.160
10.970	1.689	7.110
10.975	1.695	7.105
10.965	1.697	7.114
10.948	1.696	7.124
10.944	1.699	7.120
10.932	1.708	7.120
10.932	1.689	7.120
10.944	1.693	7.135
10.959	1.692	7.149
10.965	1.695	7.155
10.965	1.697	7.145
10.965	1.694	7.140
10.942	1.690	7.140
10.952	1.689	7.141
10.965	1.688	7.134
10.965	1.687	7.135
10.954	1.697	7.125
10.940	1.701	7.125
10.932	1.693	7.125
10.930	1.694	7.125
10.928	1.687	7.123
10.920	1.698	7.133
10.904	1.697	7.153
10.912	1.698	7.165
10.918	1.696	7.170
10.921	1.696	7.170
10.931	1.694	7.168
10.940	1.692	7.160
10.951	1.693	7.170
10.951	1.696	7.185
10.912	1.697	7.195
10.912	1.689	7.219
10.911	1.697	7.216
10.910	1.705	7.194
10.917	1.692	7.144
10.925	1.696	7.128

DATA WITH LINE REMOVED

TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
-.017839	-.012320	.010408
-.010027	-.005485	.015676
-.016215	-.013650	.020943
-.013402	-.012816	.021211
-.011590	-.009981	.026478
-.001777	-.003146	.026746
.015035	.017689	.047014
.011847	-.005477	.052281
.016660	.018358	.037549
.015472	.015193	.027816
.040285	.048028	.029084
.027097	.024863	-.011648
.024909	.026697	.013619
.022722	.023532	.015887
-.000466	-.003633	-.000846
-.003653	-.009798	-.050578
.003159	.003036	-.055310
-.005029	-.003129	-.046043
-.020216	-.019294	-.035775
-.022404	-.018459	-.039508
-.032591	-.019625	-.039240
-.030779	-.036790	-.038972
-.016967	-.018955	-.023705
-.000154	-.003120	-.009437
.007658	.007714	-.003170
.009471	.011549	-.012902
.011283	.010384	-.017634
-.009905	-.014781	-.017367
.001908	-.003947	-.016099
.016720	.009888	-.022832
.018533	.010723	-.021564
.009345	.011558	-.031296
-.002843	.003392	-.031029
-.009030	-.010773	-.030761
-.009218	-.009938	-.030494
-.009405	-.017103	-.032226
-.015593	-.012269	-.021958
-.029781	-.027434	-.001691
-.019968	-.016599	.010577
-.012156	-.010764	.015844
-.007343	-.005930	.016112
.004469	.003905	.014380
.015281	.012740	.006647
.028094	.026575	.016915
.029906	.031409	.032182
-.007281	-.004756	.042450
-.005469	-.010921	.066718
-.004657	-.002086	.063985
-.003844	.006748	.042253
.004968	.002583	-.007480
.014781	.016418	-.023212

TRACK STATION 50000

RAW DATA

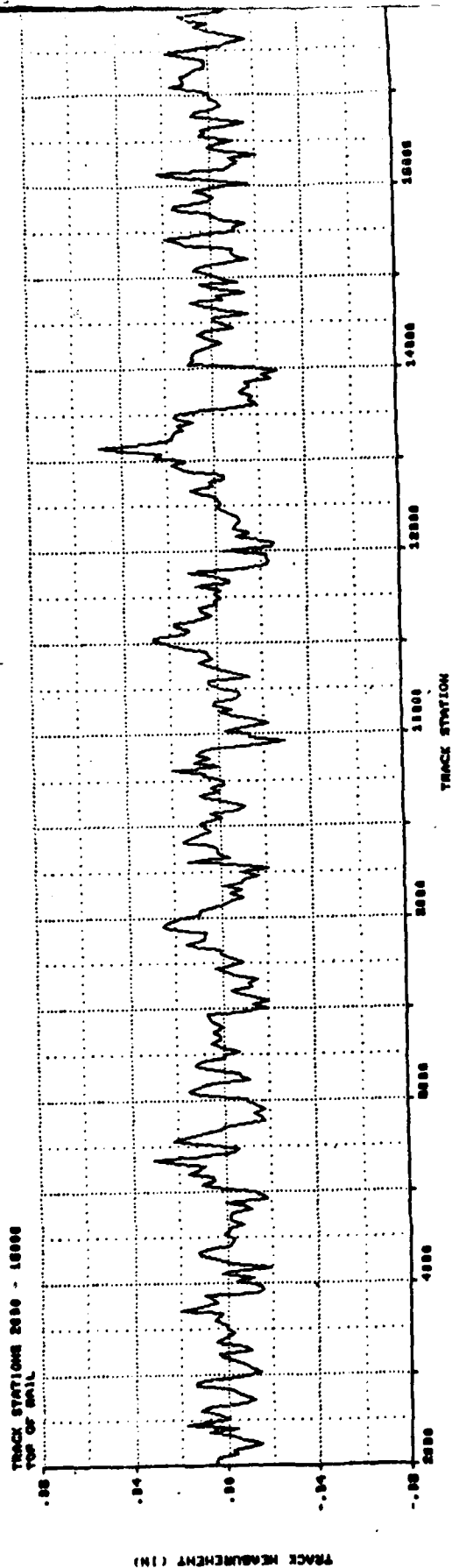
TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
10.039	1.720	6.942
10.041	1.718	6.925
10.037	1.714	6.933
10.014	1.713	6.958
9.991	1.708	6.975
9.990	1.712	6.951
9.989	1.713	6.953
9.990	1.717	6.949
10.019	1.703	6.960
10.059	1.715	6.941
10.062	1.714	6.943
10.039	1.715	6.957
10.035	1.706	6.965
10.037	1.714	6.972
10.030	1.716	6.963
10.023	1.717	6.958
10.022	1.713	6.955
10.007	1.709	6.952
10.000	1.710	6.945
10.011	1.710	6.958
10.031	1.715	6.943
10.038	1.714	6.942
10.040	1.718	6.945
10.037	1.716	6.934
10.046	1.715	6.951
10.057	1.714	6.962
10.064	1.710	6.968
10.058	1.712	6.967
10.045	1.715	6.951
10.042	1.717	6.941
10.047	1.716	6.950
10.041	1.713	6.956
10.030	1.712	6.972
10.042	1.715	6.958
10.044	1.716	6.956
10.033	1.717	6.969
10.031	1.713	6.984
10.036	1.716	6.977
10.025	1.715	6.957
10.014	1.712	6.951
10.021	1.715	6.943
10.027	1.715	6.957
10.033	1.719	6.940
10.056	1.719	6.917
10.066	1.714	6.911
10.053	1.710	6.923
10.032	1.715	6.970
10.067	1.710	6.945
10.065	1.716	6.950
10.053	1.717	6.947
10.034	1.716	6.960

DATA WITH LINE REMOVED

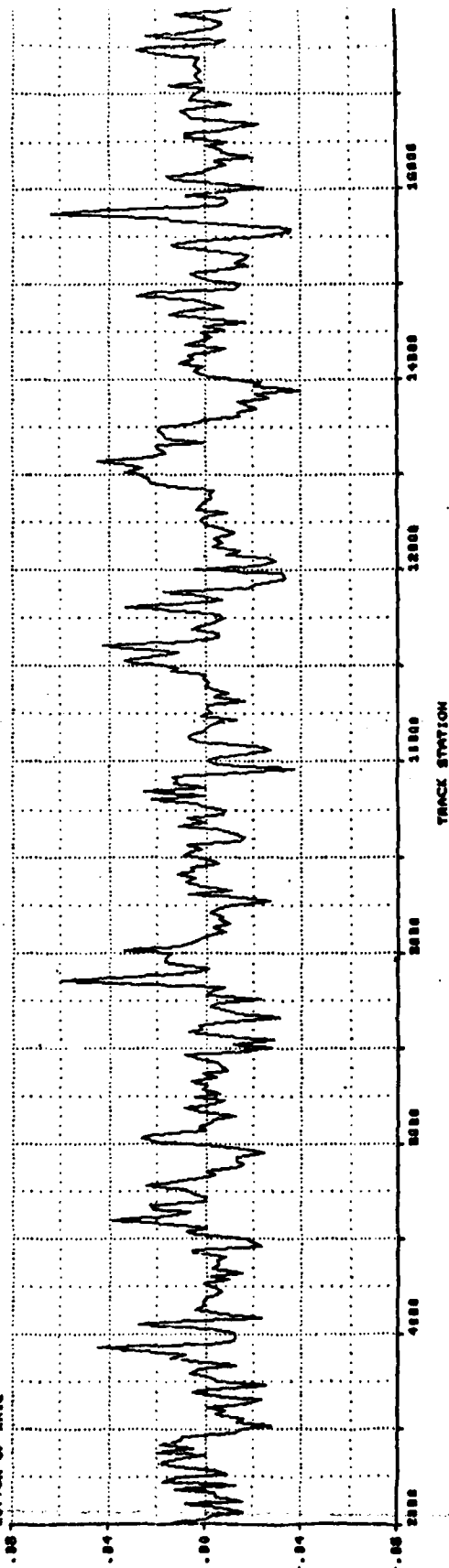
TOP OF RAIL	BOTTOM OF RAIL	SIDE OF RAIL
.019561	.026631	-.011043
.020972	.025999	-.028001
.016382	.017367	-.019960
-.007207	-.007266	.005082
-.030797	-.035898	.022124
-.032386	-.033530	-.001834
-.033976	-.034163	.000207
-.033565	-.029795	-.003751
-.005155	-.015427	.007291
.034256	.035940	-.011668
.036666	.037308	-.009626
.013077	.014676	.004416
.008487	.001044	.012458
.009898	.010411	.019499
.002308	.004779	.010541
-.005281	-.001853	.005583
-.006871	-.007486	.002625
-.022460	-.027118	-.000334
-.030050	-.033750	-.007292
-.019639	-.023383	.005750
-.000229	.000985	-.009209
.006182	.006353	-.010167
.007592	.011720	-.007125
.004003	.006088	-.018083
.012413	.013456	-.001042
.022824	.022824	.010000
.029234	.025191	.016042
.022645	.020559	.015083
.009055	.009927	-.000875
.005466	.008294	-.010833
.009876	.011662	-.001791
.003287	.002030	.004250
-.008303	-.010603	.020292
.003108	.003765	.006334
.004518	.006133	.004375
-.007071	-.004500	.017417
-.009661	-.011132	.032459
-.005250	-.003764	.025501
-.016840	-.016396	.005542
-.028430	-.031029	-.000416
-.022019	-.021661	-.008374
-.016609	-.016293	.005668
-.011198	-.006926	-.011291
.011212	.015442	-.034249
.020623	.019810	-.040207
.007033	.002177	-.028166
-.014556	-.014455	.018876
.019854	.014913	-.006082
.017265	.018280	-.001040
.004675	.006648	-.003999
-.014914	-.013984	.009043

APPENDIX B

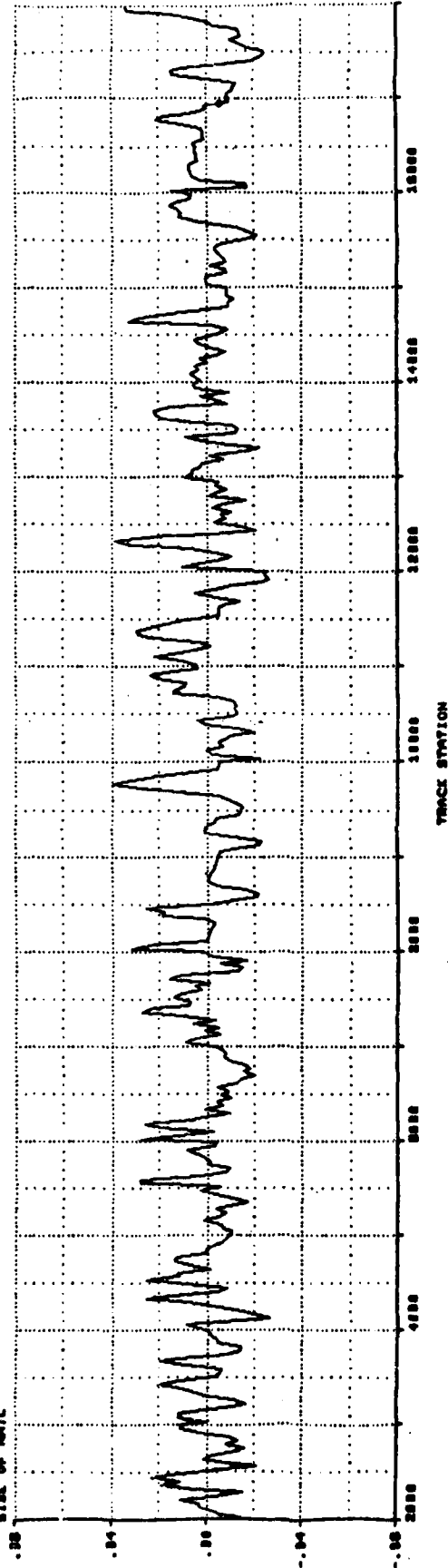
PLOTS OF ENSEMBLES RAW DATA



TRACK STATIONS 2000 - 10000
BOTTOM OF RAIL

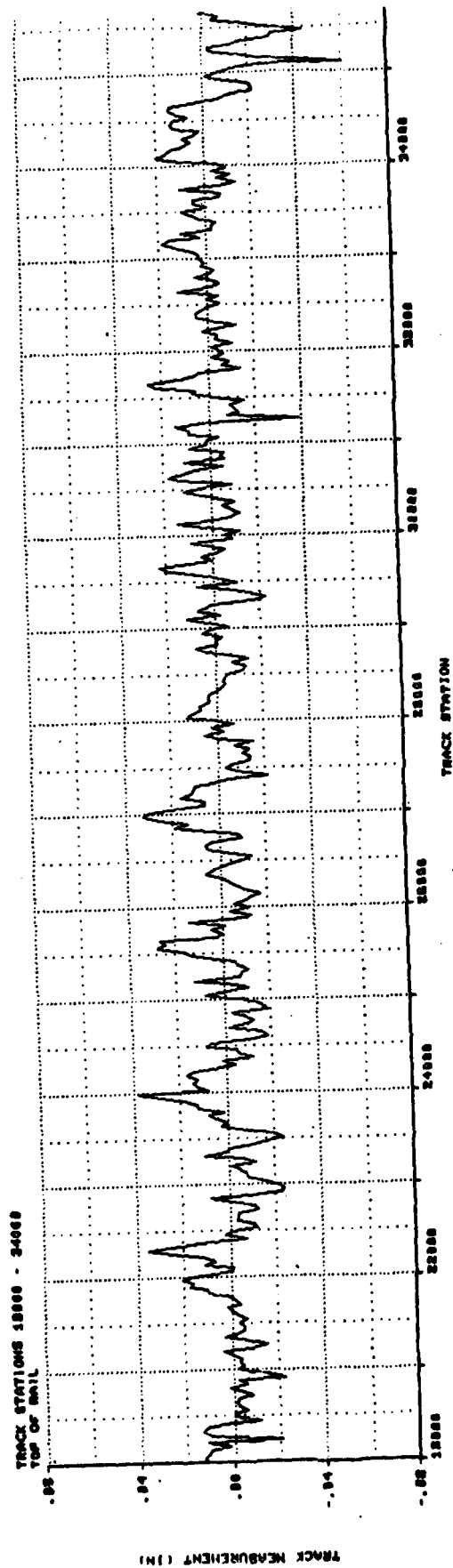


TRACK STATIONS 2000 - 16000
SIZE OF RAIL

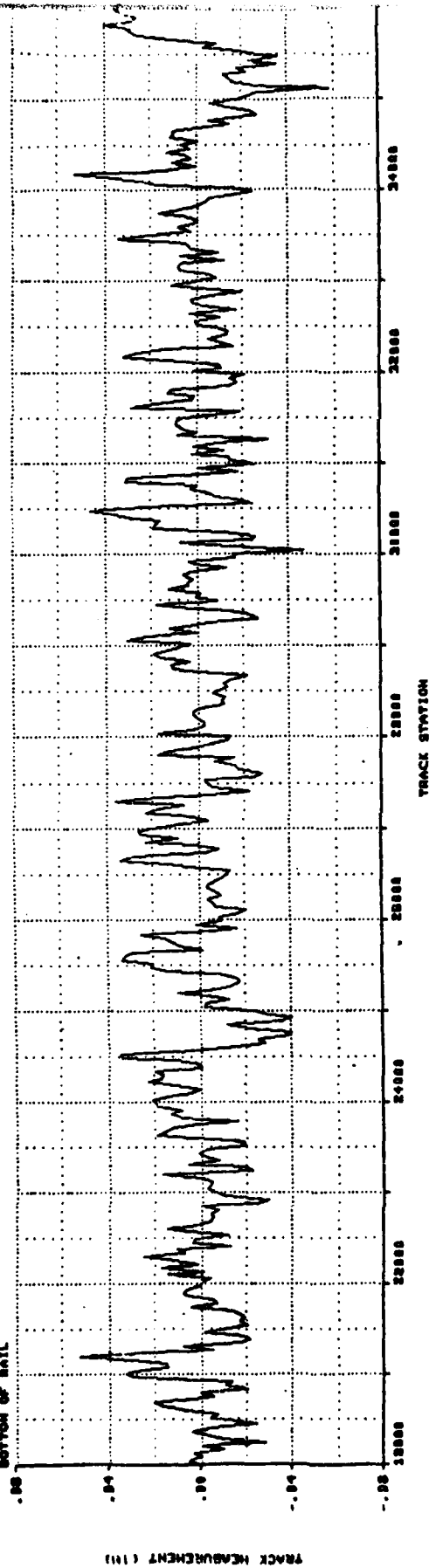


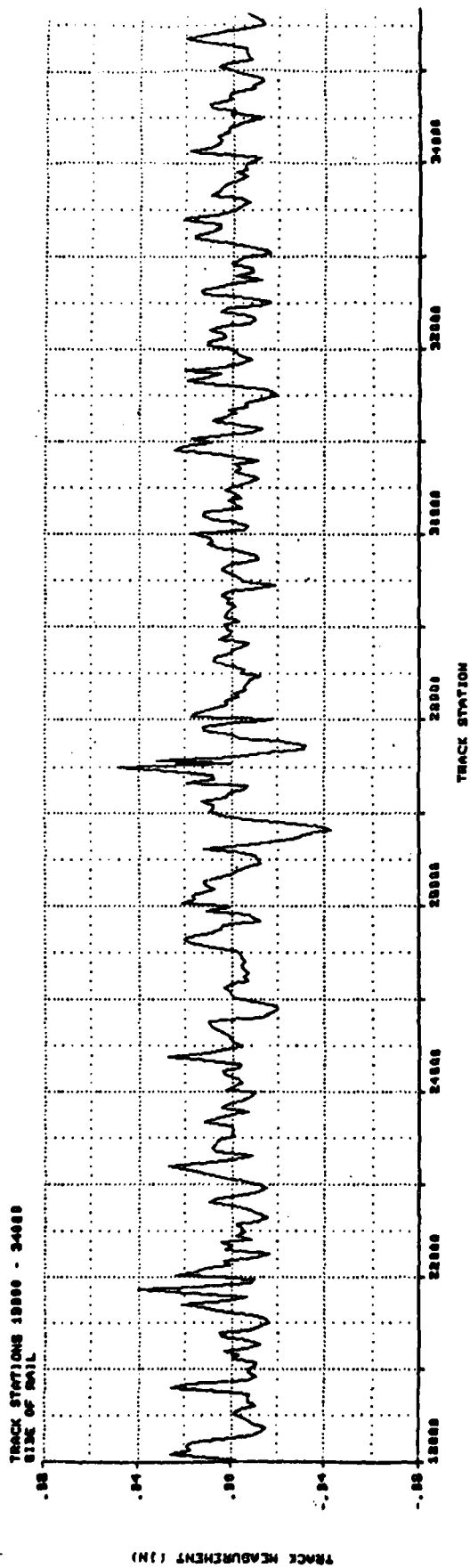
TRACK MEASUREMENT (IN)

B-4

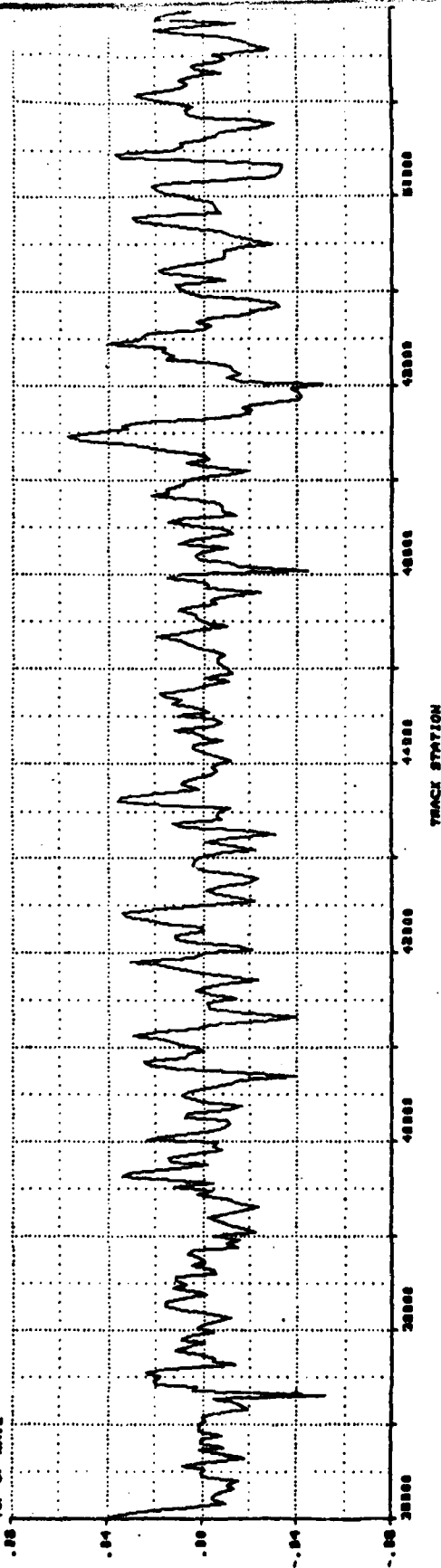


TRACK STATIONS 18000 - 24000
BOTTOM OF RAIL

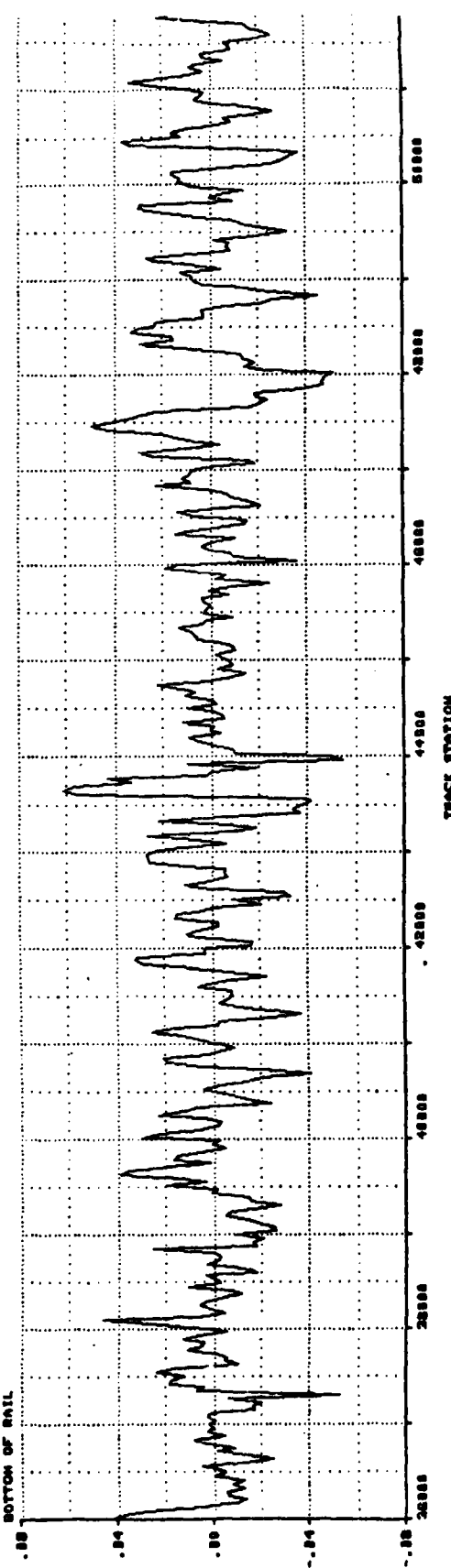




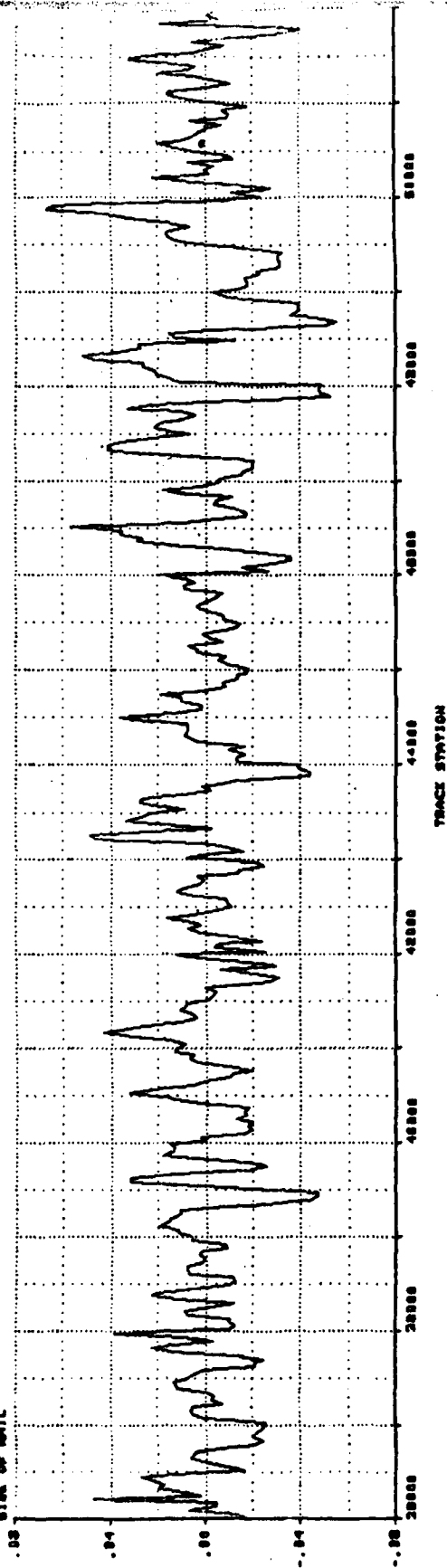
TRACK STATIONS 30000 - 50000
TOP OF HAIL



TRACK STATIONS 38000 - 50000
BOTTOM OF RAIL



TRACK STATIONS 30000 - 50000
SIDE OF RAIL



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END 11-81