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TRUCK DESIGN OPTIMIZATION PROJECT PHASE II

FRICTION SNUBBER FORCE MEASUREMENT SYSTEM FIELD TEST REPORT

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03 - Rail Vehicles & Components

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15. Supplementary Notes

This test report is supplemented by the **FSFMS Test Data Tapes, FRA/ORD/MT-79/24** and the Measurement of Friction Snubber Forces in Freight Car Trucks, Final Report, FRA/ORD-78/69, dated December 1978.

16. Abstract

This report documents the results of the Friction Snubber Force Measurement System (FSFMS) special road test program that was performed during TDOP Phase II. The FSFMS was designed, built, and shop-tested during TDOP Phase I (see FRA/ORD-78/69).

Descriptions of the test equipment, procedures, methods of data analysis, results, and recommendations are contained in this report.

The test program was successfully completed using friction snubber transducers to obtain friction forces in over-the-road truck tests. The primary purpose of the tests was to obtain estimates of the friction coefficients associated with ASF Ride Control and Barber S-2 70-ton trucks. The report provides some preliminary analyses using the test data and recommends areas where additional information may be extracted.

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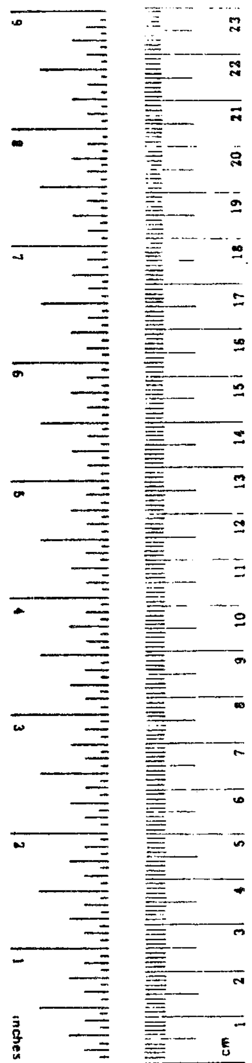
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

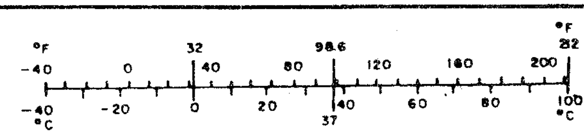
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



EXECUTIVE SUMMARY

A Friction Snubber Force Measurement System (FSFMS) was developed and shop-tested during TDOP Phase I. The primary objective of this system was to measure friction coefficients and forces transmitted between the friction shoes and the wear plate of conventional freight car trucks. During Phase II of TDOP a series of over-the-road tests was run to obtain friction snubber data in actual railroad operation.

The FSFMS was installed on both an ASF Ride Control and Barber S-2 70-ton truck. During November and December of 1978, these trucks were run through a series of tests in various load conditions over sections of Union Pacific track near Las Vegas. In addition to measuring friction snubber forces, transducers were installed on the trucks and carbody to measure relative motion between carbody and truck, and carbody rigid modes.

Results from the data analysis showed the Barber truck to have a coefficient of dynamic friction between .31 and .36 while the dynamic friction coefficient of the ASF truck was between .37 and .49. The only strong correlation between relative motion in the truck and friction forces occurred in the vertical motion of the side frame relative to the truck. As the vertical motions increased, the variation in the friction forces increased.

The quality of test data acquired during the test program was excellent. Noise floor recordings were an order of magnitude less than the test data. Comparison of data between runs and between similar measurements showed excellent agreement in relationship to track input.

ACKNOWLEDGEMENTS

A number of individuals contributed to the success of this project. Their support is hereby gratefully acknowledged.

A particular debt is owed Mr. Klaus Cappel, Chief Design Engineer, Wyle Laboratories, who conceived, designed, developed, and tested the Friction Snubber Force Measurement System (FSFMS) during TDOP Phase I. Mr. Cappel also contributed invaluable advice and guidance during this field test.

Appreciation is also expressed to Mr. Frank Brunner and the Union Pacific Railroad personnel under his direction, all of whom contributed many long hours to ensure the success of the project. Especially, gratitude is expressed to Mr. Don Joy and his crew at the Repair-in-Place track in Las Vegas during test preparation; Dr. Paul Rhine, who directed the operation of the UP's mobile laboratory car; and Mr. Tom Stewart, who coordinated the test effort with the UP operational personnel.

All of the TDOP Phase II consultants provided Wyle Laboratories with the benefit of their expert knowledge during the development of the FSFMS test plan and procedure. However, special thanks is due to Mr. Robert Bullock of the Standard Car Truck Company and Mr. Garth Tennikait of the American Steel Foundries who observed the testing in Nevada and made many useful suggestions that aided Wyle greatly.

Finally, this acknowledgement would be incomplete without mention of the continual support that Wyle Laboratories has received for the FSFMS project from the Federal Railroad Administration's Office of Freight Systems, notably from Mr. Arne Bang, Chief, Freight Services Division, and Dr. N. Thomas Tsai, Contracting Officer's Technical Representative for TDOP Phase II.

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SECTION 1 - INTRODUCTION

1.1 BACKGROUND

During the Truck Design Optimization Project (TDOP) Phase I, instrumentation did not exist to measure the forces transmitted through the spring-loaded friction shoes located between the side frame and bolster of a freight car truck. Consequently, Wyle Laboratories developed, designed, fabricated, and shop-tested a prototype Friction Snubber Force Measurement System (FSFMS). A complete description of the FSFMS, its operation, results of shop testing, and intended use are given in reference 1. Since the system was not completed prior to the conclusion of TDOP Phase I, a field test was scheduled during TDOP Phase II to acquire FSFMS data.

The test plan developed to conduct the field test (reference 2) furnishes a description of the required hardware, instrumentation layout, proposed test zones, performance regimes to be tested, vehicle configurations, schedules, and data analysis.

Based upon the approved test plan, a comprehensive test procedure (reference 3) was prepared. The test procedure defined instrumentation types, locations and mounting brackets, calibration procedures, run sequences, and the required documentation to support the test effort and preparation of the final report.

The primary objective of the test program was to obtain field test data from which measured values of friction coefficients and forces associated with the friction snubber could be calculated. A value of dynamic friction coefficient was characterized for each truck. Measured values of normal and tangential forces between the friction shoe and the wear plate were to be evaluated as a function of the following:

a. Relative displacement due to bolster motion, both vertical and horizontal

b. Relative angular displacement between side frame and bolster

c. Direction of vertical motion

d. Relative velocity of sliding motion

After the FRA approval of the test plan and procedure (references 2 and 3), the field test was conducted between November 13 and December 8 near Las Vegas, with the assistance of the Union Pacific Railroad. The testing was performed on two types of trucks: the 70-ton Barber S-2 truck and the 70-ton ASF Ride Control truck.

1.2 SCOPE

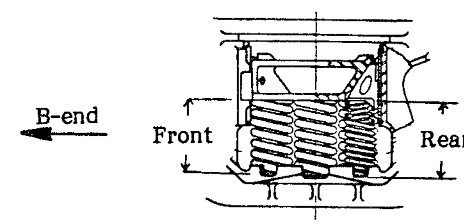
This report is divided into six sections and four appendices. Section 2 describes the equipment that was used to accomplish the test ojectives (the consist, test hardware, instrumentation, etc.). Section 3 details the actual test runs. Section 4 describes data acquisition and reduction, and Section 5 presents the data analysis, including the procedures used to extract friction coefficients for each of the two types of trucks and an evaluation of the data quality. Correlations are given between data acquired during several test runs and track geometry measurements of the test zones made previously. Some data, in addition to those required to meet the objectives of the testing, were acquired during the course of the program and are also presented. Section 6 recommends some further analyses that could be conducted to extract additional information from these data.

SECTION 2 - TEST EQUIPMENT

2.1 TRUCKS

The trucks used in this test program were 70-ton ASF Ride Control and Barber S-2 trucks. They were modified by changing the side frame snubber column to accomodate the friction snubber transducer. A photograph of the transducers installed in the ASF truck is shown in Figure 2-1. Before the over-the-road testing of the modified trucks, a structural qualification laboratory test was conducted on one of the trucks to verify structural adequacy for unlimited service. The results of these tests are documented in reference 1.

Also, laboratory measurements were made of the spring rate for the snubber springs in the Barber truck. The results of these measurements are included in Appendix A. No measurements were made on the ASF snubber spring because of the difficulty in disassembling the truck. During the test program static measurements were made at each spring nest. The results of these measurements are contained in Table 2-1 for the Barber truck and Table 2-2 for the ASF truck. A typical spring group is shown below.



2.2 CARBODIES

The test plan called for 70-ton carbodies to be used in the test program. However, at the time of testing, no 70-ton carbodies were readily available. Therefore, to expedite instrumentation and testing, two 100-ton hopper cars were used as test cars, one with the Barber truck and the other with the ASF truck. Descriptions of carbodies used in the Barber and ASF truck tests are given in Figures 2-2 and 2-3, respectively.

The modified trucks with the friction snubber instrumentation were placed at the B-end of each test car and a similar 70-ton truck from TDOP Phase I was placed under the A-end. New wheels were placed on all trucks before the start of the test program. During assembly of the test cars, the center plate at the B-end was lubricated with molybdenum disulfide to achieve uniform center plate friction characteristics.

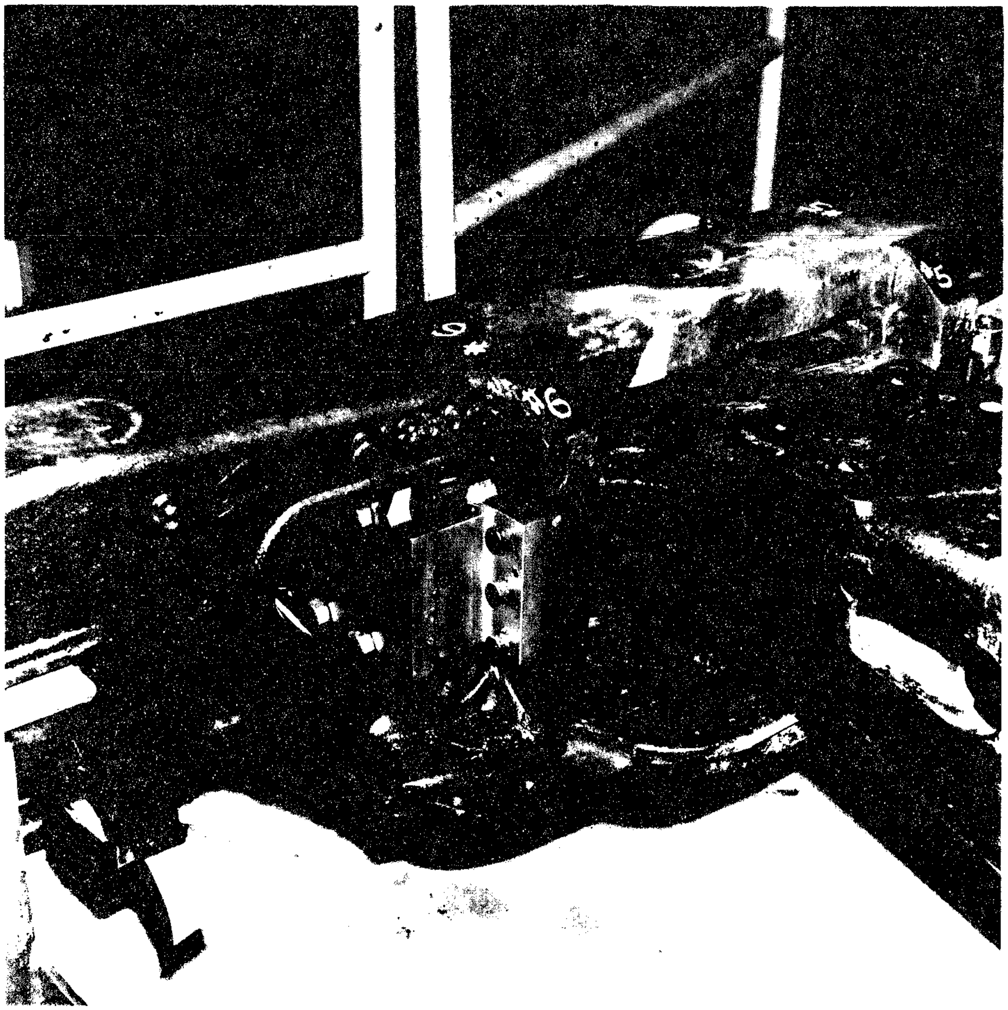


Figure 2-1. Detail of Transducers in ASF Truck

Table 2-1. Spring Group Measurements (In.) Barber Truck

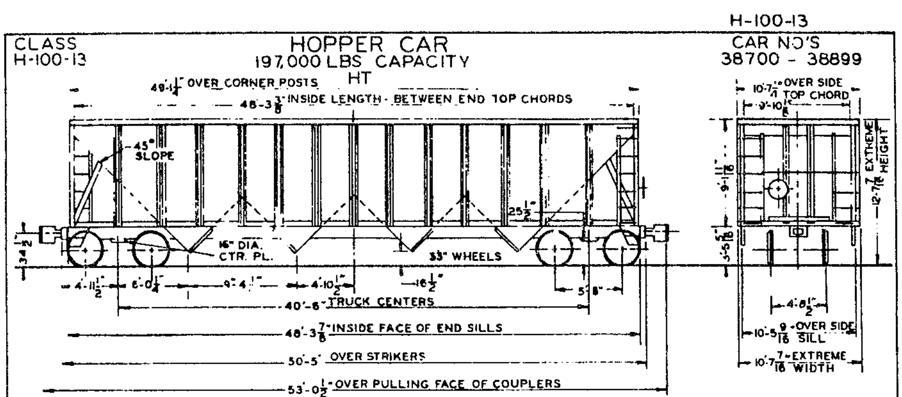
	B-End Truck				A-End Truck			
	Right		Left		Right		Left	
	Front	Rear	Front	Rear	Front	Rear	Front	Rear
Static	11	11	11	11	N/M	N/M	N/M	N/M
Empty Car	10	10	10	10	9-10/16	9-10/16	9-13/16	9-13/16
Half Loaded Car	9-1/4	9-1/4	8-3/4	8-3/4	8-7/8	8-7/8	8-3/4	8-7/8
Loaded Car	8-5/8	8-11/16	8-3/16	8-3/16	8-1/4	8-1/4	8-1/16	8-1/8

N/M: Not Measured

Table 2-2. Spring Group Measurements (In.) ASF Truck

	B-End Truck				A-End Truck			
	Right		Left		Right		Left	
	Front	Rear	Front	Rear	Front	Rear	Front	Rear
Static	N/M	N/M	N/M	N/M	N/M	N/M	N/M	N/M
Empty Car	10	10-1/8	10	10-1/16	9-15/16	9-15/16	9-7/8	9-13/16
Half Loaded Car	9-5/16	9-9/16	8-13/16	8-15/16	8-13/16	9-3/16	8-7/8	8-13/16
Loaded Car	8-5/8	8-13/16	8-3/8	8-3/8	8-1/2	8-1/2	8-3/16	8-13/16

N/M: Not Measured



LENGTH INSIDE	48'-3 3/8"
WIDTH INSIDE	9'-10 1/8"
CUBIC CAPACTY - LEVEL FULL	3625 CU.FT.
WT. OF EACH TRUCK	9100 LBS.
LT. WEIGHT OF CAR - COMPLETE	63600 LBS
SUPERSTRUCTURE - RIVETED CONSTRUCTION	BETHLEHEM
UNDERFRAME - RIVETED CONSTRUCTION	BETHLEHEM
TRUCK TYPE - ASF RIDE CONTROL 70 TON	

CAR BUILDER	NO CARS BUILT	YEAR BUILT
BETH	200	1974

MIN CURVE NEGOTIABLE COUPLED TO BASE CAR 178 FT RADIUS

GENERAL DESIGN	244-C-34580
BRAKE ARRGT	154-C-34581
TRUCK ARRGT	3741
SIDE CONSTRUCTION	134-C-34582
STENCIL ARRGT	304-C-34583
ALLOCATION OF SPEC	282-C-34584

ACI LABEL	INFO INC
AIR BRAKES - 8 1/2" X 12" ABD	WABCO
ANGLE COCKS	WABCO
AXLES - 6" X 11"	BETHLEHEM
BOTTOM ROD GUARDS	CRECO
BRAKE BADGE PLATES	SHENANGO
BRAKE BEAM - # 24	DAVIS, CRECO
BRAKE BEAM WEAR PLATE	UNIT TRUCK
BRAKE CYLINDER PUSH ROD	SCHAEFER
BRAKE LEVER	SCHAEFER
BRAKE LEVER CONN	SCHAEFER
BRAKE PIPE CLAMPS	ILL. RY EQUIP
BRAKE REGULATOR	ELLCON
BRAKE ROD JAWS	SCHAEFER
BRAKE SHOES - HF COMP	ABEX
BRAKE SHOE KEYS	ABEX
	TRUCK
CTR PLT - BODY	PRATT & LETCHWORTH
CORNER CAP	SCHAEFER
COUPLER TYPE "E"	McCONWAY & TORLEY
COUPLER RELEASE RIGGING	STANRAY
COUPLER YOKE	McCONWAY & TORLEY

CROSSOVER PLATFORM	APEX
DEAD LEVER BRACKET	PITTSBURGH FORGING
DEFECT CARD HOLDER	WESTERN RY. EQUIP
DOOR LOCKS	MINER
DRAFT GEAR	MINER
DRAFT SILL CASTINGS	PRATT & LETCHWORTH
HAND BRAKE	ELLCON
INSIDE BRACE FOOT	MIDLAND ROSS
ROLLER BEARINGS - 6" X 11"	TIMKEN
ROLLER BEARING ADAPTORS	HAYES-ALBION
ROLLER BEARING RET. KEYS	BETHLEHEM
TRUCK BOLSTER	ASF
TRUCK SIDE FRAME	ASF
TRUCK SIDE BEARINGS	STUCKI
TRUCK SPRINGS - D-5	COLT

92 CARS EQUIPPED WITH 18" DIA. CENTER PLATE

BUILT NEW	12/74
EMPTY:	63,600 LB
HALF LOADED:	149,300 LB
LOADED:	209,500 LB
LADING:	COARSE GRAVEL

Modified from Diagram F-10-7, Union Pacific Railroad Co. Research and Mechanical Standards

Figure 2-2. Barber Truck Test Car -UP38768

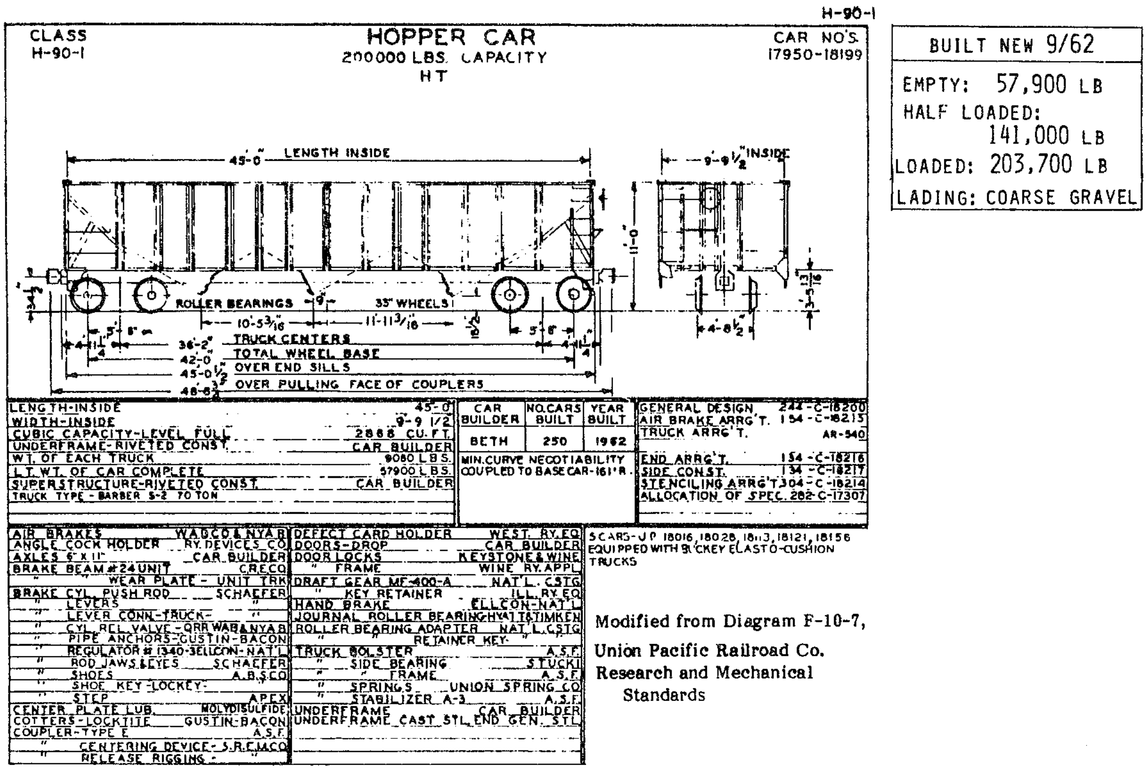


Figure 2-3. ASF Truck Test Car - UP17966

2.3 UP MOBILE LABORATORY CAR 210

2.3.1 Description

The Union Pacific mobile laboratory car 210 was used as the instrumentation car. It is an 85-foot, heavy steel car converted from a former Pullman sleeper car. It has a reinforced underframe, six-wheel trucks, and alignment control draft gear, giving it an exceptionally smooth ride, safety, and stability at all speeds and in any position within a freight train. The car is completely self-contained, although it is not self-propelled. On-board power is generated by a diesel engine/generator set. The layout of the car is shown in Figure 2-4.

2.3.2 Data Acquisition System

An onboard data acquisition and processing system provides the capability for acquisition of raw data, processing and storage, and presentation for real-time and quick-look data display. Block diagrams of the system are shown in Figures 2-5 and 2-6.

Transducer signals for the test vehicle are routed to the signal conditioners in mobile laboratory car 210 (Figure 2-5). From the signal conditioners, a patch panel provides the flexibility of routing the signals to any A/D channel, and/or FM tape recorder and real-time oscillograph display. The onboard HP2100 MX minicomputer (Figure 2-6) is used to control the processing of test data. The intelligent CRT terminal is used to enter test information for storage on tapes and to process data from the tapes for quick-look data display. An analog-to-digital (A/D) converter connects 64 channels of analog signals from the signal conditioner, then the data are recorded on magnetic tape, with such other information as test descriptions, channel designations, and calibration information. The tape reader is used to supply pre-processed information, such as a test condition summary list, to the computer at test time. The Versatek printer-plotter provides displays for the pretest information files, calibration value, real-time train location, ALD detection, etc.

2.3.3 Data Display

With the data acquisition system described in the preceding paragraph, real-time display, quick-look display, and magnetic tapes of the data were acquired for all test runs. Examples of typical real-time and quick-look displays are given in Section 4. The magnetic tapes consist of files containing written descriptions of the test, calibration files, and the raw test data. The sequence of files written to tape is given in Table 2-3. An example of a tape header file is given in Table 2-4. The general description is intended to provide a written account of the test and to note any problems or changes in the test procedure which may have been required. For example, in the test shown in Table 2-4, it was necessary to change A/D channel 33 to channel 25; this change is recorded in the tape header file. The second file is a test condition summary file, a rigidly structured file which contains a listing of 61 variables associated with a particular test. An example of this file for test 012 is contained in Table 2-5. The third file is the channel description file (see Table 2-6). It contains a listing of all transducer channels for the test listed by increasing A/D number. This table provides the engineering units associated with a channel and the magnitude of these units for the zero and the positive-step calibration values.

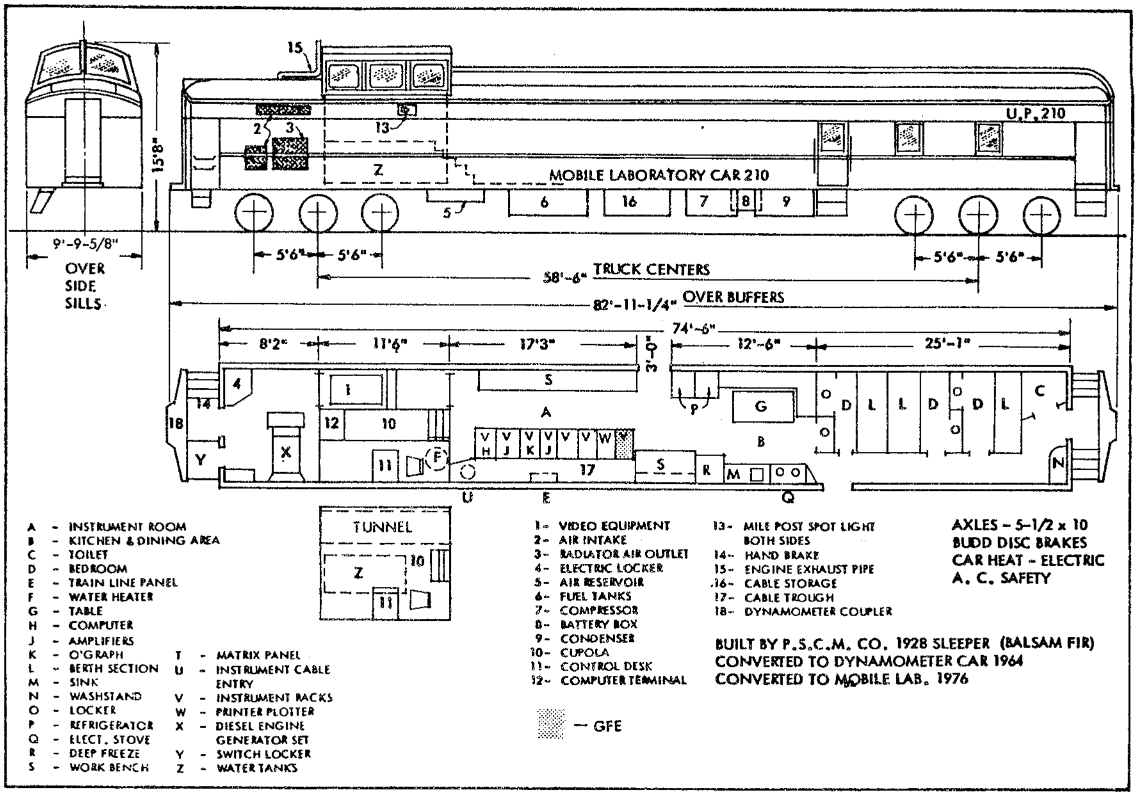


Figure 2-4. Mobile Laboratory Car 210 Configuration

FIELD TEST DATA ACQUISITION SYSTEM

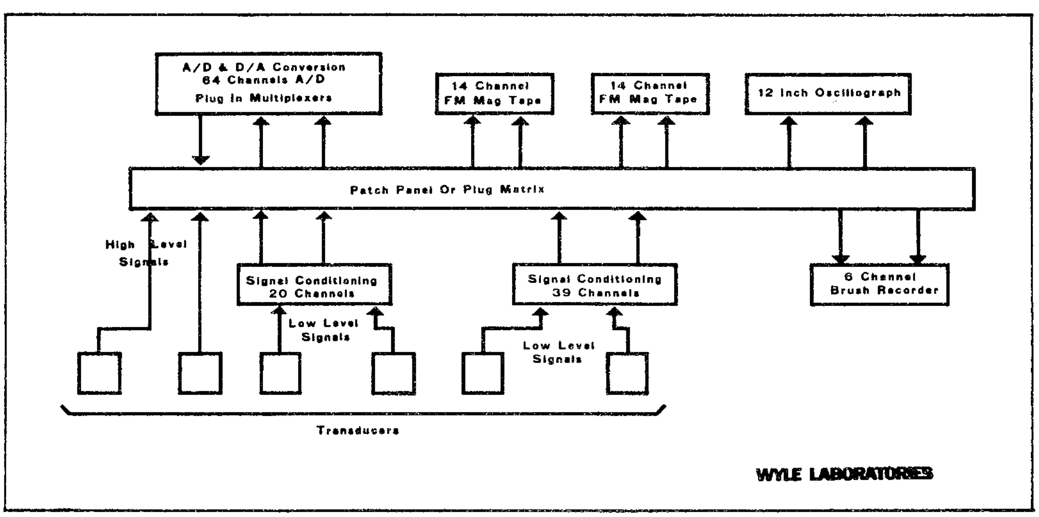


Figure 2-5. Analog Subsystem

FIELD TEST DATA ACQUISITION SYSTEM

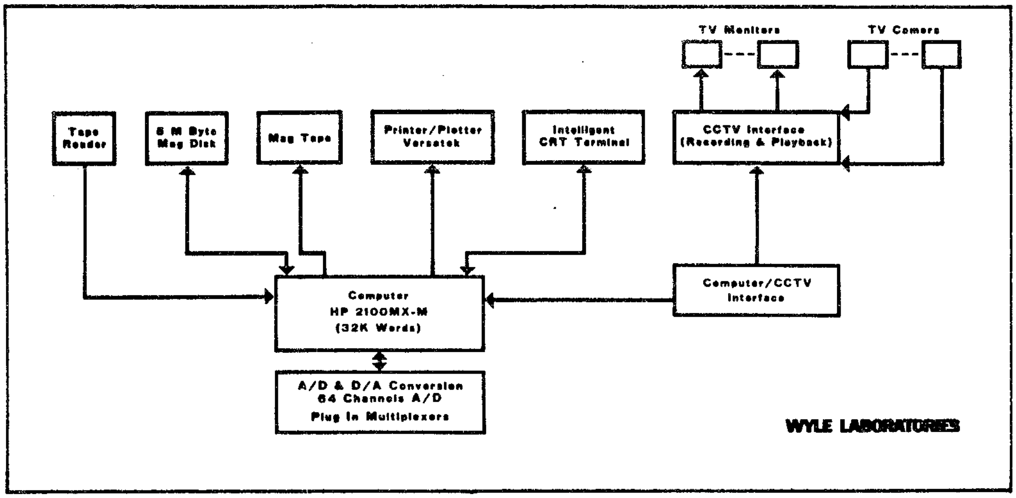


Figure 2-6. Digital Subsystem

Table 2-3. Test Tape Data Description

```
TAPE HEADER FILE

TEST CONDITION SUMMARY

CHANNEL DESCRIPTION FILE

PRETEST CALIBRATION

RAW TEST DATA

POSTEST CALIBRATION

POSTEST INFORMATION FILE
```

Table 2-4. Example of Tape Header File

```
 1            GENERAL DESCRIPTION
 2 TEST ID:   TDOP-II-FSFMS- 012
 3 PREVIOUS TRAFIC OVER ZONE:
 4         MAINLINE TRACK
 5 DEVIATION FROM NOMINAL TEST HARDWARE:
 6         B-END TRUCK HAS BEEN MODIFIED
 7         TO TAKE FRICTION SNUBBER FORCE
 8         MEASUREMENT SYSTEM
 9 VERBAL DESCRIPTION OF TEST:
10         THIS TEST IS BEING RUN USING THE
11         FRICTION SNUBBER FORCE MEASUREMENT
12         SYSTEM.  THIS RUN HAS THE MODIFIED
13         ASF TRUCK UNDER THE FULLY LOADED
14         HOPPER CAR AT THE B-END.
15         DETAILS OF THE TEST ARE CONTAINED
16         IN THE TEST PLAN (C-901-0001-A)
17         AND THE DETAILED TEST PROCEDURE
18         (C-901-0005-A).
19         THIS TEST RUN STARTS AT 50 MPH
20         AT MILEPOST 323 AND CONTINUES
21         UNTIL MP 324.5 WHERE THE SPEED STA
22         DECREASING DOWN TO 5 MPH AT THE
23         END OF THE TEST AT MP 326.8.
24 -1
25 MEAS F18 CHAN 35 SWITCHED TO
26 MEAS A10 CHAN 25.  A10 DELETED.
27 -1
```

Table 2-5. Test Condition Summary File

```
 1 TDOP TEST PARAMETERS -------------------
 2 TEST ID:  TDOP-II-FSFMS-012
 3 TDOP TAPE NO. 206
 4 SEQUENCE ON TAPE: 2
 5 TEST DATE: 12/08/78
 6 TEST START TIME: 2100
 7 TEMPERATURE: 2 DEGREES C
 8 PRECIPITATION: NONE
 9 RAIL SURF CONDITION: DRY
10 LINE:  MAINLINE ARDEN TO BOLDER JUNCTION
11 DIRECTION:  W TO E
12 MILEPOST START:  323
13 MILEPOST STOP:  326.8
14 MIN SPEED:  5 MPH
15 MAX SPEED:  50 MPH
16 SPEED TYPE:  VARYING
17 TRACK CLASSIFICATION:  CLASS 4
18 APPROX. GRADE:  DOWNHILL 0.8%
19 RAIL TYPE:  JOINTED
20 RAIL WEIGHT:  133 LBS/YD
21 RAIL LAID IN:  1966
22 CAR INITIALS:  UNION PACIFIC
23 CAR NUMBER:  UP17966
24 CAR TYPE:  100 TON OPEN HOPPER
25 CAR ORIENTAION:  B-END FORWARD
26 CAR CAPACITY:  180,000 POUNDS
27 CAR TARE WEIGHT:  57,900 POUNDS
28 TARE WEIGHT: 204,700 POUNDS
29 TYPE OF LADING: GRAVEL
30 ALD + LD. TRUCK:  83 FEET 3 INCHES
31 TRUCK CENTER:   36 FEET 2 INCHES
32 NO. OF LOCO'S:  1
33 TOTAL H.P.:  2250
34 NO. OF CARS FORE:  2
35 TOTAL TONS FORE: 163.0
36 NO. OF CARS AFT:  2
37 TOTAL TONS AFT:  118.3
38 TRUCK TYPE:  ASF 70 TON RC
39 WHEEL BASE:  68 INCHES
40 SPRINGS GROUP OUT:  7-D5
41 SPRING GROUP IN:  6-D5
42 STAT SPRING COMP:  NOT MEASURED
43 CENTER PLATE DIA:  14 INCHES
44 CENTER PLATE MATL:  STEEL
45 CENTER PLATE LUB:  MOLY DISULFIED
46 SIDE BEAR A-END:  STUCKI DOUBLE
47 SIDE BEAR B-END:  STUCKI DOUBLE
48 SIDE BEAR CLEAR:  0.25 INCHES
49 SIDE BEAR SUPPL:  NONE
50 SIDE BEAR PRELD:  NONE
51 SNUBBER TYPE:  CONSTANT
52 SNUBBER SPRINGS:  2 ASF 3020
53 S./FR INTERTIE:  NONE
54 OUTER GIB CLR:  0.64 INCHES
55 INNER GIB CLR:  0.40 INCHES
56 ROLLER BEARING:  AAR 6 X 11 TAPERED
57 ADAPTER PAD TYPE:  NONE
58 PAD SHEAR COEFF: N/A
59 LAT DAMPER TYPE:  NONE
60 LAT DAMPER RATE:  N/A
61 WHEEL CONTOUR:  REPROFILED 1/20
62 WHEEL DIAMETER:  33 INCHES
```

Table 2-6. Channel Description File

A/D NUMBER	CHANNEL ID & DESCRIPTION	UNITS	ZERO CAL	POSITIVE CAL
1	S 1 - Car Velocity	MPH	0.000	50.000
2	S 2 - Automatic Location Detector	TTL	0.000	5.000
3	F 1 - FS4 Upper Normal Force	Pounds	0.000	2912.000
4	F 2 - FS4 Lower Normal Force	Pounds	0.000	3012.000
5	F 3 - FS4 Upper Lateral Force	Pounds	0.000	1644.000
6	F 4 - FS4 Lower Lateral Force	Pounds	0.000	1488.000
7	F 5 - FS4 Vertical Force	Pounds	0.000	1499.000
8	F 6 - FS3 Upper Normal Force	Pounds	0.000	2871.000
9	F 7 - FS3 Lower Normal Force	Pounds	0.000	2824.000
10	F 8 - FS3 Upper Lateral Force	Pounds	0.000	1654.000
11	F 9 - FS3 Lower Lateral Force	Pounds	0.000	1677.000
12	F10 - FS3 Vertical Force	Pounds	0.000	1268.000
13	D 1 - RT FT Spring Group Vert Disp	Inches	0.000	0.519
14	D 2 - RT RR Spring Group Vert Disp	Inches	0.000	0.471
15	D11 - RT Carbody/Bolster Vert Disp	Inches	0.000	2.054
16	A 1 - B-End Center Plate Vert Accel	G's	0.000	5.450
17	A 2 - A-End Center Plate Vert Accel	G's	0.000	5.380
18	A 3 - B-End Outboard Vert Accel	G's	0.000	3.160
19	A 4 - A-End Outboard Vert Accel	G's	0.000	3.250
20	A 5 - B-End Lateral Accel	G's	0.000	3.430
21	A 6 - A-End Lateral Accel	G's	0.000	5.450
22	A 7 - RT Side Frame Vert Accel	G's	0.000	1.617
23	A 8 - LF Side Frame Vert Accel	G's	0.000	-1.583
24	A 9 - RT Side Frame Over Range V Accel	G's	0.000	35.540
25	A10 - LF Side Frame Over Range V Accel	G's	0.000	34.830
26	F11 - FS1 Lower Normal Force	Pounds	0.000	2835.000
27	F12 - FS1 Lower Normal Force	Pounds	0.000	2808.000
28	F13 - FS1 Upper Lateral Force	Pounds	0.000	1671.000
29	F14 - FS1 Lower Lateral Force	Pounds	0.000	1574.000
30	F15 - FS1 Vertical Force	Pounds	0.000	1518.000
31	F16 - FS2 Upper Normal Force	Pounds	0.000	2914.000
32	F17 - FS2 Lower Normal Force	Pounds	0.000	2805.000
33	F18 - FS2 Upper Lateral Force	Pounds	0.000	1607.000
34	F19 - FS2 Lower Lateral Force	Pounds	0.000	1607.000
35	F20 - FS2 Vertical Force	Pounds	0.000	1480.000
36	D 3 - LF FR Spring Group Vert Disp	Inches	0.000	0.527
37	D 4 - LF RR Spring Group Vert Disp	Inches	0.000	0.518
38	D12 - LF Carbody/Bolster Vert Disp	Inches	0.000	2.053
39	D 5 - RT FR Bolster/Side Frame Lat Disp	Inches	0.000	1.000
40	D 6 - RT RR Bolster/Side Frame Lat Disp	Inches	0.000	1.000
41	D 7 - RT Bolster/Side Frame Rotation	Inches	0.000	1.000
42	D15 - RT Bolster/Side Frame Long. Disp	Inches	0.000	1.000
43	D 8 - LF RR Bolster/Side Frame Lat Disp	Inches	0.000	1.000
44	D 9 - LF FR Bolster/Side Frame Lat Disp	Inches	0.000	1.000
45	D10 - LF Bolster Side Frame Rotation	Inches	0.000	1.000
46	D16 - LF Bolster/Side Frame Long. Disp	Inches	0.000	1.000
47	D13 - Center Plate Rotation Forward	Inches	0.000	-0.768
48	D14 - Center Plate Rotation Back	Inches	0.000	-0.791

The fourth file on the data tapes is the pretest calibration file and is described in detail in paragraph 2.4.4. The raw data file contains the test data acquired during a test. It is written in multiplexed format with the data for one time point written sequentially through the run.

At the completion of each run, a post test calibration was conducted and the results were written on the test tape. Finally, any post test comments were entered on an information file.

During the tests, each test run was written on a single tape. At the completion of the entire test program, the tapes were edited to correct errors and omissions, such as test car weights which were often not available when the test was run. The data files run from each were then written, two test runs on a tape, starting with tape number 201.

2.4 INSTRUMENTATION

2.4.1 Data Channel Description

Forty-eight channels of data were acquired during the FSFMS test program. They consisted of 20 channels of friction snubber forces, 16 displacements, 10 accelerations, vehicle speed, and ALD detection. The instrumentation list is given in Table 2-7. This list is included in each tape header as the third file in the format previously described in Table 2-6. Dual identifiers are used for each channel. The measurement identifier is a generic designation for each channel and is the description used in planning and running the test program. The A/D channel is the digital channel number on which each of the measurements was written and is the identifier which was used when addressing the channels for data reduction. Table 2-7 also includes the location description and the units associated with each channel.

2.4.2 Location

The instrumentation was located on the B-end truck and at both the A- and B-ends of the carbody. The truck instrumentation consisted of force transducers in each friction snubber group and displacement and acceleration measurements on the bolster and side frames. Typical instrumentation is shown in the photographs of the bolster/side frame in Figure 2-7, A and B. For this instrumentation, an aluminum bracket was bolted to the side frame and another to the bolster. The eddy current transducers (D5, D6, D7, and D15 shown in Figure 2-7) were attached to the bracket on the bolster to sense the distance from the transducer to a target, in this case, the bracket on the side frame. The bending beam transducers (D1 and D2), were mounted to the bolster bracket and attached by wire at the other end to the side frame bracket. As the bolster/side frame move relative to each other in the vertical direction, the amount of bending in the beam measured by strain gages increases or decreases. The amount of motion is directly proportional to this change and is calibrated using a known displacement. Eddy current transducers are shown in Figure 2-8, A and B.

Before testing the ASF truck, the center of the side frame bracket was removed (see Figure 2-7B) to permit access to the fricion snubber pins so they could be pinned back during calibration.

Two string potentiometers were used to measure the center plate rotation (shown in Figure 2-9). The string potentiometers were mounted on a bracket secured to the bolster. The strings were extended and tied to the truck body bolster at the longitudinal centerline of the carbody. As the center plate rotates, one string potentiometer is extended and the other is retracted.

The carbody/truck bolster rotation was measured by string potentiometers shown in Figure 2-10, A and B. The string potentiometer was mounted on the carbody bolster and the string attached to the truck bolster. The string potentiometer arrangement was used on both sides of the Barber truck (Figure 2-10A). Prior to the start of testing on the ASF truck, the right string potentiometer failed and was replaced by a linear potentiometer as shown in Figure 2-10B.

Typical carbody and side frame accelerometer installations are shown in Figure 2-11, A and B. The carbody accelerometers were mounted on brackets welded to the carbody. An outboard vertical (A3) and lateral (A5) accelerometer are shown in Figure 2-11A. The accelerometers on the truck (Figure 2-11B) were mounted with dental cement directly to the side frame. Each side frame had a 5-G and an overrange 50-G accelerometer mounted on them. However, evaluation of the results showed the one 5-G accelerometer was completely adequate to measure side frame acceleration without saturating.

2.4.3 Signal Conditioning

The data from the transducers on the test vehicle were routed to the junction boxes (see Figure 2-7A) on each side of the car. Large transfer cables were used to route the signals to car 210 and the signal conditioner from the junction boxes. Ectron signal conditioning was used for the following transducers: all friction snubbers, all accelerometers, all bending beams, and the two truck/carbody bolster string potentiometers. All signals routed through the Ectron signal conditioner were filtered at 20 Hz. The Ectron signal conditioners proved to be a constant source of trouble during the course of the entire test. Most of them were kept on-line by continuous repair work; however, some data channels were lost due to failure of these conditioners, as noted in Section 3.

The eddy current transducers (measurements D5-D10 and D15-D16) were routed through the Dynamics signal conditioner only for purposes of filtering. No signal amplification is required for these transducers. The filtering was done at 25 Hz.

The two string potentiometers for center plate rotation (D13 and D14) were routed through the B and F and Dana signal conditioners. They were filtered at 100 Hz.

2.4.4 System Calibration

All instrumentation was calibrated before the start of the test program. Some transducers, such as the friction snubber force measurement system, were calibrated by the manufacturer before delivery and were supplied with calibration curves. Other transducers, such as the accelerometer from Phase I, were sent to a calibration laboratory for recalibration before the start of testing. Finally, others, such as the eddy current transducers, were field-calibrated by using a known displacement and measuring the output.

Before the start of testing on each truck type, each of the friction snubber groups was backed off (i.e., all the forces were removed) and a zero-calibration value was obtained so the subsequently measured forces on all the friction snubbers were the total force. The friction shoes were backed off on the Barber truck by jacking the bolster up, and on the ASF truck by pinning the friction shoes back.

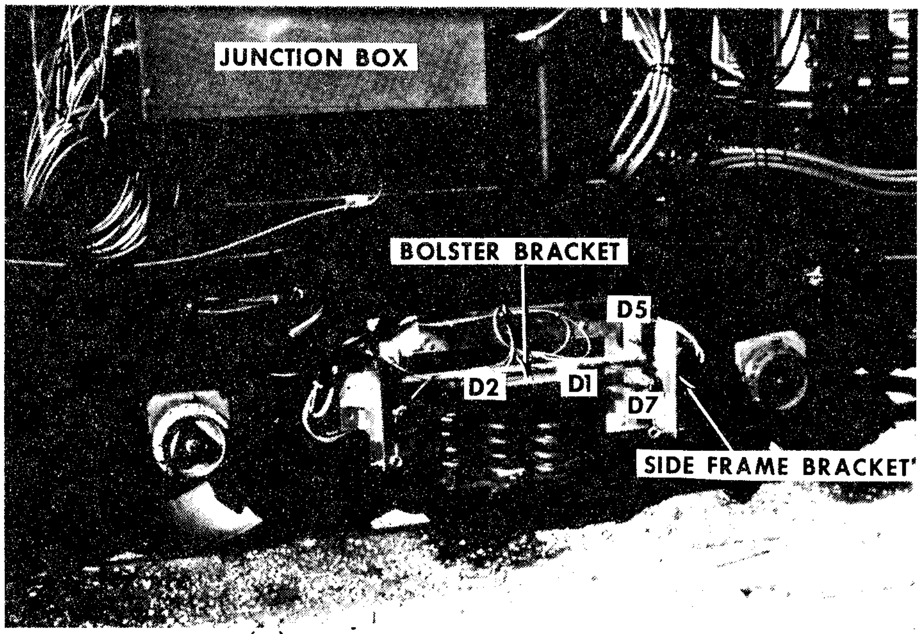
As a part of the calibration procedure conducted just before and after each test run, a shunt resistance calibration on all resistive transducer elements was done. With the consist stationary, the static (zero) setting response of each channel was recorded. Insertion of shunt resistance into the positive resistive bridge leg was then made for each channel. Both the zero and positive calibrations were obtained from the computer and reviewed for acceptability before recording onto magnetic tape.

Table 2-7. Instrumentation List

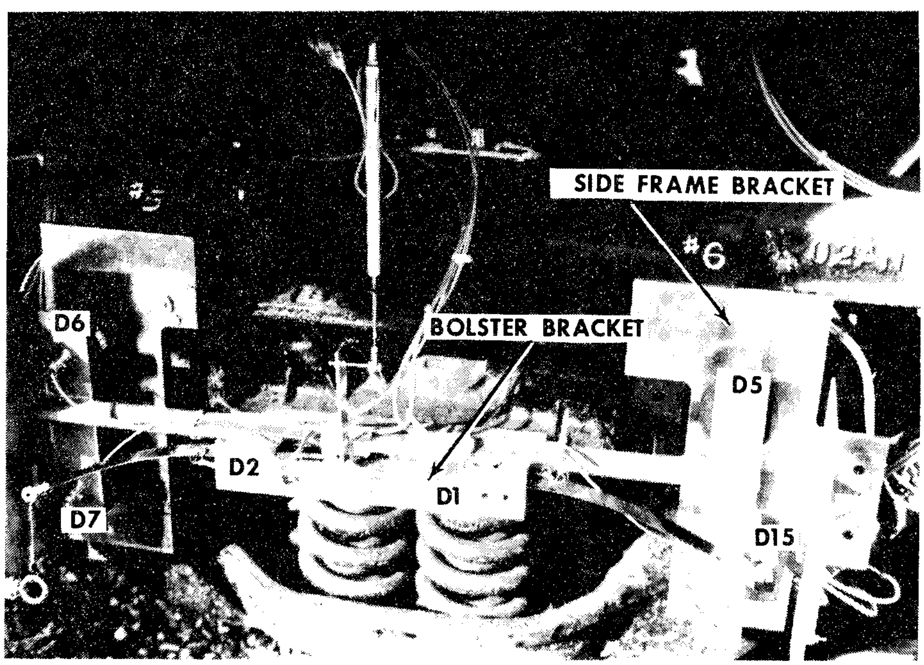
Measurement Identification	A/D Channel	Description	Location	Unit
S1	1	Car Speed		MPH
S2	2	Car Location (ALD)	Car 210	
F1	3	Friction Snubber 4-UN	Right Front Spring Group	Pound
F2	4	Friction Snubber 4-LN	Right Front Spring Group	Pound
F3	5	Friction Snubber 4-UL	Right Front Spring Group	Pound
F4	6	Friction Snubber 4-LL	Right Front Spring Group	Pound
F5	7	Friction Snubber 4-V	Right Front Spring Group	Pound
F6	8	Friction Snubber 3-UN	Right Rear Spring Group	Pound
F7	9	Friction Snubber 3-LN	Right Rear Spring Group	Pound
F8	10	Friction Snubber 3-UL	Right Rear Spring Group	Pound
F9	11	Friction Snubber 3-LL	Right Rear Spring Group	Pound
F10	12	Friction Snubber 3-V	Right Rear Spring Group	Pound
F11	26	Friction Snubber 1-UN	Left Front Spring Group	Pound
F12	27	Friction Snubber 1-LN	Left Front Spring Group	Pound
F13	28	Friction Snubber 1-UL	Left Front Spring Group	Pound
F14	29	Friction Snubber 1-LL	Left Front Spring Group	Pound
F15	30	Friction Snubber 1-V	Left Front Spring Group	Pound
F16	31	Friction Snubber 2-UN	Left Rear Spring Group	Pound
F17	32	Friction Snubber 2-LN	Left Rear Spring Group	Pound
F18	33	Friction Snubber 2-UL	Left Rear Spring Group	Pound
F19	34	Friction Snubber 2-LL	Left Rear Spring Group	Pound
F20	35	Friction Snubber 2-V	Left Rear Spring Group	Pound
D1	13	Vertical Displacement	Right Front Spring Group	Inch

Measurement Identification	A/D Channel	Description	Location	Unit
D2	14	Vertical Displacement	Right Rear Spring Group	Inch
D3	36	Vertical Displacement	Left Front Spring Group	Inch
D4	37	Vertical Displacement	Left Rear Spring Group	Inch
D5	39	Lateral Displacement	Right Front Spring Group	Inch
D6	40	Lateral Displacement	Right Rear Spring Group	Inch
D7	41	Lateral Displacement	Right Bolster Spring Group	Inch
D8	43	Lateral Displacement	Left Front Spring Group	Inch
D9	44	Lateral Displacement	Left Rear Spring Group	Inch
D10	45	Lateral Displacement	Left Bolster Spring Group	Inch
D11	15	Vertical Displacement	Right Carbody/Bolster	Inch
D12	38	Vertical Displacement	Left Carbody/Bolster	Inch
D13	47	Center Plate Rotation	Front	Inch
D14	48	Center Plate Rotation	Rear	Inch
D15	42	Longitudinal Displacement	Right Bolster/Side Frame	Inch
D16	46	Longitudinal Displacement	Left Bolster/Side Frame	Inch
A1	16	Vertical Acceleration	Center Plate, Front	G
A2	17	Vertical Acceleration	Center Plate, Rear	G
A3	18	Vertical Acceleration	Outboard, Front	G
A4	19	Vertical Acceleration	Outboard, Rear	G
A5	20	Lateral Acceleration	Front End	G
A6	21	Lateral Acceleration	Rear End	G
A7	22	Vertical Acceleration	Right Side Frame	G
A8	23	Vertical Acceleration	Left Side Frame	G
A9	24	Vertical Acceleration	Right Side Frame Overrange	G
A10	25	Vertical Acceleration	Left Side Frame Overrange	G

NOTE: UN = Upper Normal
LN = Lower Normal
UL = Upper Lateral
LL = Lower Lateral
V = Vertical

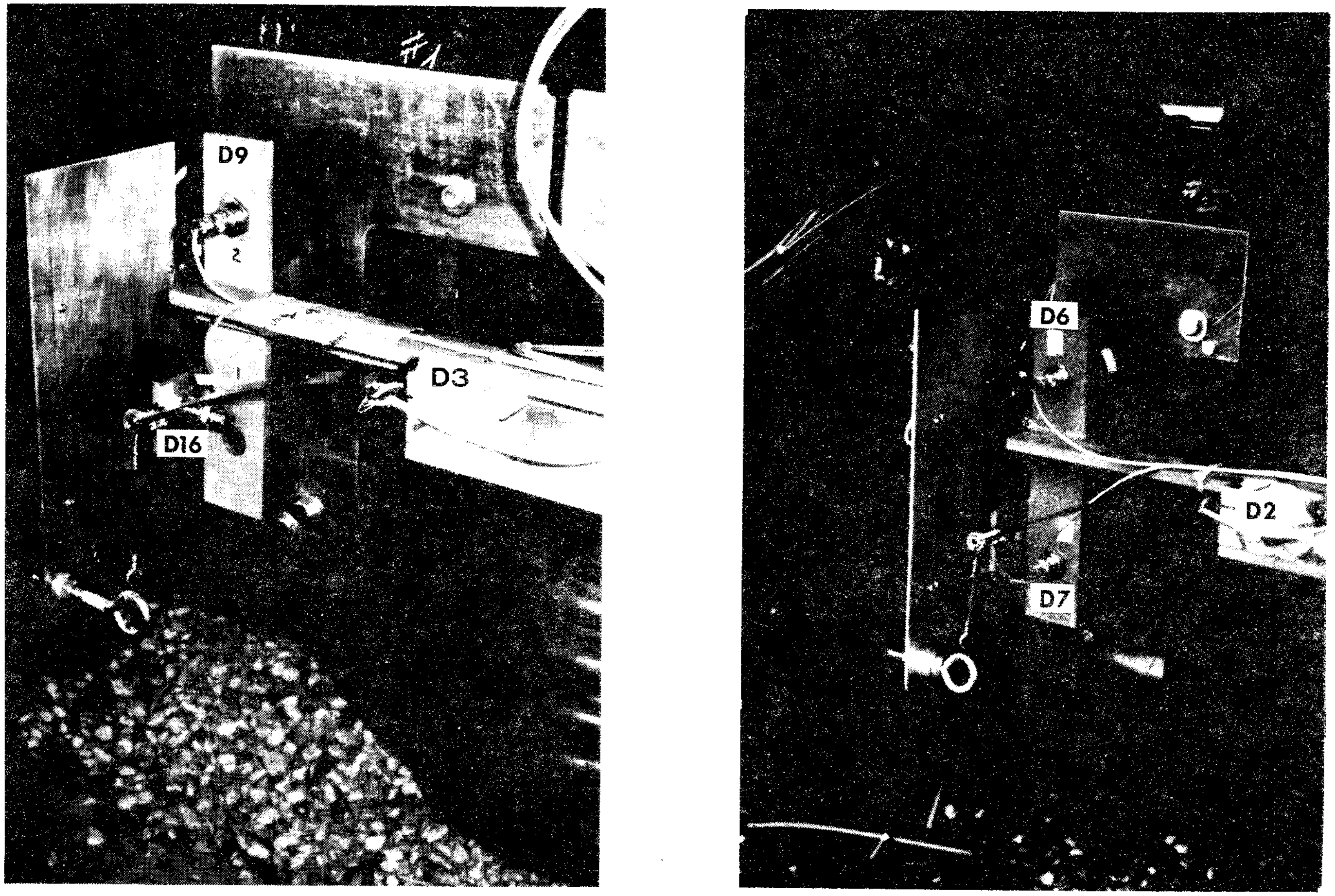


(A) BARBER TRUCK, RIGHT SIDE



(B) ASF TRUCK, RIGHT SIDE

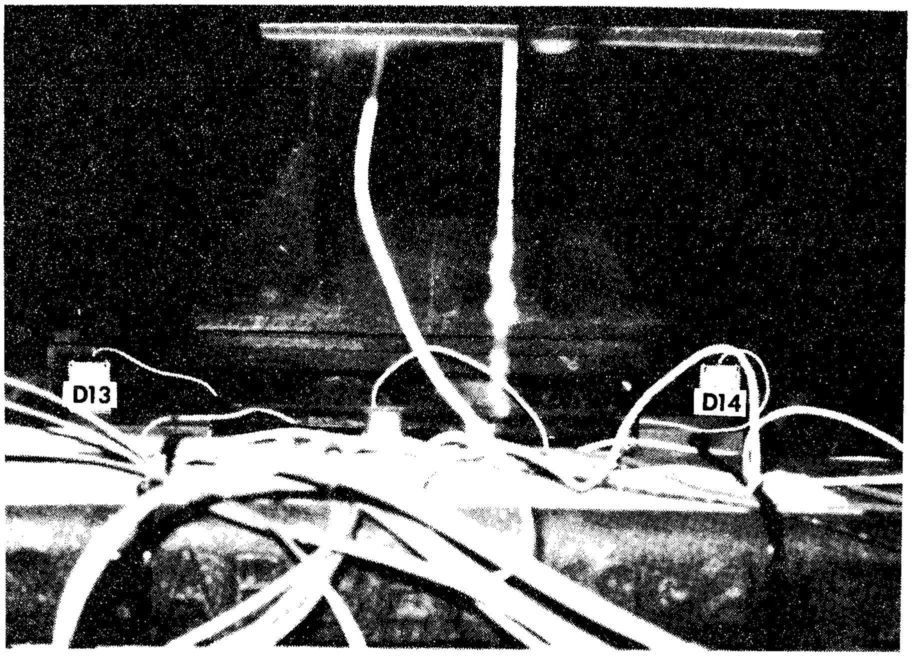
Figure 2-7. Typical Truck Instrumentation



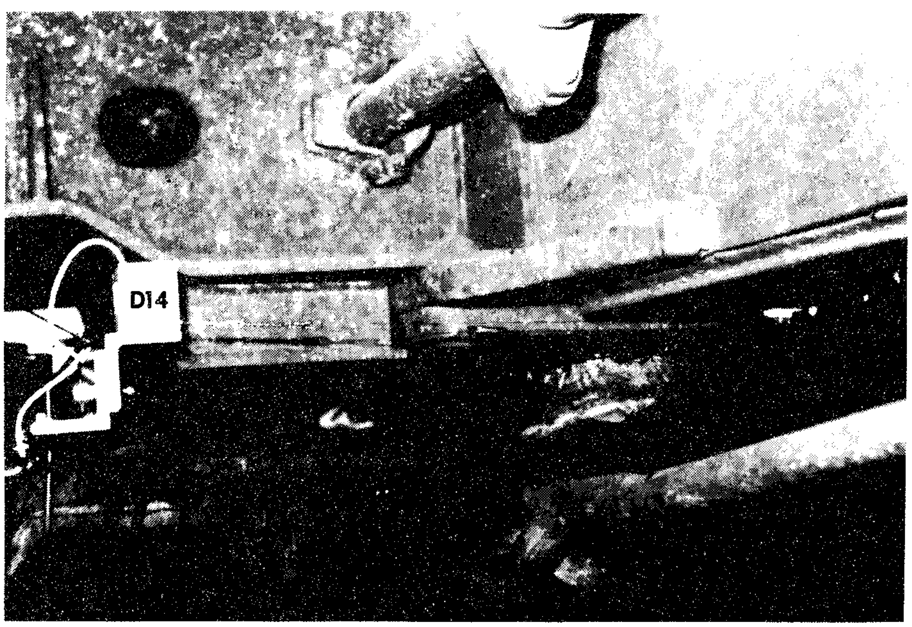
(A) BARBER TRUCK, LEFT FRONT

(B) ASF TRUCK, RIGHT REAR

Figure 2-8. Eddy Current Transducers

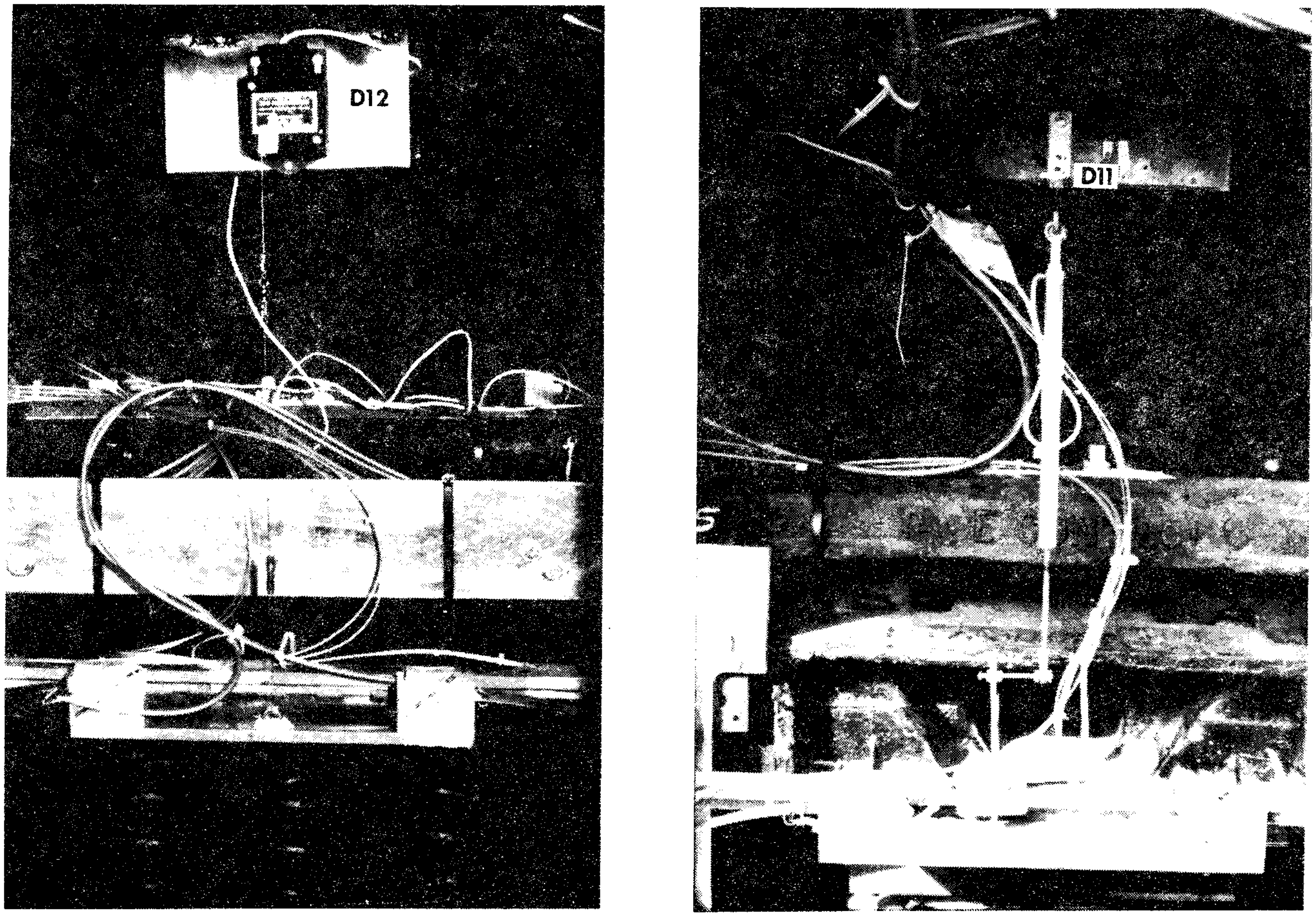


(A) SIDE VIEW LOOKING TOWARD CENTER PLATE



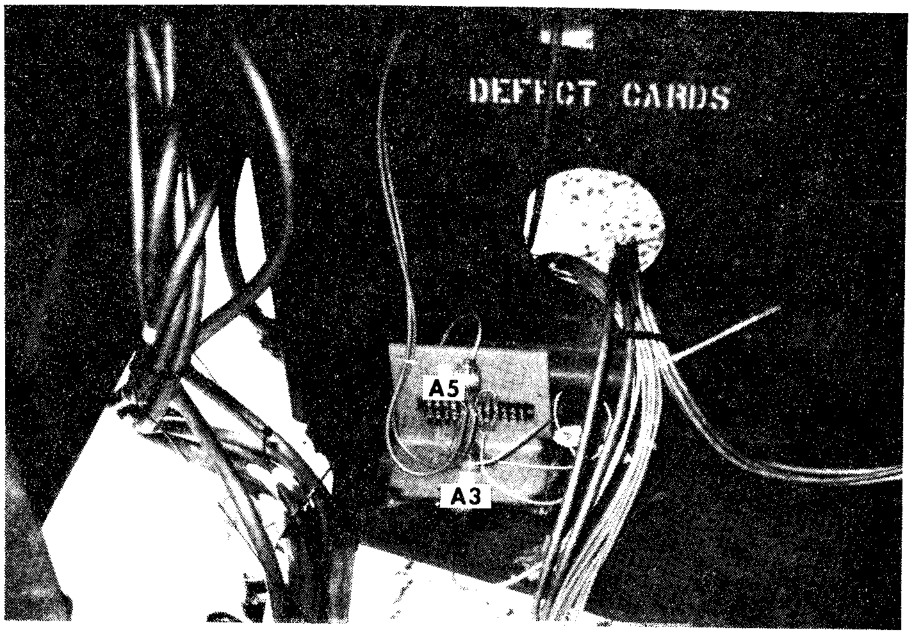
(B) END VIEW LOOKING TOWARD COUPLER

Figure 2-9. Truck Center Plate Rotation String Potentiometers

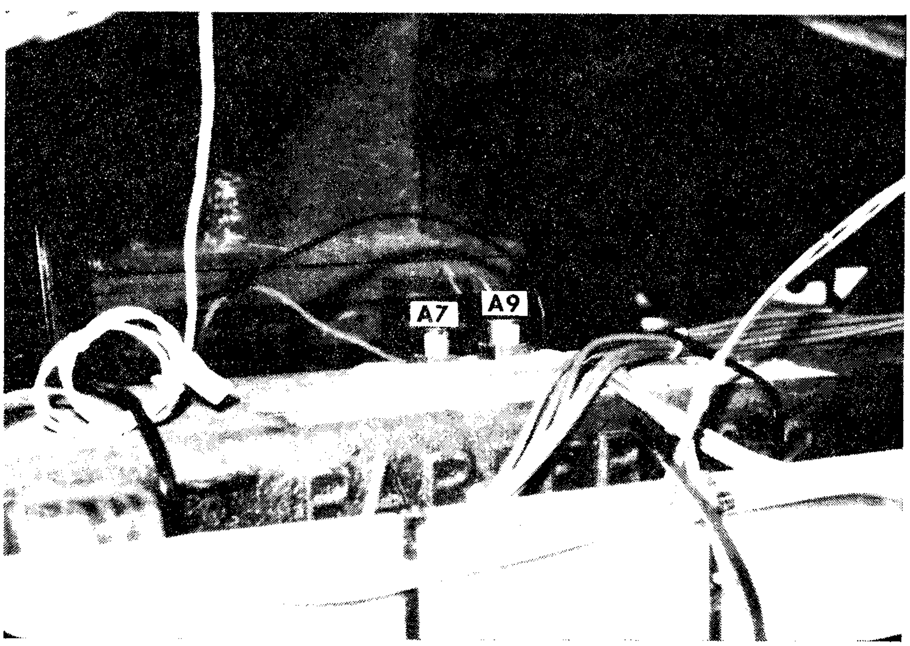


(A) BARBER LEFT SIDE (B) ASF RIGHT SIDE

Figure 2-10. Carbody Rotation Potentiometers



(A) BARBER CARBODY ACCELEROMETERS



(B) BARBER TRUCK ACCELEROMETERS

Figure 2-11. Accelerometer Installation

An example of the calibration file written on tape is contained in Table 2-8. The first column shows the zero, or low calibration; the second gives the positive, or high calibration. The difference between these two columns is equated to the difference in engineering unit values contained in Table 2-6 to obtain a conversion factor for the test data (i.e., the engineering units/volt conversion constant).

Table 2-8. Typical Calibration File

TDOP-II-FSFMS-007

CHANNEL NO.	1	LO CAL =	0.00000	HI CAL =	5.1190
CHANNEL NO.	2	LO CAL =	0.00000	HI CAL =	4.9990
CHANNEL NO.	3	LO CAL =	0.00000	HI CAL =	5.0088
CHANNEL NO.	4	LO CAL =	0.00000	HI CAL =	5.0289
CHANNEL NO.	5	LO CAL =	0.00000	HI CAL =	5.0488
CHANNEL NO.	6	LO CAL =	0.00000	HI CAL =	5.0390
CHANNEL NO.	7	LO CAL =	0.00000	HI CAL =	5.0188
CHANNEL NO.	8	LO CAL =	0.00000	HI CAL =	4.9990
CHANNEL NO.	9	LO CAL =	0.00000	HI CAL =	5.0289
CHANNEL NO.	10	LO CAL =	0.00000	HI CAL =	5.0289
CHANNEL NO.	11	LO CAL =	0.00000	HI CAL =	5.0188
CHANNEL NO.	12	LO CAL =	0.00000	HI CAL =	5.0086
CHANNEL NO.	13	LO CAL =	-7.5452	HI CAL =	-6.0852
CHANNEL NO.	14	LO CAL =	-8.0966	HI CAL =	-6.6122
CHANNEL NO.	15	LO CAL =	-0.56810	HI CAL =	0.22584
CHANNEL NO.	16	LO CAL =	0.91557E-02	HI CAL =	8.4467
CHANNEL NO.	17	LO CAL =	0.18617E-01	HI CAL =	8.4272
CHANNEL NO.	18	LO CAL =	0.86979E-01	HI CAL =	8.6469
CHANNEL NO.	19	LO CAL =	0.73246L-02	HI CAL =	8.2606
CHANNEL NO.	20	LO CAL =	0.88505E-02	HI CAL =	6.4467
CHANNEL NO.	21	LO CAL =	0.18617E-01	HI CAL =	8.5884
CHANNEL NO.	22	LO CAL =	1.0734	HI CAL =	2.7336
CHANNEL NO.	23	LO CAL =	1.2003	HI CAL =	2.9289
CHANNEL NO.	24	LO CAL =	0.96745E-01	HI CAL =	8.2462
CHANNEL NO.	25	LO CAL =	-1.4307	HI CAL =	-0.73490
CHANNEL NO.	26	LO CAL =	0.00000	HI CAL =	5.0289
CHANNEL NO.	27	LO CAL =	0.00000	HI CAL =	5.0390
CHANNEL NO.	28	LO CAL =	0.00000	HI CAL =	5.0188
CHANNEL NO.	29	LO CAL =	0.00000	HI CAL =	5.0188
CHANNEL NO.	30	LO CAL =	0.00000	HI CAL =	5.0588
CHANNEL NO.	31	LO CAL =	0.00000	HI CAL =	5.0390
CHANNEL NO.	32	LO CAL =	0.00000	HI CAL =	4.9587
CHANNEL NO.	33	LO CAL =	0.00000	HI CAL =	5.0289
CHANNEL NO.	34	LO CAL =	0.00000	HI CAL =	4.9990
CHANNEL NO.	35	LO CAL =	0.00000	HI CAL =	4.9990
CHANNEL NO.	36	LO CAL =	-7.8394	HI CAL =	-6.3782
CHANNEL NO.	37	LO CAL =	-7.0325	HI CAL =	-5.5676
CHANNEL NO.	38	LO CAL =	-0.57986E-02	HI CAL =	0.79990
CHANNEL NO.	39	LO CAL =	0.00000	HI CAL =	0.99980
CHANNEL NO.	40	LO CAL =	0.00000	HI CAL =	0.99980
CHANNEL NO.	41	LO CAL =	0.00000	HI CAL =	0.99980
CHANNEL NO.	42	LO CAL =	0.00000	HI CAL =	0.99980
CHANNEL NO.	43	LO CAL =	0.00000	HI CAL =	0.99980
CHANNEL NO.	44	LO CAL =	0.00000	HI CAL =	0.99980
CHANNEL NO.	45	LO CAL =	0.00000	HI CAL =	0.99980
CHANNEL NO.	46	LO CAL =	0.00000	HI CAL =	0.99980
CHANNEL NO.	47	LO CAL =	0.00000	HI CAL =	0.99980
CHANNEL NO.	48	LO CAL =	0.00000	HI CAL =	0.99980

SECTION 3 - TEST RUNS

3.1 PROCEDURE

The FSFMS test program was conducted over the main and branch lines of the Union Pacific South Central District, California division, outside of Las Vegas, Nevada. Two test zones were used for the test. Test zone 1 (Figure 3-1) consists of a class 2 branch line track with both tangent and curved track. The curves range from 2 to 7 degrees. Test zone 2 (Figure 3-2) consists of a class 4 main line tangent track. Both zones are jointed track.

The test procedure specified one pass through each zone, starting at a constant speed of 20 mph for zone 1 and 50 mph for zone 2. Halfway through the zone, the speed was decreased to near zero at the end of the zone. Typical speed profiles for the two zones are shown in Figure 3-3.

In order to locate the test car position in each zone, an automatic location detector (ALD) system was developed by Wyle and installed before the start of testing. The system relied upon detection of a magnetic field propagated by a cylindrical magnet, 3/4 inches in diameter and 4 inches long. A hole was drilled in the center of a tie at each ALD location and the magnet was buried in the tie. A sensor was installed under the mobile laboratory car to detect the magnetic field when the car passed over it. This ALD system was installed before the start of any testing on TDOP Phase II, and will be used for all tests (track geometry, FSFMS, and Types I and II trucks). Thus, it is possible to correlate results between the various tests. See paragraph 5.5.3 for an example of data correlation between FSFMS test results and track geometry results.

The FSFMS test data were recorded as a function of time, for example, 200 samples/second. However, a distance channel was created as part of the post processing by integration of the speed channel starting at detection of the first ALD. It is thus possible to plot data versus either time or milepost. Typical plots of ALD detection versus milepost are shown in Figure 3-4. A complete listing of the mileposts at which the ALD was detected is shown in Table 3-1 for all test runs. It shows excellent repeatability between test runs and there is no problem in comparing data from one run to the next. For each test run, a listing was obtained as part of the data reduction which listed the milepost versus time for each run. An example of this type of listing is contained in Appendix B. From these listings, it is easy to transfer back and forth between the time and distance domains.

The test program was run in two test series, the first with the Barber S-2 truck and the second with the ASF Ride Control truck. Each series was conducted with three lading conditions: empty, half loaded, and fully loaded. Each of the lading conditions was run over both test zones 1 and 2. The complete test matrix is defined in Table 3-2. The test ID specified in Table 3-2 for each run is the identifier used on the plots presented in the data analysis section.

Each hopper car was loaded with 1½-inch coarse gravel from a rock quarry at Sloan, Nevada (Figure 3-5). Ten-ton dump truck loads were used to fill each car. At some point in the testing of each lading configuration, the test cars were weighed. The actual weights of the three lading configurations for the two carbodies are contained in Figures 2-2 and 2-3. Typical lading conditions are shown in Figure 3-6, A and B.

3.2 CONSIST

The test consist for all test runs, shown in Figure 3-7, A and B, was made up of the locomotive, mobile laboratory car 210, forward buffer car, test car, rear buffer car, and caboose. Loaded, open hopper cars were used for the buffers and were configured as follows:

	Car Number	Weight
Forward Buffer	UP 88006	132,500 lb
Rear Buffer	UP 90937	180,500 lb

The test car was always located in the consist so that the B-end was leading.

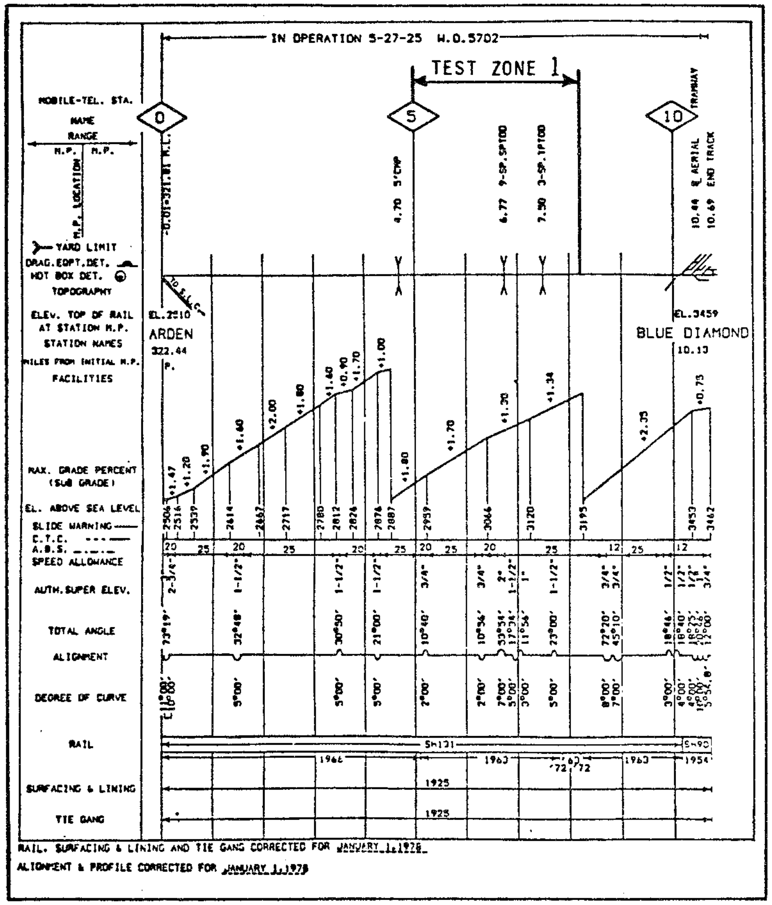


Figure 3-1. Track Profile - Test Zone 1

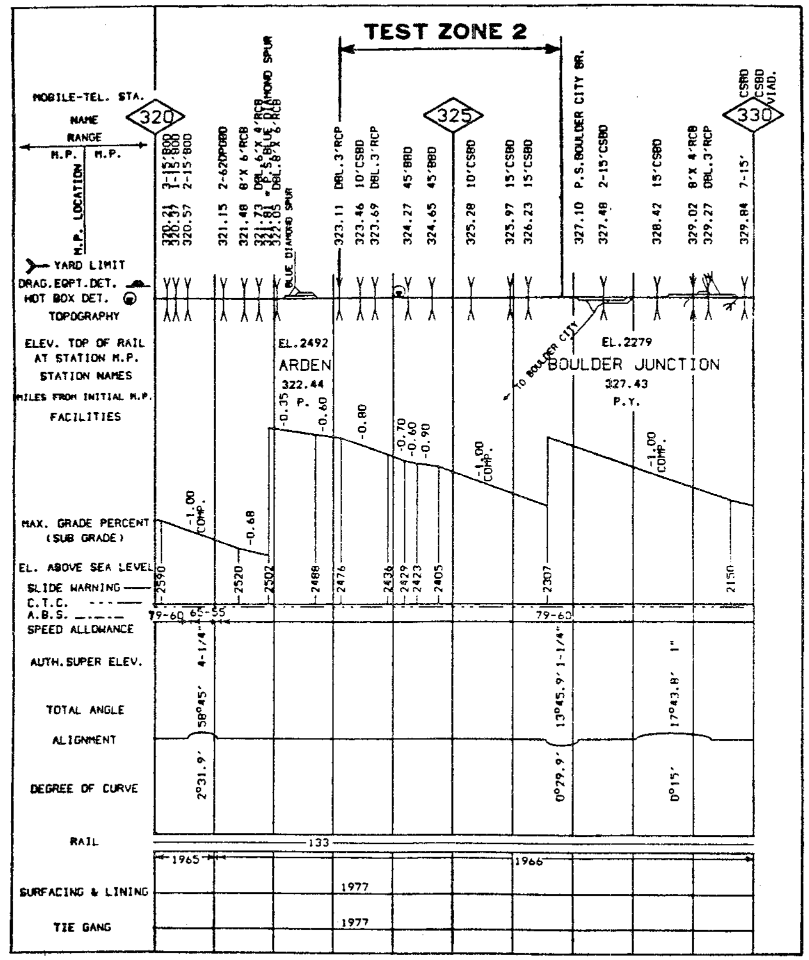


Figure 3-2. Track Profile - Test Zone 2

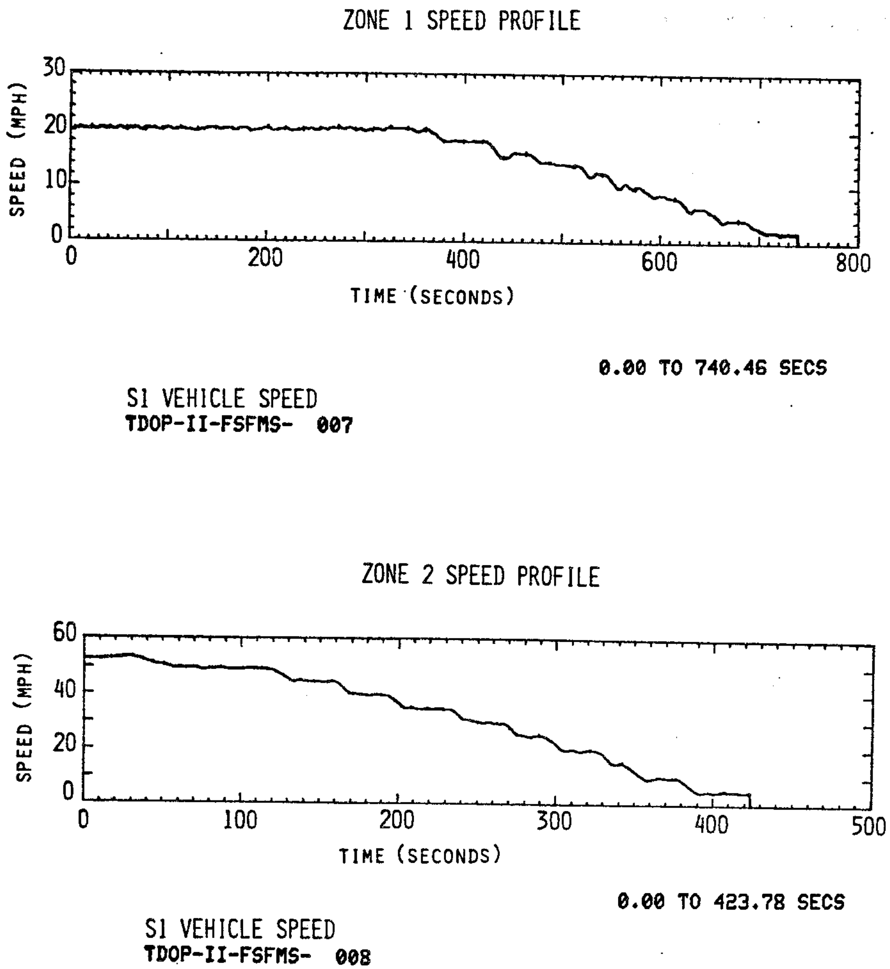


Figure 3-3. Typical Speed Profiles

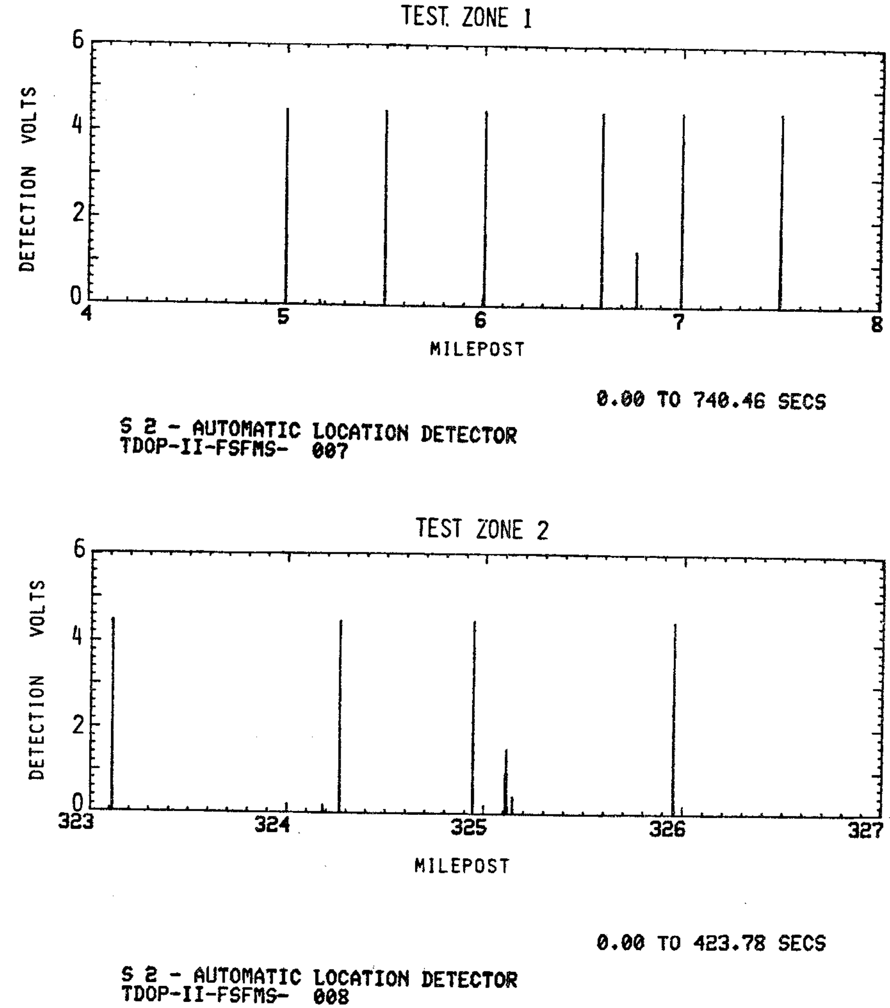


Figure 3-4. ALD Locations

Table 3-1. ALD Mileposts by Run Number

TEST ID	TDOP TAPE NUMBER	TRUCK	ZONE	LADING
TDOP-II-FSFMS-001	201	Barber	1	Empty
TDOP-II-FSFMS-002	201	Barber	2	Empty
TDOP-II-FSFMS-003	202	Barber	1	Half Loaded
TDOP-II-FSFMS-004	202	Barber	2	Half Loaded
TDOP-II-FSFMS-005	203	Barber	1	Loaded
TDOP-II-FSFMS-006	203	Barber	2	Loaded
TDOP-II-FSFMS-007	204	ASF	1	Empty
TDOP-II-FSFMS-008	204	ASF	2	Empty
TDOP-II-FSFMS-009	205	ASF	1	Half Loaded
TDOP-II-FSFMS-010	205	ASF	2	Half Loaded
TDOP-II-FSFMS-011	206	ASF	1	Loaded
TDOP-II-FSFMS-012	206	ASF	2	Loaded

Table 3-2. Test ID Matrix

ZONE 1						
Run No.	001	003	005	007	009	011
MP 5	5.000	5.000	5.000	5.000	5.000	5.000
MP 5.5	5.502	5.502	5.502	5.502	5.502	5.502
MP 6	6.000	6.001	6.000	6.000	6.000	6.001
MP 6.6	6.593	6.594	6.593	6.594	6.594	6.594
MP 7	7.000	7.000	7.000	7.000	7.000	7.000
MP 7.49	7.498	7.499	7.498	7.498	7.498	7.498

ZONE 2						
Run No.	002	004	006	008	010	012
MP 323.11	323.109	323.110	323.109	323.110	323.110	323.110
MP 324.27	323.268	324.268	324.259	324.268	324.268	324.268
MP 324.95	324.930	324.939	324.940	324.939	324.940	324.940
MP 325.97*				325.951	325.952	325.953

*ALD missing until it was replaced after run 006.

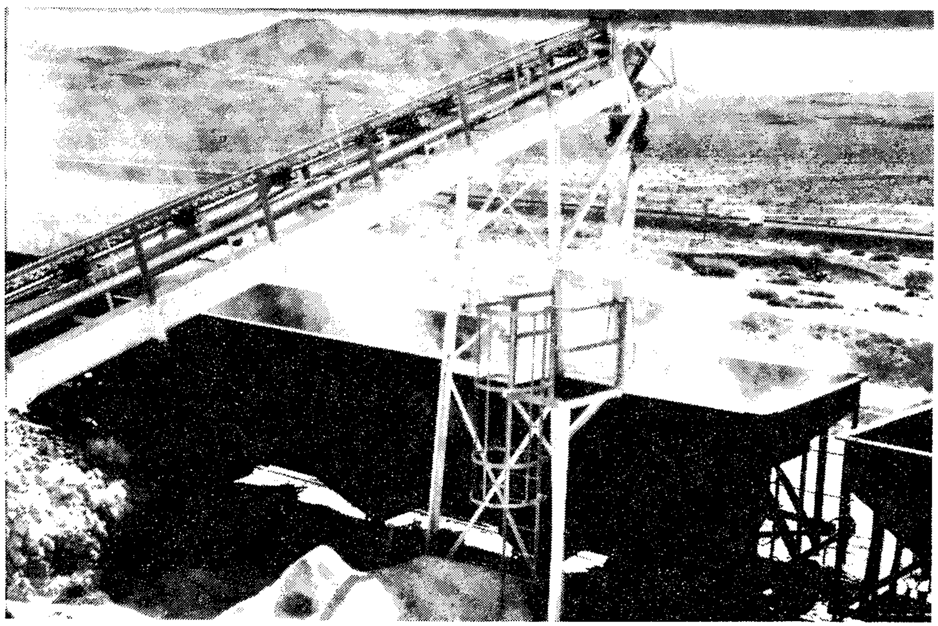
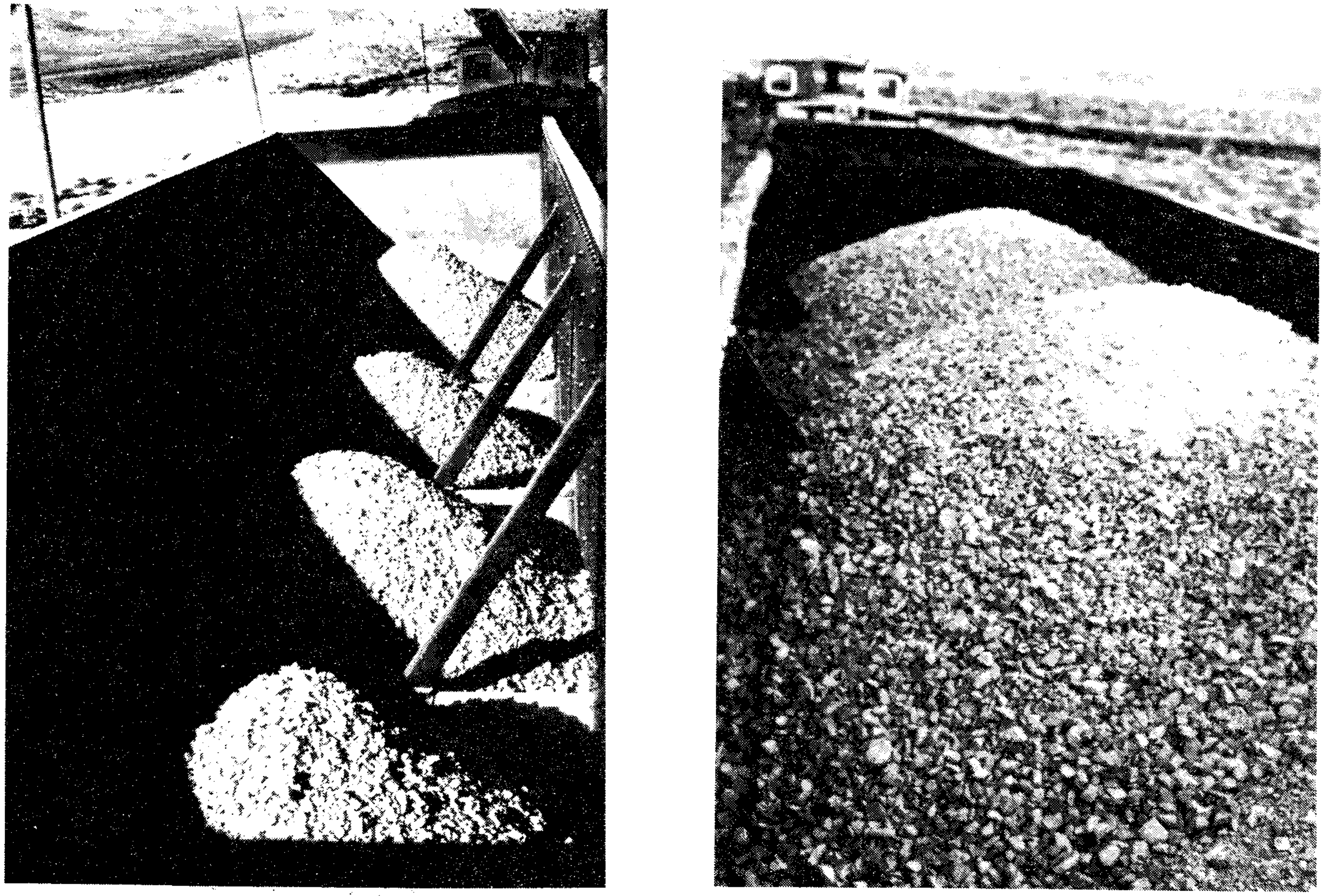


Figure 3-5. Loading Test Car

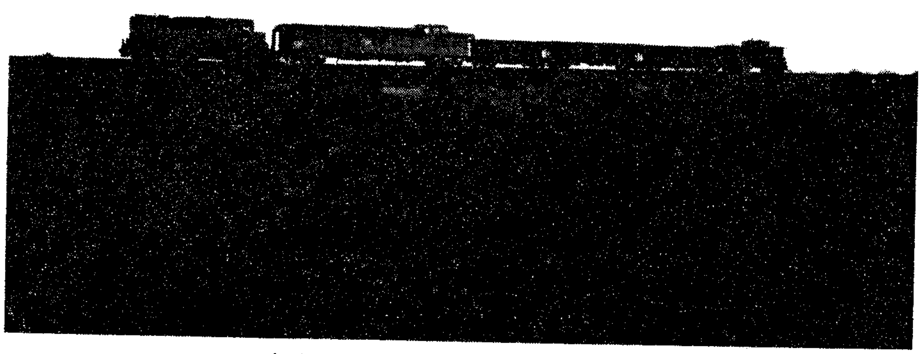


(A) HALF LOADED BARBER TEST CAR

(B) FULLY LOADED ASF TEST CAR

Figure 3-6. Typical Lading Conditions

(A) BARBER TRUCK TEST CONSIST



(B) ASF TRUCK TEST CONSIST

Figure 3-7. Test Train Consist

3.3 BARBER TRUCK TEST

The Barber truck test configuration was prepared for the first series of test runs. The instrumentation is described in paragraph 2.3. Preparation of the test car and checkout of instrumentation were performed between November 13 and 28, 1978. The first test run with an empty carbody and the Barber truck was conducted on November 29. Runs through both zones 1 and 2 were successful. At the end of the pass through zone 2, noise floor data were recorded for 60 seconds. This procedure is described in Section 5 (paragraph 5.5.1), where some sample plots of the data also are given. At the completion of the test pass through zone 2, a special test run was made through the zone in which various levels of braking force were applied to provide data for a future evaluation of the effects of brakes on the friction snubber operation.

The test car with the Barber truck was half loaded at the Sloan quarry on November 30, 1978. In a pretest calibration for the run through zone 1, measurement D7 signal conditioning was defective and this channel was lost. It was repaired the next morning, and since no analyses have been done to date which require this measurement for a half loaded vehicle, the test results have not been affected. Should this information become necessary, the roll rotation measurement on the other side frame should be sufficient. The first start through zone 1 missed the ALD at milepost 5.0, so the consist was backed up and started a second time. The data acquisition computer was stopped and restarted, therefore, test 003 starts at record 480. The pass through zone 2 resulted in excessive parity errors on tape; the pass was rerun successfully on December 1, 1978.

A fully loaded test run of the Barber truck was conducted on the afternoon of December 1, 1978. Review of the quick-look data from the first pass through zone 1 showed clipping of the lower normal forces. Therefore, the gains for all these channels were reduced by a factor of 2 and the test was repeated. The gains were left the same for the pass through zone 2. Rain hampered operations and some channels started showing questionable data toward the end of the run through zone 2. However, quick-look data indicated sufficient data were available to accept the test results.

3.4 ASF TRUCK TEST

The completion of instrumentation of the ASF truck was accomplished between December 2-5, 1978. Runs with the ASF truck and the empty carbody were made on December 6, 1978. Before the start of testing, signal conditioning to F17 was lost, so the amplifier was changed from A10 to F17 and the test was conducted without A10. Measurement A10 is an over-range acceleration measurement duplicating measurement A8. Since A8 provided the required information, the loss of A10 had no effect on the analysis of the test data. Test runs through zones 1 and 2 were successfully completed. As with the Barber truck, a special test run was conducted through zone 2 where the brakes were applied.

During checkout, the D15 transducer was found to be defective, so the remainder of the test was conducted without it. D15 is a measurement of the longitudinal displacement of the side frame relative to the bolster. This measurement did not involve any of the primary objectives of the test program; it was added to provide secondary information, if required. Quick-look data indicated little motion in this direction and the measurement being made on the other side (D16) will provide sufficient information. To date, the loss of this measurement has had no effect on data analysis. The half loaded test runs (009 and 010) through zones 1 and 2 were conducted successfully. At the completion of test run 010, noise floor data were recorded for 60 seconds.

The ASF test car then was fully loaded and prepared for the two final test runs on December 8, 1978. During pretest checkout, A/D channel 33 became defective. Measurement F18 on channel 33 was moved to channel 25 for the two final tests. Test run 011 was successfuly completed through zone 1. Quick-look data obtained through zone 2 (run 012) showed some data clipping. Gains on F2, F5, F7, F10, F12, F15, F17, and F20 were reduced by 2 and the test was rerun. Quick-look data were acceptable and the test program was completed.

SECTION 4 - DATA ACQUISITON

4.1 REAL-TIME AND QUICK-LOOK

Real-time and quick-look data were acquired for all test runs to provide an immediate review of data quality and to determine any requirements for retest.

Real-time data consisted of a brush recorder display of the analog time history of six selected channels. The signals from the signal conditioner were patched to the brush recorder to obtain this display. An example of a short section of this display is contained in Figure 4-1. It shows the start of test run 011. The ALD detection at the start of the zone at milepost 5.0 is shown. About half way through this plot, the brush recorder was speeded up which accounts for the change in time scale. This chart was monitored by the instrumentation engineer during the entire test to monitor data quality.

At the computer cathode ray tube (CRT), a real-time display of ALD detections was provided to verify the digital recording of the ALD. This display was summarized at the completion of the run as shown in Table 4-1, which also contains a summary of the data quality. The summary shows the total distance traveled, number of records recorded, test duration, and ALD detected. It also lists the number of samples or scans missed, and if any transfer records were missed (a transfer record consists of 42 scans).

The record count summary in Table 4-1 was used to locate the portions of the tape to be used for quick-look data reduction. The quick-look data display consisted of a strip chart of five seconds of data for each channel. An example of a partial display is shown in Figure 4-2. Usually, the quick-look display was done at the start of the run to verify ALD detection. Sometimes, a second quick-look display was made later in the run if there was any question about the data quality. If the review of this quick-look data was satisfactory, the run was considered acceptable.

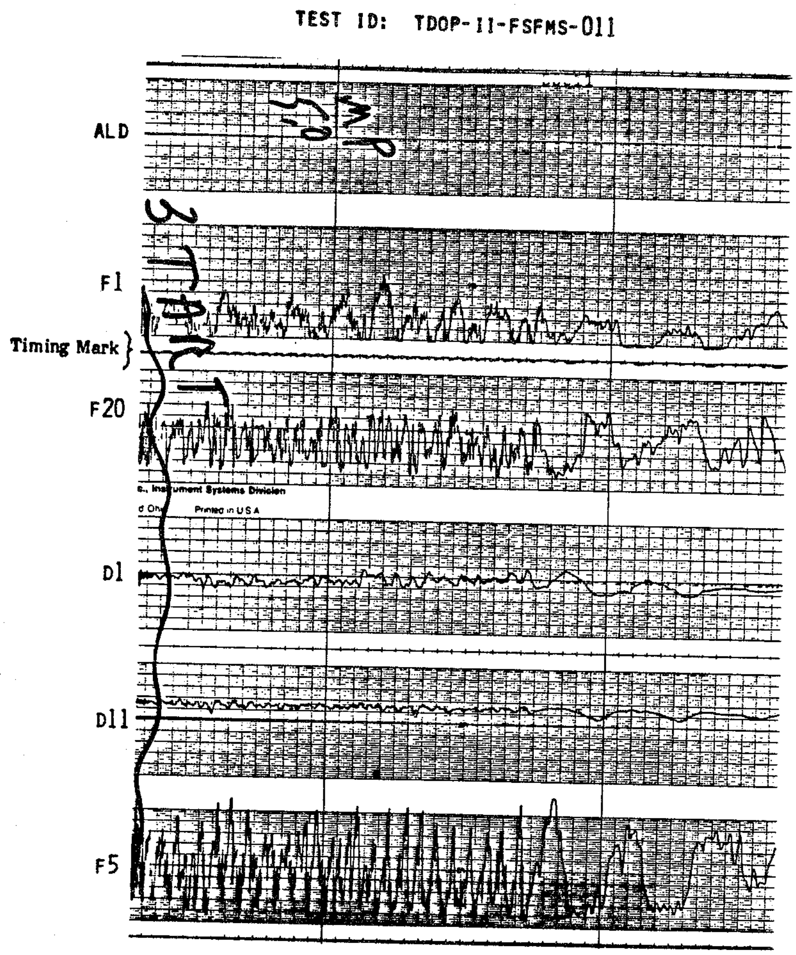


Figure 4-1. Typical Real-Time Data Display

Table 4-1. Quick-Look Tape Quality Display

TDOP-II-FSFMS-012

12/ 8/78 21:33

DISTANCE TRAVELED = 3.78 MILES

DATA RECORDS RECORDED = 1928

DURATION OF TEST WAS 6.7 MINUTES

TOTAL XFER REJ = 0

TOTAL ALD'S = 5

TOTAL SCANS MISSED = 4

ALD MP-MILEAGE.VELOC.REC COUNT

1	323.11	50.63	63
2	324.27	47.82	445
3	324.94	45.67	682
4	324.94	45.67	682
5	325.95	31.82	1145

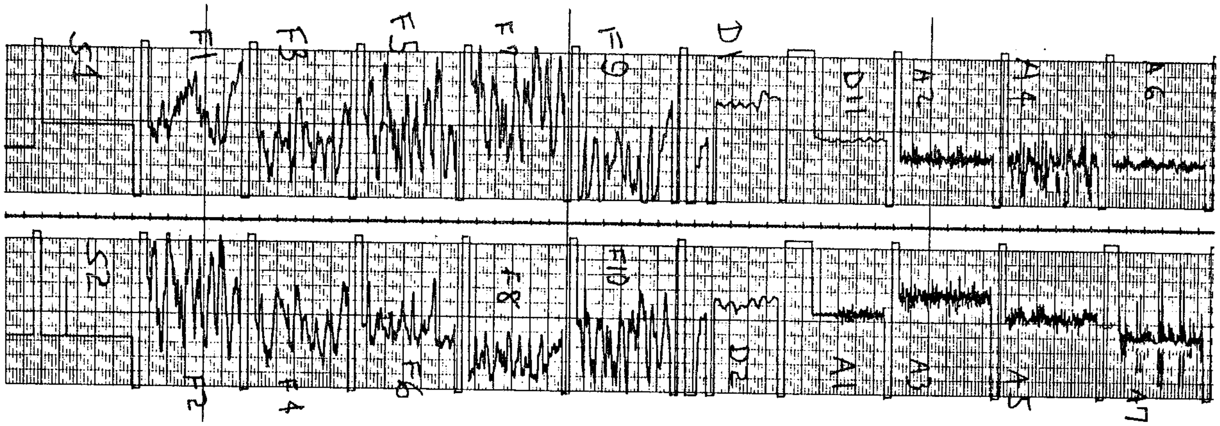


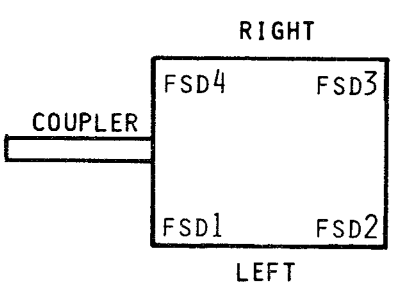
Figure 4-2. Partial Quick-Look Data Display

4.2 DATA REDUCTION

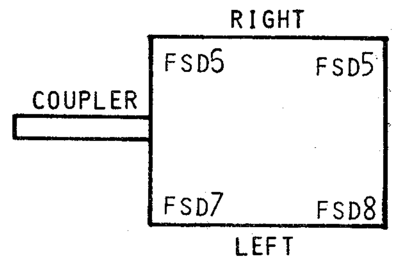
Based upon experience gained from running the test and a brief data review, data taken over five sections of track were chosen for reduction. These five sections are specified in Table 4-2 along with the rationale for choosing each section. Three sections of track were chosen from test zone 1 and two sections from test zone 2 for data reduction. For each test car configuration, data were taken in each of the five track sections for 20 to 50 seconds.

The first step in the data reduction was a quick-look display of the engineering data for each channel in the selected zone. For a trial case, test TDOP-II-FSFMS-011 was selected for data reduction. The time period selected was from 340 to 390 seconds. The reduced data for this run are shown in Appendix C.

The second step in the data reduction process was calculation of the data reduction parameters defined in reference 2. These are reproduced in Table 4-3 and consisted of friction shoe parameters, side frame/bolster relative motion, truck/carbody relative motion, and carbody accelerations. Table 2-7 lists the conversion from the measurement ID nomenclature to the A/D nomenclature used in the data reduction. There were eight friction snubber devices manufactured and calibrated for the friction snubber test program. They were mounted on the trucks in the following locations:

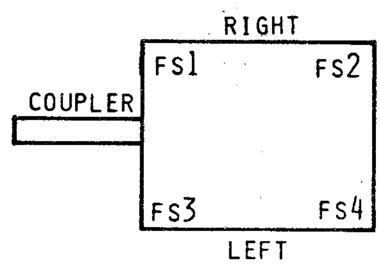


BARBER TRUCK



ASF TRUCK

For purposes of data reduction and analysis, each friction snubber position was assigned a designation as follows:



The diagram above shows a schematic of the B-end truck and the nomenclature for measurement references. The right- and left-hand side of the truck are noted on the diagram. The right forward friction snubber is denoted by FS1, right rear by FS2, etc. This nomenclature was used for both the Barber and ASF trucks so comparisons could be easily made between the trucks.

In order to compare plotted variables within and between runs, a consistent set of scales was used. For example, all forces were plotted on a scale of -4000 to 16,000 lb. To make the display of the data easier to read, the mean value was removed from all displacement measurements (both linear and rotational). The mean values for the car rigid body motions (linear and angular accelerations) were removed and filtered at 10 Hz.

Table 4-2. Selection of Data Reduction

TEST ZONE 1

Section 1: Milepost 5.50 to Milepost 5.78

This is a section of tangent, branch line track. A review of track geometry shows this section to have as high a crosslevel variation (+.3 inch) as any section in the test zone. The test data reviewed show the fully loaded hopper car to have experienced maximum roll excitation in this zone. The vehicle speed in this zone was approximately 20 mph.

Section 2: Milepost 6.6 to Milepost 6.88

This is a section of curved track with a high degree of curvature (7.5 degrees). A review of track geometry also shows it to have significant misalignment (+1.0 inch). Both trucks had difficulty in tracking through this curve and showed significant truck swivel rotation. The vehicle speed in this zone was approximately 20 mph.

Section 3: Milepost 6.86 to Milepost 7.14

This section of track consists of a very short curve, followed by a reverse curve. The initial curve is 7.5 degrees followed by a 3-degree curve. The 3-degree curve is relatively smooth with a significant variation in curvature going through. Both trucks were able to track fairly well through this curve. In this zone, the train began slowing down, going from 20 mph to 16 mph.

TEST ZONE 2

Section 4: Milepost 323.11 to Milepost 323.53

This section occurs at the beginning of the test zone with the consist moving at maximum test speed (approximately 50 mph). Immediately after milepost 323.11, the track geometry shows a significant misalignment (0.4 inches) and a variation in curvature which excited the body modes of a loaded hopper car.

Section 5: Milepost to be Determined

This section of data occurs at different milepost locations for each truck. The excitation in the roll direction will be reviewed for each vehicle configuration tested and the vehicle speed at which the largest amplitudes occur will be used for data reduction.

Table 4-3. Data Reduction Parameter Calculations*

Friction Shoe Parameters	
Normal (Column) Load (F_n)	$F_{un} + F_{\ell n}$
Lateral Friction Force (F_ℓ)	$F_{u\ell} + F_{\ell\ell}$
Vertical Friction Force (F_v)	F_v
Friction Coefficient	$\dfrac{\sqrt{(F_{u\ell} + F_{\ell\ell})^2 + F_v^2}}{(F_{un} + F_{\ell n})}$
Lateral Energy Dissipation (N time intervals)	$\sum_{i=0}^{N} \left\lvert \dfrac{F_{\ell i} + F_{\ell i+1}}{2} \right\rvert \cdot \lvert \Delta x_1 \rvert$
Vertical Energy Dissipation (N time intervals)	$\sum_{i=0}^{N} \left\lvert \dfrac{F_{vi} + F_{vi+1}}{2} \right\rvert \cdot \lvert \Delta y_i \rvert$
Side frame/Bolster Relative Motion (Right Side Frame)	
Lateral Displacement (Δx)	(D5 + D6)/2
Vertical Displacement (Δy)	(D1 + D2)/2
Pitch Rotation	(D1 - D2)/a
Yaw Rotation	(D6 - D5)/b
Roll Rotation	(D7 - D5)/d
Truck/ Carbody Relative Displacements	
Truck Swivel Angle	(D14 - D13)/e
Lateral Displacement	(D14 + D13)/2
Roll Angle	(D11 + D12)/2f
Carbody Acceleration	
Bounce	(A1 + A2)/2
Pitch	(A1 - A2)/L
Yaw	(A6 - A5)/L
Roll	(A3 - A1 + A4 - A2)/2g
Sway	(A6 + A5)/2

*See reference 2 for a complete definition of the variables given in this table.

SECTION 5 - DATA ANALYSIS AND RESULTS

5.1 FRICTION COEFFICIENTS

One of the major objectives established in the friction snubber test plan (reference 2) was to characterize the damping or energy dissipating capabilities of the two trucks. The procedure originally planned for accomplishing this objective was to calculate friction coefficient values with the following formula to obtain an average friction value for each truck.

$$\text{friction coefficient} = \frac{\sqrt{(F_{u\ell} + F_{\ell\ell})^2 + F_v^2}}{(F_{un} + F_{\ell n})}$$

where:

F_{un} = upper normal force measurement

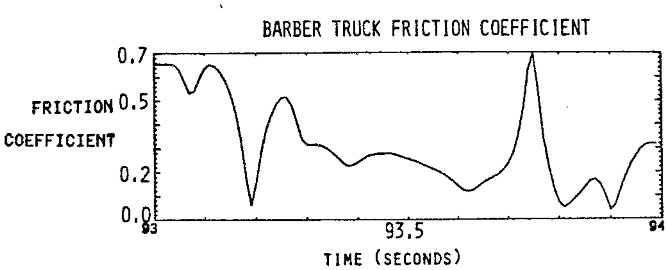
$F_{\ell n}$ = lower normal force measurement

$F_{u\ell}$ = upper lateral force measurement

$F_{\ell\ell}$ = lower lateral force measurement

F_v = vertical force measurement

The initial calculations using this procedure showed a large variation in values from one time to another. After plotting some of the friction values (typical coefficients are shown in Figure 5-1), it became obvious that alternative techniques needed to be developed. The plots in Figure 5-1 show the instantaneous values of friction coefficients to be varying from nearly 0 to almost 0.9. This is because the friction groups are not always in motion, so the plots contain both static and dynamic friction coefficients. The static coefficient may vary from zero (no friction force) to nearly twice the dynamic friction coefficients at the breakaway point. Thus, simply averaging instantaneous coefficient values is meaningless; for this reason, techniques were developed to select those coefficients associated with energy dissipation in the friction snubber.



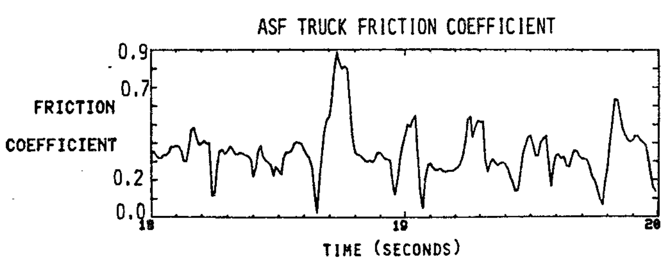


Figure 5-1. Typical Friction Coefficients

Because energy dissipation can only occur when there is relative motion between the friction shoe and the wear plate, the determination of the coefficient of sliding friction required selection of intervals from the data wherein the greatest amount of relative motion between side frame and bolster occurred. However, since the transducer structure is not quite as rigid as the unmodified column on which the wear plate is normally mounted, breakaway of the friction shoe sometimes appeared to result in an overshoot. As the motion of the friction shoe is not directly measured, but is assumed to be equal to the measured side frame displacement with respect to the bolster, the overshoot sometimes resulted in friction forces in the direction of side frame motion, rather than in the direction opposing it.

Thus, those segments from the record in which the friction force was clearly opposed to the side frame motion, as determined by the relative velocity, were selected. The product of friction force and velocity is the rate of energy dissipation (negative because the friction force opposes the motion in the analysis) or power, and the criterion for accepting a reading for determination of the coefficient of sliding friction was that the power should be less than -250 in-lb/sec.

A chart of cut-off values for power versus friction coefficients is shown in Table 5-1. The -250 in-lb/sec cut-off was chosen to make the positive and negative energy dissipation as nearly equal as possible. As an example, note the plots in Figure 5-2 of power level versus time. The area under this curve is energy. For FS1 in Figure 5-2 the area above the zero line gives 3070 in-lb and the area below zero gives -12170 in-lb. Thus the total energy is -9100 in-lb. The percent energy below the zero in-lb/sec line is:

$$\text{percent energy} = \frac{-12170 \text{ in-lb}}{-9100 \text{ in-lb}} = 133.7\%$$

If the cut-off is moved down to -250 in-lb/sec, the energy below this line is now -9680 in-lb and the percent energy is calculated:

$$\text{percent energy} = \frac{-9680 \text{ in-lb}}{-9100 \text{ in-lb}} = 106.3\%$$

(See the friction coefficient calculations for FS1 on the ASF truck in Appendix D.)

Thus the 100 percent energy line represents the point at which the positive and negative energy are the same. From Table 5-1, 100 percent energy occurs at the -250 in-lb/sec line, and hence was chosen for this analysis.

As shown in Table 5-1, the values for the friction coefficients tend to increase as the negative cut-off power decreases.

Because the maximum motions of the friction snubbers occurred in fully loaded cars, test runs 005 and 001 were selected for analysis, using data from a section of tangent track in test zone 1, between mileposts 5.52 and 5.80.

Plots of the rate of energy dissipation are shown in Figures 5-2 and 5-3 for the ASF and Barber trucks, respectively. They clearly show that this rate is predominantly negative, i.e., the overshoot accounts for a small part of the measured behavior of the friction shoes.

The results of the analytical effort that selected snubbing regimes according to the criterion given above are contained in Appendix D. The calculations of friction coefficients, also included in Appendix D, give average sliding friction coefficients of 0.33 (0.31 - 0.36) for the Barber truck, and 0.43 (0.37 - 0.49) for the ASF truck.

The shop tests of the instrumented trucks, documented in reference 1, were primarily intended to assure the proper functioning of the transducers assembled on the modifed trucks. No extensive data reduction was performed on the test results, and only spot checks were made to determine friction coefficients. For the Barber trucks, the value given in reference 1 is 0.24, although other values between 0.04 and 0.35 were noted. For the ASF truck, the coefficient given in reference 1 is 0.42, which agrees more closely with that determined from the results of the road tests.

Table 5-1. Friction Coefficient vs Power (ASF Truck)

	FS1		FS2		FS3		FS4	
Power Less Than	Friction Coeff.	Percent Energy*	Friction Coeff.	Percent Energy*	Friction Coeff.	Percent Energy*	Friction Coeff.	Percent Energy*
-250 in-lb/sec	.46	106.3	.37	81.1	.41	102.1	.49	105.5
-500 in-lb/sec	.49	84.5	.40	49.1	.41	72.2	.43	62.8
-1000 in-lb/sec	.51	56.5	.42	20.4	.39	30.6	.41	23.8

Percent Energy = energy from "power less than" value indicated / total energy (positive energy - negative energy)

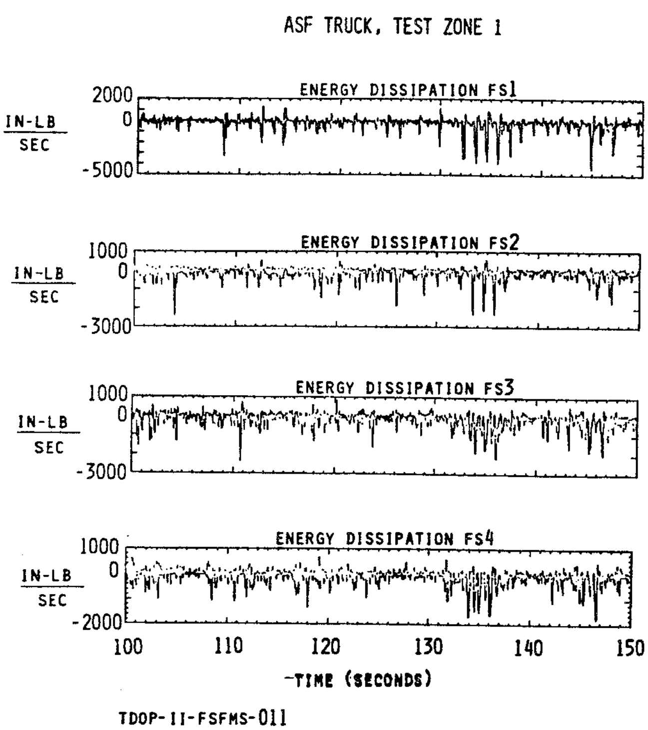


Figure 5-2. ASF Truck Energy Dissipation

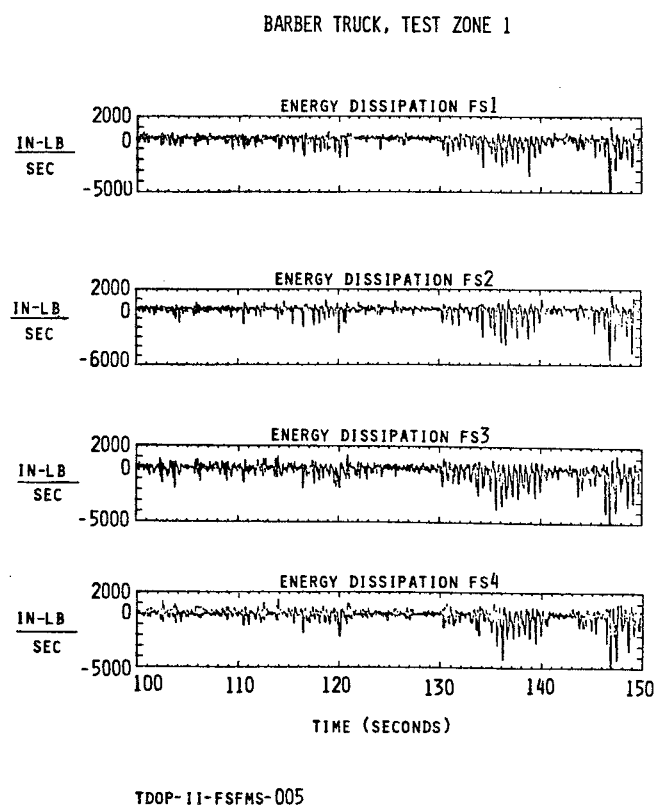


Figure 5-3. Barber Truck Energy Dissipation

5.2 FRICTION FORCES vs TRUCK MOTION

Five force measurements (two normal, two lateral, and vertical) were made in each friction snubber group. The two normal and the two lateral forces were combined and values of force in each of the three directions were plotted. This is shown in Figure 5-4 for the three forces in friction snubber FS2. The normal force has an offset value due to the preload, while the lateral and vertical force both oscillate about zero. Figure 5-4 shows FS2 for the empty car with the Barber truck. For contrast, plots for the loaded car with the Barber truck are shown in Figure 5-5. Again, the normal force shows an offset and the lateral and vertical forces oscillate about zero. A big change in the magnitudes of the peak values occurs from the empty car to the loaded car configuration.

A comparison of the normal forces between the Barber and ASF trucks is shown in Figure 5-6. Note that the heavier car results in a greater variation (oscillation) of the force values than the empty car configuration. In the loaded car, there is a greater oscillation of the normal force about the mean than in the empty car. As expected from the differences in the method of loading the friction shoes, the normal force in the ASF truck stays constant with car weight, while it increases with weight in the Barber truck. Table 5-2 illustrates this point where the approximate mean normal force for each friction snubber group is listed versus loading condition.

During the data analysis, it was discovered that measurement F16 was giving much higher than expected levels during the loaded runs on the Barber truck. This is readily apparent in Table 5-2 where the mean normal for FS4 is significantly higher than any of the others. It was probably caused by the strain gage getting wet in the rain during the loaded test. This high normal force resulted in unrealistically low friction forces and for this reason FS4 on the Barber truck was not included in the friction coefficient analysis in Appendix D. However, this loss is not deemed critical to the data analysis because the information provided from the other three transducers was sufficient to characterize the friction coefficient for the Barber truck. Other than the loss of the transducer, no effect of the rain on the test results has been observed in the analysis.

The correlation of the friction snubber forces with relative motions between side frame and bolster is illustrated in Figure 5-7. The one motion which most strongly correlates with the normal force is the vertical displacement in the spring group. The strong increase in normal forces at about 16 seconds correlates with a sudden increase in tram angle. However, changes in tram angle do not result in any appreciable correlation with the friction snubber forces in other parts of the record. The lateral displacement and pitch of the side frame show almost no correlation with the normal forces.

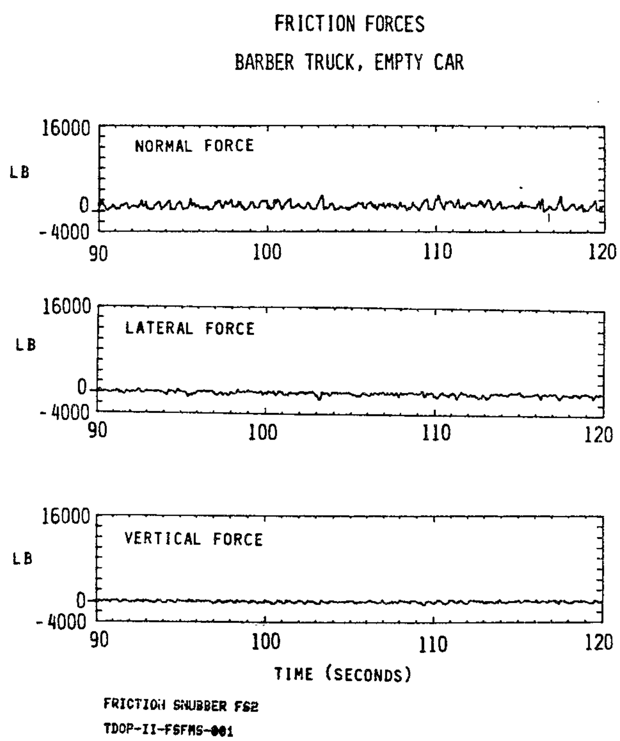


Figure 5-4. Friction Snubber Forces(Empty Car)

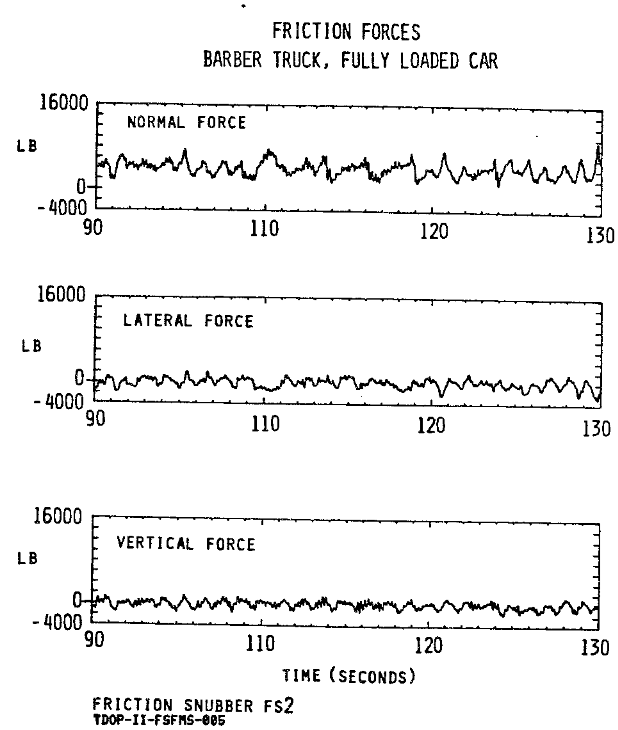


Figure 5-5. Friction Snubber Forces(Loaded Car)

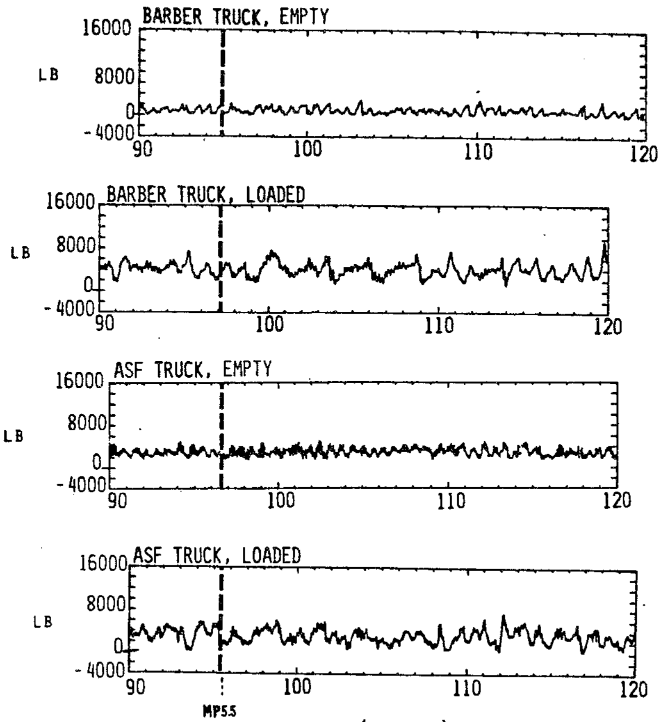


Figure 5-6. Comparison of Normal Forces in Barber and ASF Trucks

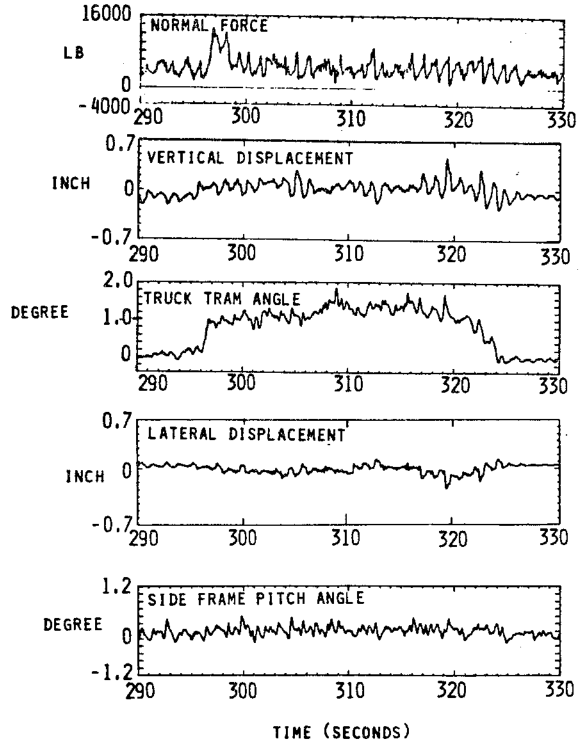


Figure 5-7. Friction Force vs Relative Motion

Table 5-2. Mean Normal Force

TEST ZONE 1

MP 5.48 - 5.64

		Force (lb)			
		FS 1	FS 2	FS 3	FS 4
Barber Truck	Empty	1500	1000	2000	1900
	Half Loaded	2600	3000	3000	2900
	Loaded	3800	4000	3900	5800
ASF Truck	Empty	3000	3000	2900	1800
	Half Loaded	3100	3900	3000	1900
	Loaded	4000	3500	2800	1800

5.3 CENTER PLATE RESISTANCE TO MOTION

A preliminary review of data acquired during the FSFMS field test indicates that information on truck kinematics may be extracted, in addition to data on snubber friction discussed in paragraph 5.1. One analysis planned uses numerical methods to extract information from the data regarding center plate friction and torsional spring rate of the bolster/side frame connection. The measurements to be used in this analysis are:

- Rotation of bolster with respect to carbody
- Rotation of side frames with respect to bolster
- Normal loads on side frame columns
- Friction couple resisting relative rotation of the side frame and bolster

In order to reduce the problem to its simplest form, dynamic effects are neglected, thus reducing the regime to statics and kinematics. Figure 5-8 shows the system under consideration.

Over a short interval, all physical constants (such as K_t) may be assumed to remain constant. Disregarding, for the time being, any difference between static and kinetic friction, the equation of static equilibrium is:

$$2K_t\theta + bF_n = aF_\ell + \mu W\bar{r} = 0 \qquad \text{(Eq. 1)}$$

The friction torque at the center plate is:

$$T_f = \frac{W}{A} \int_0^r 2\pi\rho \bullet \rho d\rho = \frac{W}{\pi r^2} \bullet \frac{2\pi r^3}{3} = \frac{2}{3} W\bar{r}$$

$$\text{Thus } \bar{r} = \frac{2}{3} r \qquad \text{(Eq. 2)}$$

Equation 1 contains two unknowns, K_t and μ. However, as the tests were run with both loaded and empty cars, the value of F_n depends upon W, as clearly evident in the test data. Thus, if two segments of the test data with equal side frame deflections are selected, one for the loaded and one for the empty car, two equations of the form (1) may be solved simultaneously for K_t and μ, assuming that the coefficient of friction is independent from the normal load on the center plate. Repeating these calculations for different values of side frame rotation, θ gives an indication of the extent of nonlinearity in the side frame/bolster torsional spring rate.

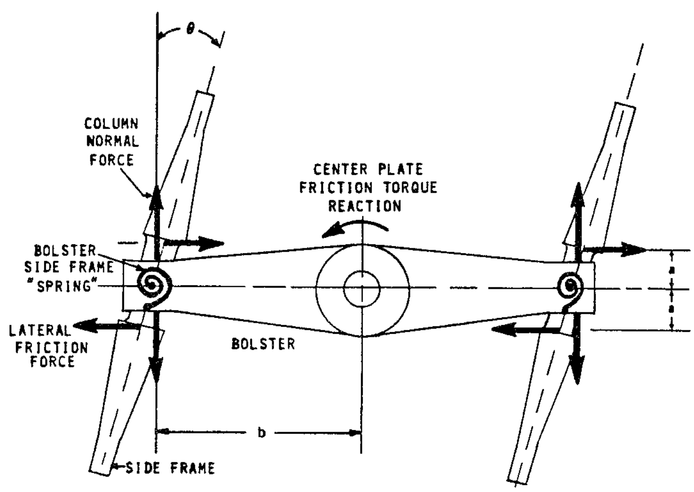
If calculations for the same conditions show appreciable scatter in the values of the unknowns, the least-squares method may be used to determine best-fit values.

The largest values of the normal column loads are likely to be found during curve entry and exit, where the highest side frame and bolster rotations also occur. The computation may be simplified by the fact that rotations of the bolster and side frames usually occur out of phase, as evident in test records for Phase I of TDOP.

Let W = weight on center plate

r = radius of center plate

$\bar{r}$ = friction radius of center plate



μ = coefficient of friction of center plate

K_t = torsional spring rate of side frame-bolster connection (not necessarily linear)

θ = angular deflection of side frame with respect to bolster

ψ = angular deflection of bolster with respect to car body

b = offset of side frame with respect to truck center

F_n = sum of normal forces on columns

F_l = sum of lateral friction forces at wear plates

a = offset of wear plate from center line of truck

p = unit bearing pressure on center plate

Figure 5-8. Definition Sketch of Forces Acting against Center Plate Friction Torque

5.4 RIDE QUALITY

A limited measure of the ride quality of the two trucks for different load conditions was made by comparing the vertical accelerations of the various configurations. This study was conducted only over one section of track in test zone 1 and at only one speed (20 mph). Comparisons between the Barber and ASF truck are shown in Figures 5-9 and 5-10, respectively. Three load conditions are shown for each truck (empty, half loaded, and loaded). In all cases, the acceleration levels were low (less than 0.05 G). Little difference was seen between the two trucks; all accelerations were slightly lower for the loaded than the unloaded condition.

As discussed in Section 6.2, additional information could be extracted which would also characterize ride quality as a function of speed and track condition.

5.5 DATA QUALITY DISCUSSION

5.5.1 Noise Floor

The test procedure called for the recording of 60 seconds of quiescent or noise floor data at the completion of one run of both the Barber and ASF trucks to insure that the signal level of the test data was greater than the noise floor. Examples of calculated parameters using data from these recordings are shown in Figures 5-11 to 5-14. Figure 5-11 shows calculations for the three force components on FS1. The normal force shows a static offset, as expected, and there is no noise visible in the data. Figure 5-12 shows no noise in the displacement calculations. The rotation and car rigid body accelerations in Figures 5-13 and 5-14 show a very small amount of noise; however, when these levels are compared with the measured responses (see Appendix C for examples), they are insignificant.

All the other noise data reduced for the FSFMS test showed similar levels. We concluded that any noise in the data is too small to be consequential in the analyzed data.

5.5.2 Track Geometry Correlation

A comparison of the truck/carbody rotation angle (Figure 5-15A) measured during the FSFMS test, and the track curvature (Figure 5-15B) measured during the FRA track survey shows excellent agreement. The plots in Figure 5-15 are from milepost 5 to milepost 8 and show the entire test run for the FSFMS test zone 1. A comparison of the track curvature measurements in Figure 5-15 and the track profile in Figure 3-1 shows the curves to agree exactly, with the exception of the second right hand curve, which the profile data list as a five-degree curve but the track survey shows it to be an eight-degree curve.

The truck follows the curvature of the track very well through the curve. Almost all of the truck center plate rotation is caused by the track geometry. However, in the tangent sections, the truck shows a significant amount of rotation not associated with the track input.

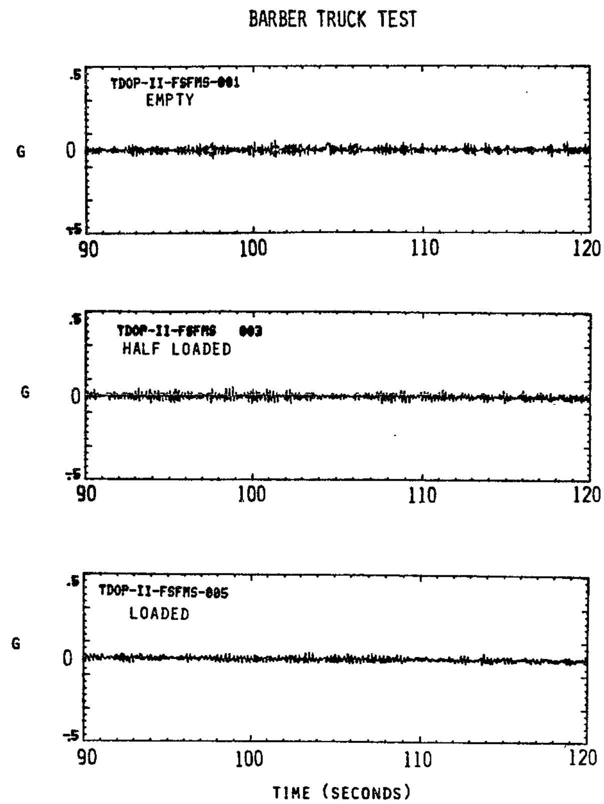


Figure 5-9. Carbody Bounce Acceleration (Barber Truck)

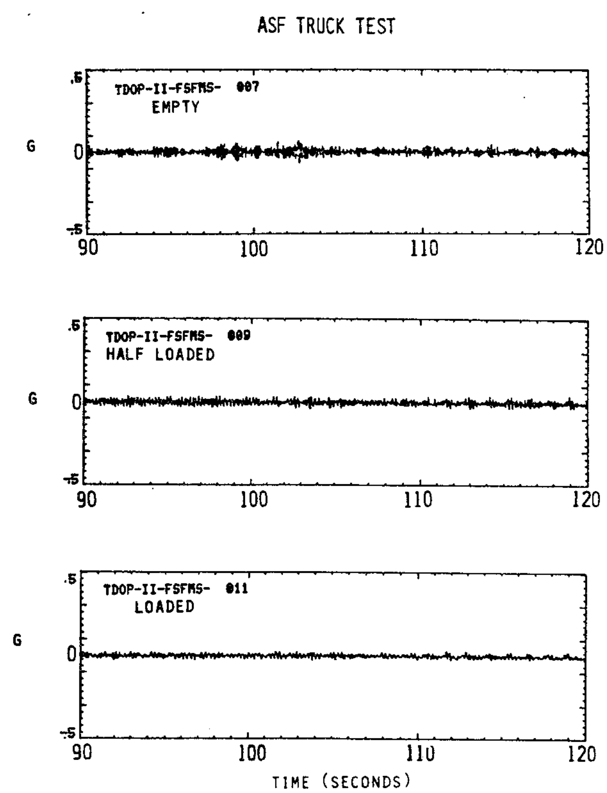


Figure 5-10. Carbody Bounce Acceleration (ASF Truck)

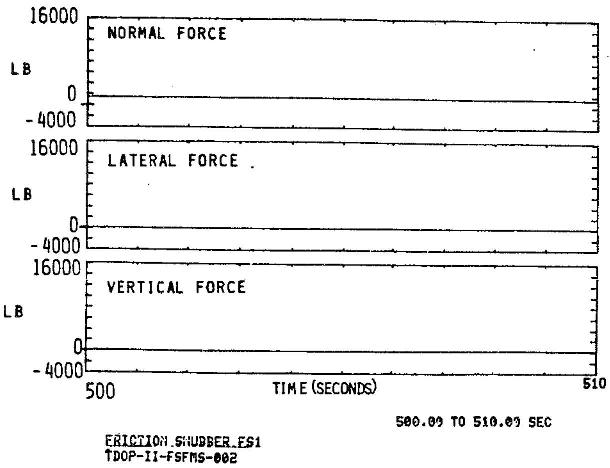


Figure 5-11. Noise Floor for Force Measurements

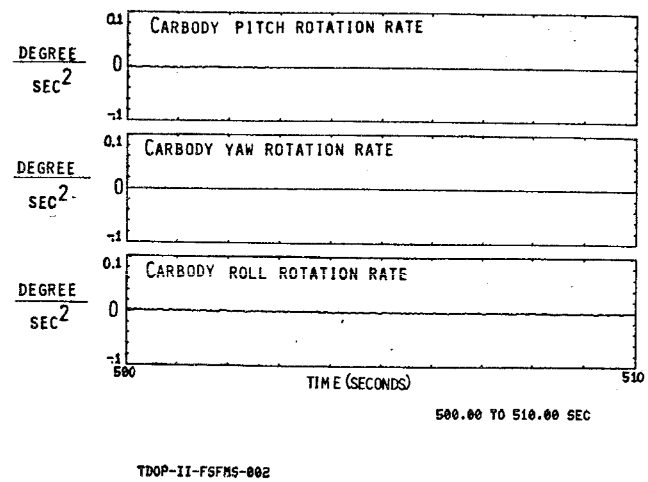


Figure 5-14. Noise Floor for Acceleration Measurements

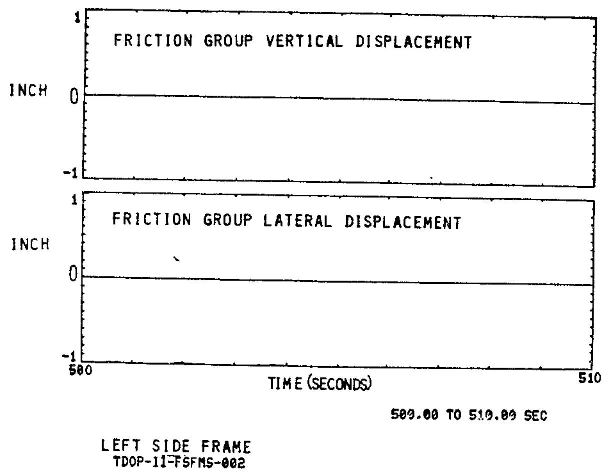


Figure 5-12. Noise Floor for Displacement Measurements

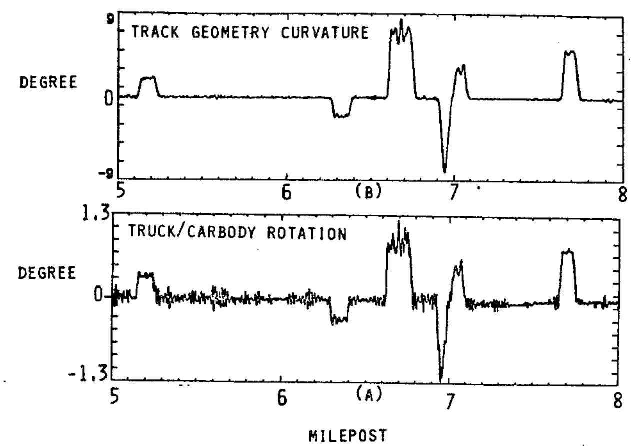


Figure 5-15. Comparison of Track Geometry Curvature and Truck/Carbody Rotation

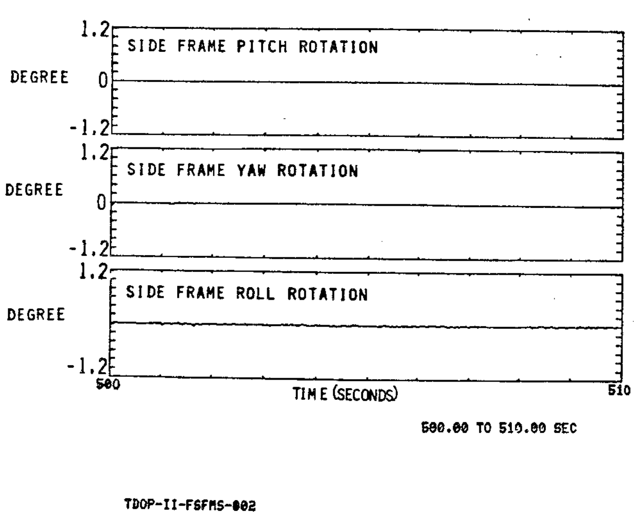


Figure 5-13. Noise Floor for Rotation Measurements

5.5.3 Rail Joint Input

Accelerometers were placed at the center of the right and left side frames to measure vertical track input. These two acceleration measurements are plotted in Figure 5-16 for the empty Barber truck and for the half loaded ASF truck. A comparison of these two plots shows a great deal of repeatability in the vertical track input between runs. A comparison made between all test runs over this section shows the same degree of repeatability. The distance between the pair of impulses in Figure 5-16 is 68 inches, which corresponds to the wheel base on both the Barber and ASF trucks. The impulse pairs occur because the rail joint sends a transient up through each wheel as it crosses a joint.

The rail profile data taken from the FRA track survey for the same section of track are shown in Figure 5-17. The large negative impulses in the profile data show where a rail joint occurs. The more severe a rail joint was, the larger the impulse. These rail joint locations obtained from the FRA track survey are superimposed on Figure 5-16 (plots from FSFMS test) as dashed lines. In each case they occur at almost exactly the center of the impulse pairs in Figure 5-16, thus showing excellent correlation between the track geometry and FSFMS test data. The spacing between the impulses in Figure 5-17 shows the joint spacing to be less than the standard 39-foot rail joint spacing, which means that this section of branch track was probably built with used rail with the ends cut off. This caused non-uniform excitation from the rail joints.

The ALD sensor is shown in Figures 5-16 and 5-17 at different locations in the track geometry and the FSFMS test data because the sensor was not at the data collecting location of the consist in either tests. For the track geometry, the ALD sensor was six feet behind the location where the track geometry was taken. For the FSFMS test, the ALD sensor was on laboratory car 210, 83 feet ahead of the B-end truck center line. Thus, the milepost figure for both runs was corrected to take this into account, and the resultant separation of the ALD signals between Figures 5-16 and 5-17 is 89 ft (83 ft + 6 ft). This means that the data locations correspond exactly.

5.5.4 Truck/Carbody Motion

5.5.4.1 Side Frame Lateral Displacement. Measurements were made on both side frames of the relative lateral motion between the side frame and bolster. A typical comparison of these two measurements is made in Figures 5-18 and 5-19 for the Barber and ASF trucks, respectively. These figures show that the lateral motion of one side frame relative to the bolster is identical to the motion of the other side frame to the bolster. Thus, only one measurement of side frame/bolster motion is required.

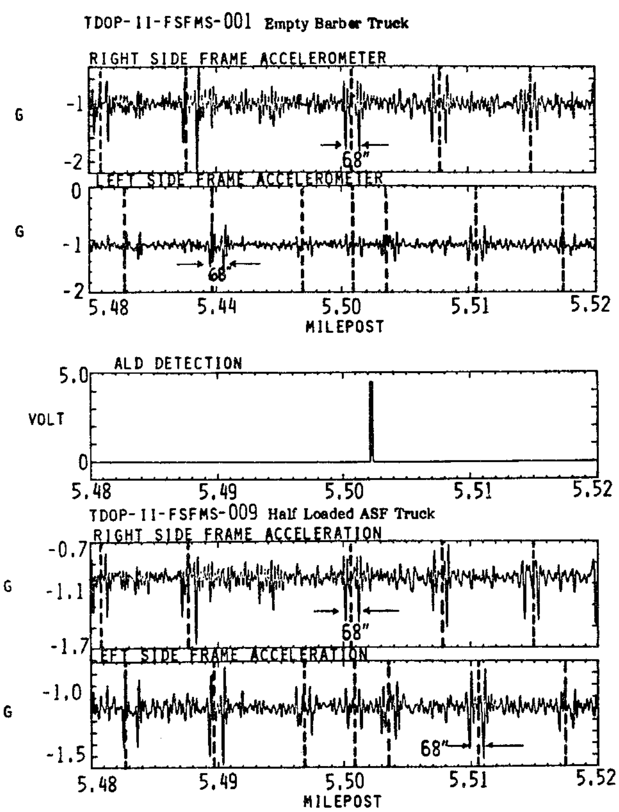


Figure 5-16. Vertical Track Input on Side Frames

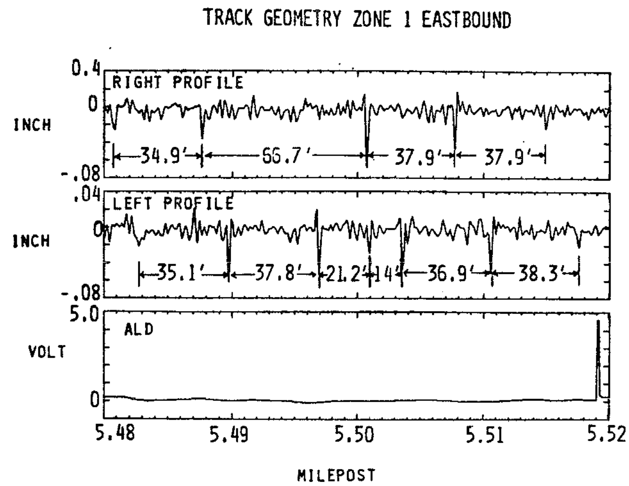


Figure 5-17. Track Geometry Rail Profile

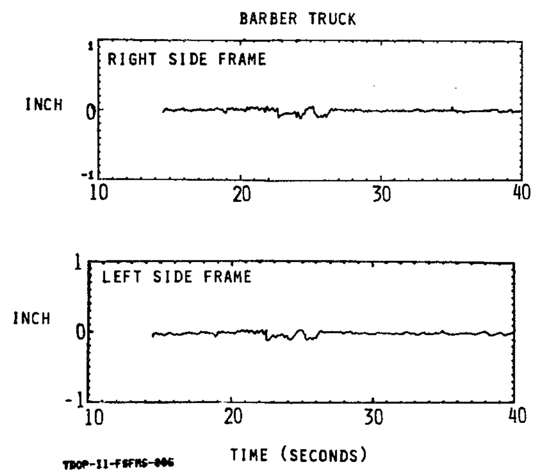


Figure 5-18. Relative Lateral Displacement (Barber Truck Side Frames)

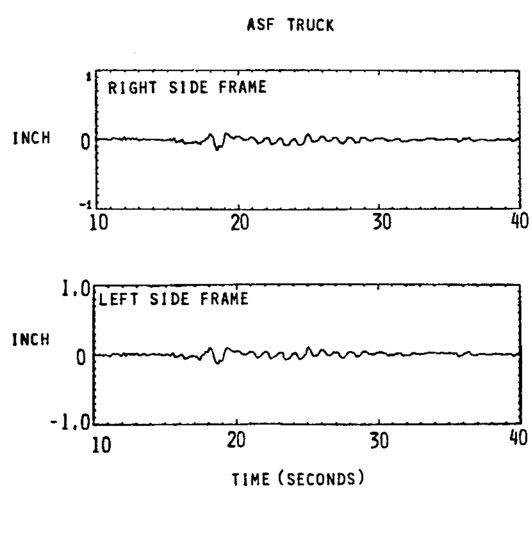


Figure 5-19. Relative Lateral Displacement (ASF Truck Side Frames)

5.5.4.2 Side Frame Pitch Rotation. The pitch degree of freedom of the right side frame is plotted in Figure 5-20 and the left side frame in Figure 5-21. Each figure shows several plots covering both trucks and two load conditions. From these plots, one may see that the pitch motion of the side frame varies little from run to run for a given side of the truck. The pitch motion of the two side frames are independent of each other, but closely follow the track profile.

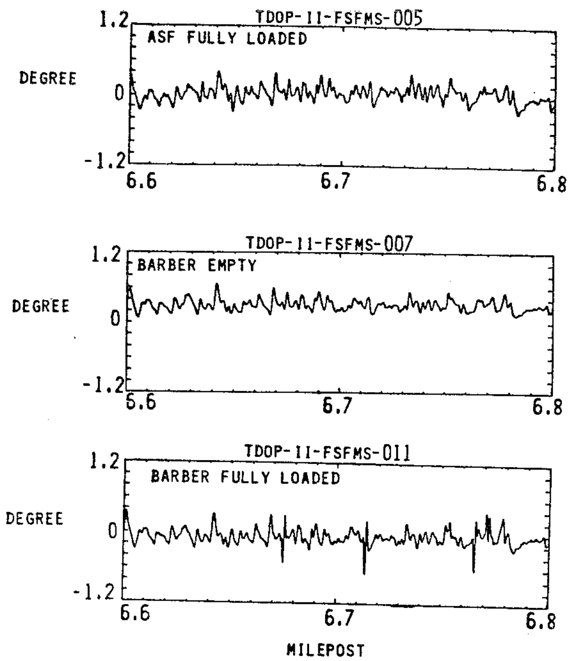


Figure 5-20. Right Side Frame Pitch Rotation

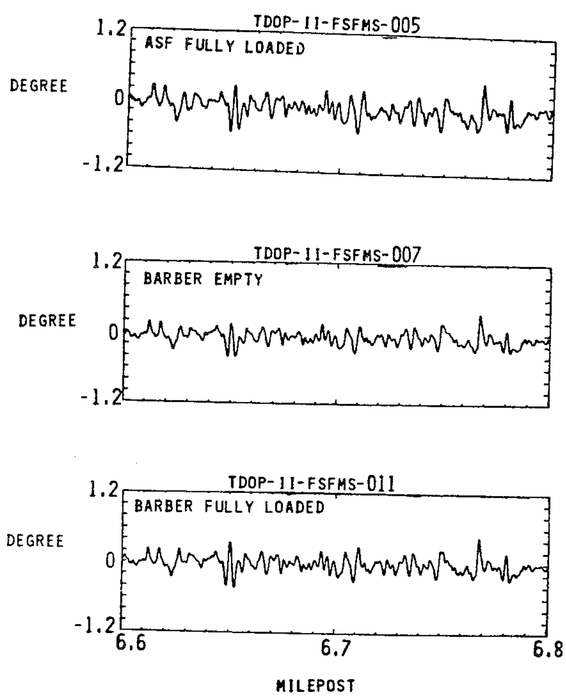


Figure 5-21. Left Side Frame Pitch Rotation

5.5.4.3 Side Frame Yaw Rotation. The side frame yaw rotations (or tram angle) of the two side frames are very closely related to each other. This may be seen in Figures 5-22 and 5-23 where these rotations are plotted for the Barber and ASF trucks, respectively. The yaw rotations of the two side frames are nearly the same from one side frame to the other. These plots are typical of the relationship between yaw rotation measurements on all runs. Thus, it is not necessary to make test measurements of the yaw rotations on both side frames.

5.6 CARBODY ROLL EXCITATION

Displacement measurements were made between the carbody and truck bolsters and across the truck spring group. By combining these two measurements, the total carbody roll response was obtained. This is shown in Figure 5-24 where the first two curves are added to obtain the third curve, which is total carbody roll angle.

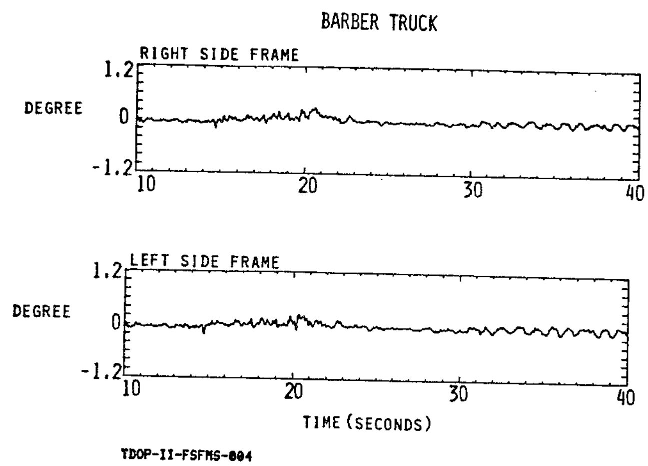


Figure 5-22. Side Frame Yaw Rotation, Barber Truck

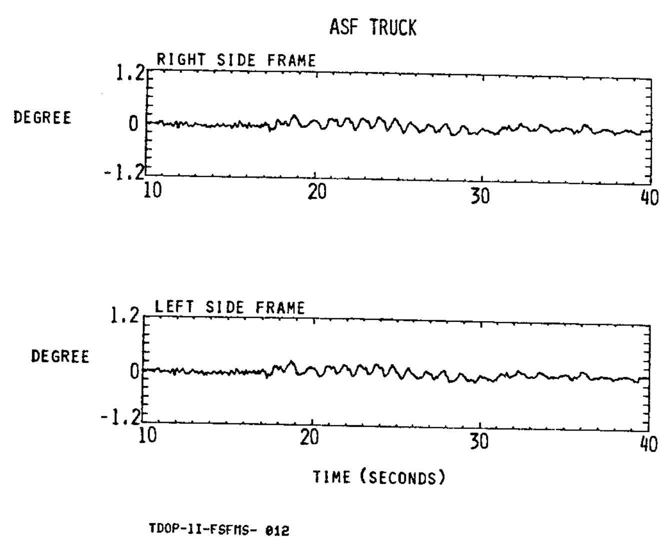


Figure 5-23. Side Frame Yaw Rotation, ASF Truck

The fourth curve is the carbody roll **acceleration** measured by the accelerometers on the carbody. The roll accelerations should be 180 degrees out-of-phase with the displacement, as shown by the curves. Figure 5-24 shows displacements for an empty Barber truck. When the truck is loaded, the roll excitation appears as shown in Figure 5-25. The frequency of the oscillation is lower and there is more motion in the spring group.

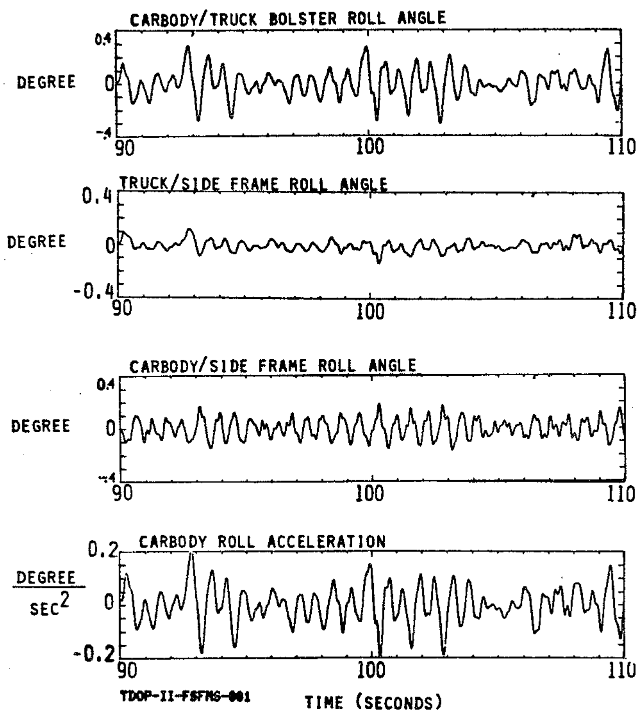


Figure 5-24. Empty Barber Truck Test, Carbody Roll

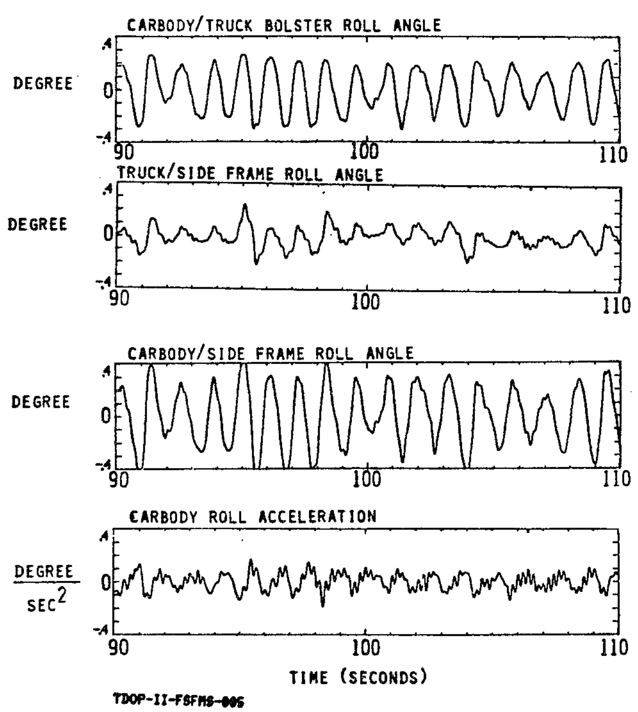


Figure 5-25. Loaded Barber Truck Test, Carbody Roll

Similiar curves for the ASF truck are shown in Figures 5-26 and 5-27. The amplitudes of spring group motion are somewhat smaller for the ASF truck.

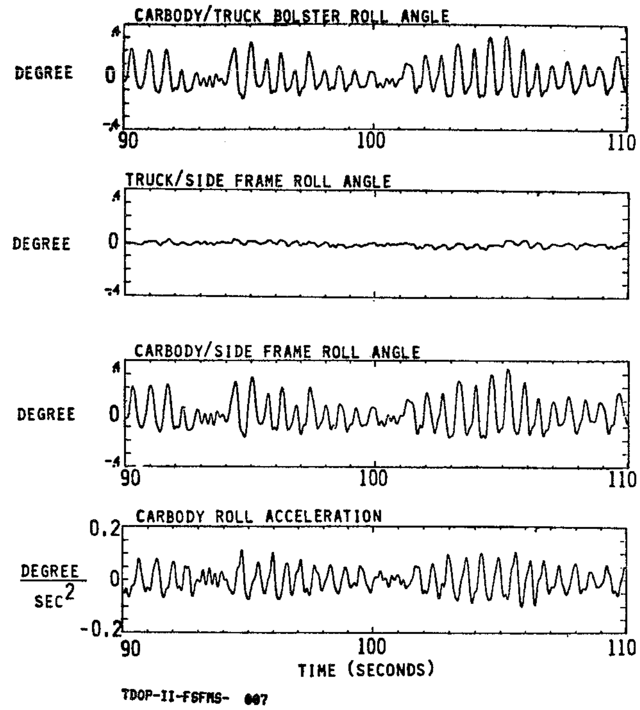


Figure 5-26. Empty ASF Truck Test, Carbody Roll

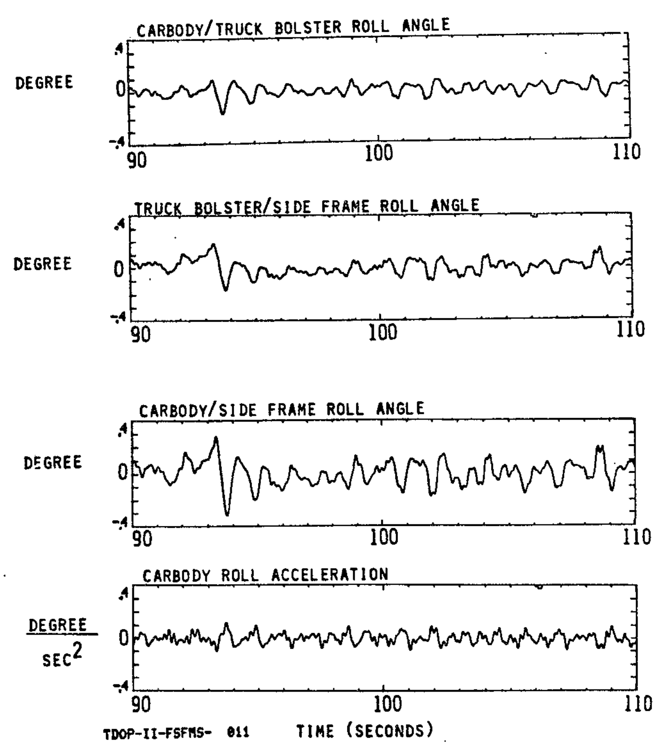


Figure 5-27. Loaded ASF Truck Test, Carbody Roll

A comparison of the total roll angle for all four of the configurations previously discussed is contained in Figure 5-28. The four plots correspond to exactly the same section of track (milepost 5.46 to milepost 5.58). There is some similarity in the trends of the curves, e.g., at milepost 5.485 all of them experience a sharp increase in oscillation. However, the curves are far from identical, thus showing that each configuration responds in a different manner. The frequency of the oscillation decreases from the empty (approximately 1.55 Hz) to the fully loaded (approximately .9 Hz), with the Barber truck always having a slightly lower frequency than the ASF truck.

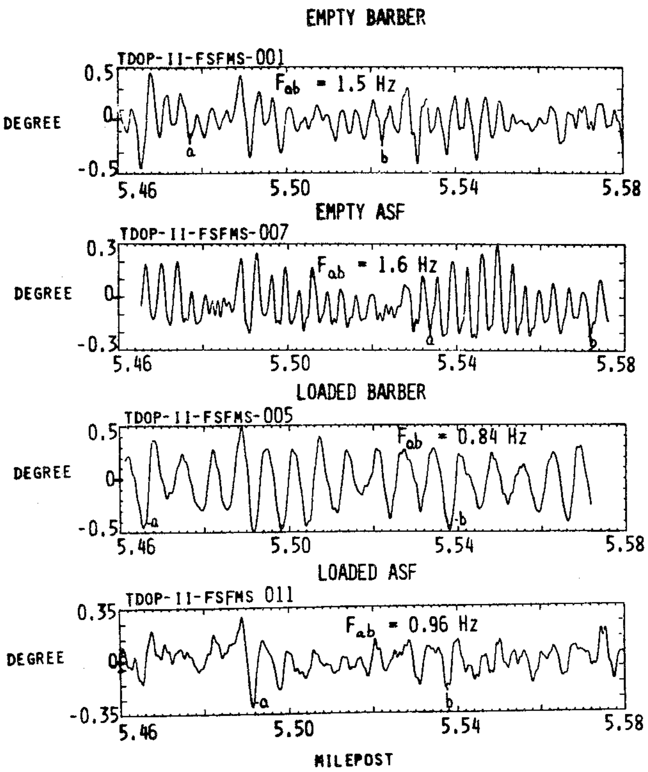


Figure 5-28. Carbody to Bolster Roll Angle

The track geometry net profile and crosslevel are shown in Figure 5-29 for the same section of track as in the previous figure. The net profile is the left profile (space curve) minus the right profile (space curve). The profile space curves are calculated based on a 62-foot length of cord. Attempts to visually correlate track geometry and carbody roll response were not successful. Therefore, plans are being made to use an analytical model in which to enter the track geometry. Then the analytical and measured responses may be compared.

5.7 TRACK GEOMETRY MEASUREMENTS

ENSCO, Inc., under contract to the FRA, measured the track geometry (reference 4) before starting FSFMS testing so that the response measurements made on test vehicles could be correlated with a known track input. The first set of measurements was taken during the first week in November 1978, using the T-6 track geometry survey car. The Wyle-developed ALD system was used during the initial track survey. A plot of the ALD signals in zone 1 is shown in Figure 5-30 with the ALD

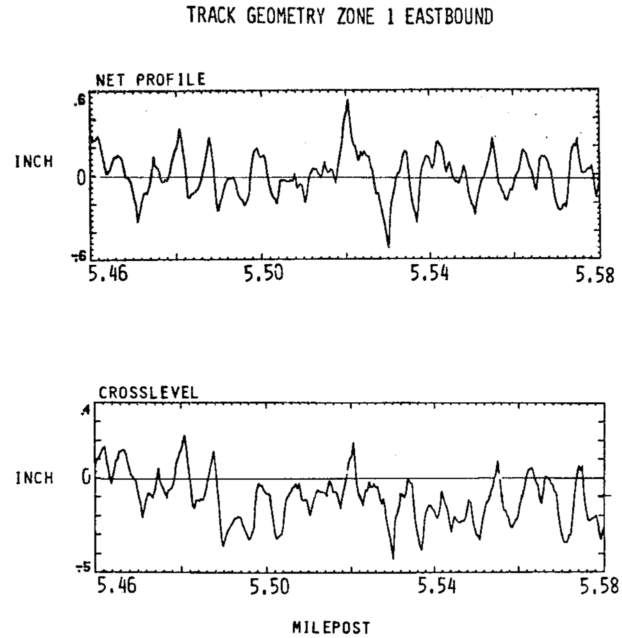


Figure 5-29. Track Geometry Crosslevels

locations. This is compared with the location of the curves in this zone; these curve locations agree well with published curve locations. Table 5-3 compares distances measured during the FSFMS test with those made during the track geometry measurement. The error in the two measurements is constant and means that the milepost locations on the branch line were not exactly one mile apart; exact agreement may be obtained by applying a small correction to the FSFMS measurements.

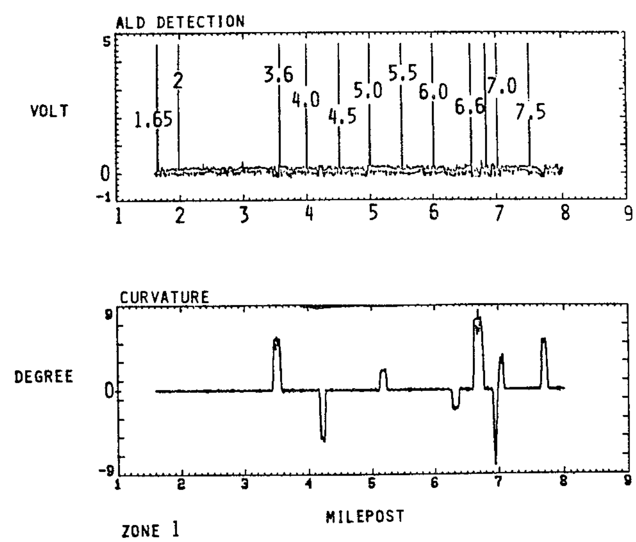


Figure 5-30. ALD Signals and Curve Locations

Table 5-3. Comparison of Measured Distance

MP1	MP2	FSFMS Test	Track Geometry	% Error
5.0	5.5	.502	.505	.6
5.0	6.0	1.0005	1.0057	.5
5.0	7.0	2.000	2.01155	.6
6.0	6.6	.594	.597	.5
7.0	7.49	.498	.5004	.5

ENSCO measured the track geometry at the track class maximum speed in both directions. The reported parameters were: right and left profile, right and left alignment, crosslevel, gage, and curvature (degrees per 100 ft). A digital tape of these parameters was supplied to Wyle in the form of both space curve and short midchord offset with a sample interval of six inches. The digital tape also contains the speed and ALD. Examples of the track geometry parameters are plotted in Figure 5-31 for test zone 1.

5.8 TRUCK TRACKING THROUGH CURVES

Two string potentiometers at the front and back of the truck center plate were used to measure truck swivel angle. A previous comparison (Figure 5-15) between this measurement and the track curvature obtained from the track geometry survey showed excellent agreement. A more detailed look at the tracking ability of the two trucks is given in Figures 5-32 and 5-33 as they went through the 7.5-degree curve just after milepost 6.6 in test zone 1. The Barber truck (empty and loaded) is shown in Figure 5-32 and the ASF truck (empty and loaded) is shown in Figure 5-33. The track curvature is shown in both figures for comparison with the truck swivel angle. The track curvature is the actual curvature of the track while the swivel angle is the relative rotation of the truck bolster versus the carbody bolster. Although the magnitudes of the two measurements are different, the truck swivel angle clearly is directly proportional to the track curvature.

The Barber truck (Figure 5-32) shows little difference in the way the truck tracks through the curve in the empty versus the loaded condition. The ASF truck (Figure 5-33) shows improvement tracking through curves from the empty to the loaded condition. However, both trucks appear to be quite similar in this capability.

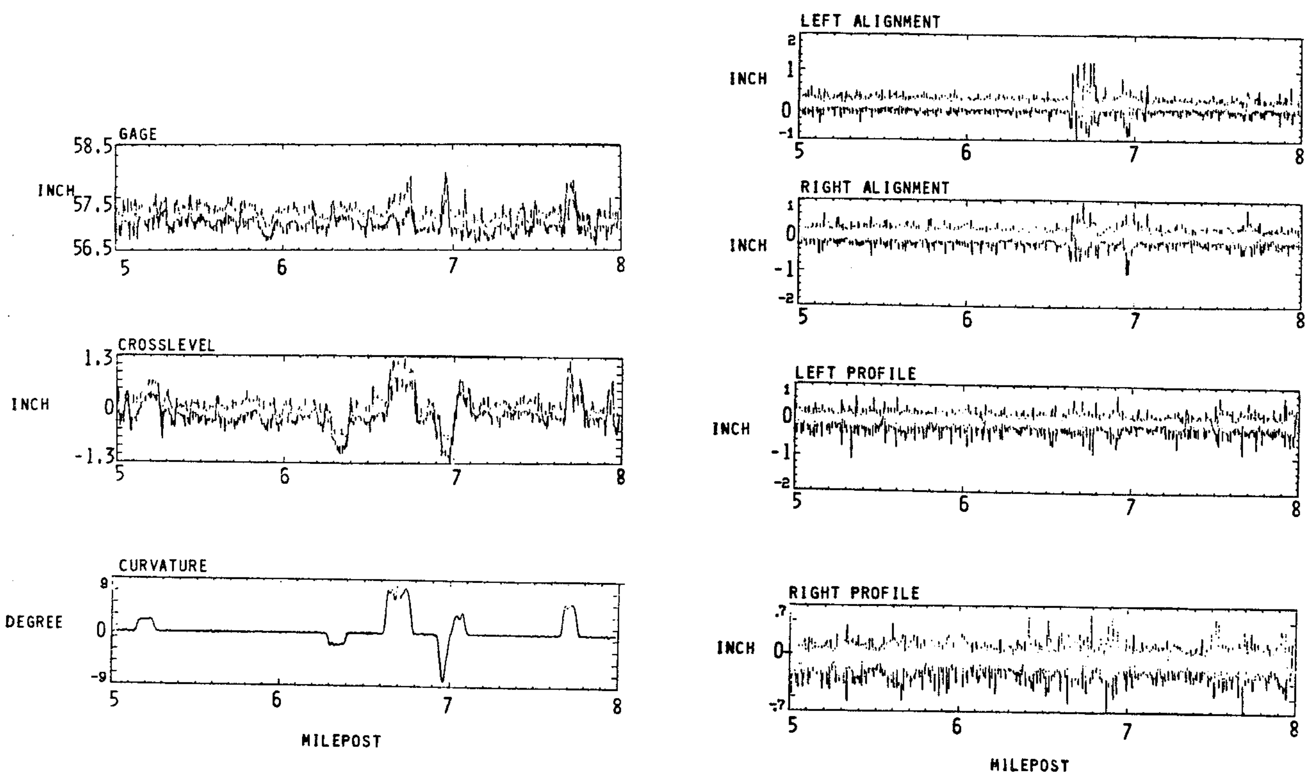


Figure 5-31. Typical Track Geometry, Zone 1

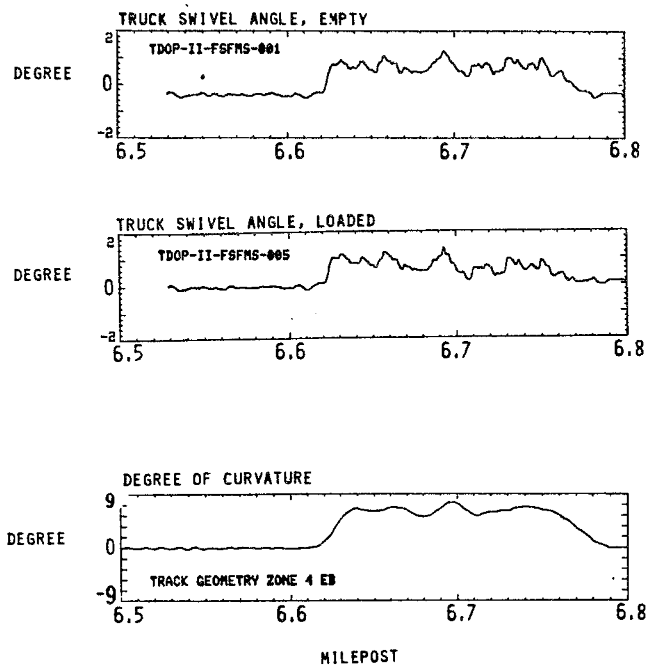


Figure 5-32. Truck Swivel Angle vs Track Curvature, Barber Truck

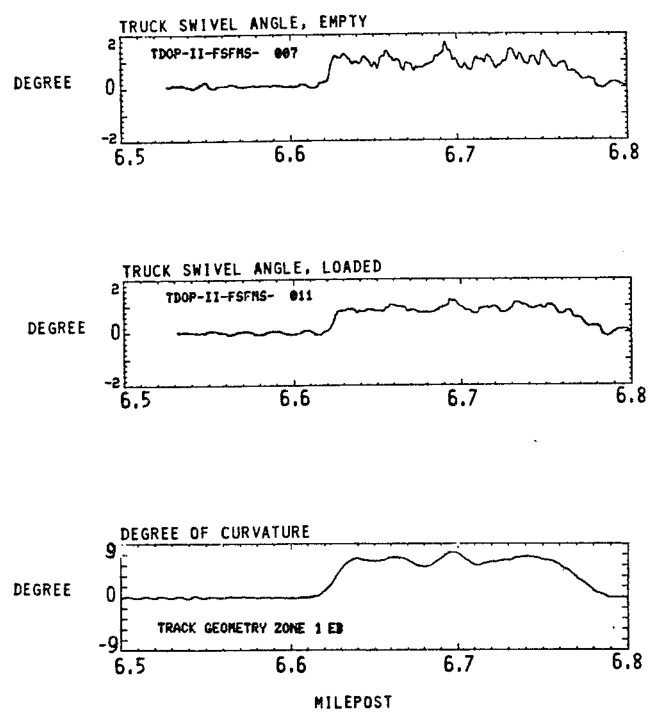


Figure 5-33. Truck Swivel Angle vs Track Curvature, ASF Truck

SECTION 6 - CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The test program was successfully completed using friction snubber transducers to obtain friction forces in over-the-road truck tests. The quality of the acquired data was excellent. Noise floor data were orders of magnitude less than the test data. Attempts to correlate previous track geometry data and data from friction snubber runs were highly successful. Comparison of data between runs showed close agreement in relationship to track input. Truck bolster/side frame motions in the lateral and yaw directions were identical from one side frame to the other; therefore, these measurements on one side frame may be eliminated in future testing.

The primary purpose of the tests was to obtain estimates of the friction coefficients associated with the two truck types. The mean values established from the data analysis were 0.43 for the ASF truck and 0.34 for the Barber truck.

6.2 RECOMMENDATIONS

The friction forces obtained as a result of this test program could be applied to other work, for example, as input to analytical models, to validate roll and bounce models, and as considerations in truck design.

Only those data required to meet the objectives of the program were analyzed for this test report. There is a significant amount of analysis information which may still be extracted from the data. Some of the areas in which additional work is recommended are as follows:

1. Determining friction coefficients in curves to see if they differ from those for tangent track. (The analysis in this report was done for a section of tangent track.)
2. Completing the center plate kinetic friction coefficient analysis.
3. Exploring the relationship of the half loaded to the empty and loaded car configurations.
4. Determining the relationship of braking to friction forces.
5. Investigating the effect of asymmetric column loading on snubber friction.
6. Using track geometry as input to a model to compare analytical and measured carbody responses.
7. Establishing an equivalent viscous damping representation of the friction snubbers.
8. Using the vertical and lateral displacement measurements to determine any change in friction coefficient as a function of direction of motion.
9. Using the test data from the speed-varying runs and from test zone 2 to perform a more detailed evaluation of ride quality.

REFERENCES

1. FRA Report No. FRA/ORD-78-69, "Measurement of Friction Snubber Forces in Freight Car Trucks," Klaus L. Cappel, December 1978.

2. Wyle Document C-901-0001-A, "Friction Snubber Force Measurement System Test Plan," September 1978 (Revision B, February 1979).

3. Wyle Document C-901-0005-A, "Friction Snubber Force Measurement System Test Procedure," November 1978 (Revision A, January 1979).

4. ENSCO Survey T6-400 Report, "Survey Results Report Track Geometry Measurements in Support of TDOP," December 1978.

APPENDIX A

COMPRESSION MEASUREMENTS ON FRICTION SHOE SPRING OF BARBER TRUCK

The following raw data sheets show the friction shoe springs of the Barber truck. The first column of numbers is the applied load (lb); the second column is the measured height of the spring plus the compression fixture; the third column is the calculated compressed height (in.) of the spring; the fourth column is the calculated amount of compression (in.). The free height noted on each data sheet is the measured free height (in.) of the spring.

DATA SHEET

WYLE LABORATORIES

Customer FRA
Specimen SPRING #1 (Barber FSD 1)
Part No.
Spec.
Para.
S/N
GSI
Amb. Temp. 72°F
Photo YES
Test Med.
Specimen Temp.
Job No. 75002
Report No.
Start Date 10-4-78

Test Title #1 ↓ COMP

0	17.44	11.05	Free height 11.05"
500	16.86	10.47	= 0.58
1000	16.34	9.95	1.10
1500	15.84	9.45	1.60
2000	15.38	8.99	2.06
2500	14.89	8.50	2.55
3000	14.41	8.02	3.03
3500	13.93	7.54	3.51
4000	13.45	7.06	3.99
4500	13.00	6.61	4.44
4000	13.38	6.99	4.06
3500	13.83	7.45	3.60
3000	14.30	7.91	3.14
2500	14.78	8.39	2.66
2000	15.27	8.88	2.17
1500	15.76	9.37	1.68
1000	16.25	9.86	1.19
500	16.78	10.39	0.66
0	17.39	11.00	0.05

Specimen Failed
Specimen Passed
NOA Written
Tested By ______ Date:
Witness ______ Date:
Sheet No. ______ of
Approved

WH-614A

DATA SHEET

WYLE LABORATORIES

Customer
Specimen Barber FSD 2
Part No.
Spec.
Para.
S/N
GSI
Amb. Temp.
Photo
Test Med.
Specimen Temp.
Job No.
Report No.
Start Date

Test Title #2 2" Block = 2.50"

0	- 17.41	11.00	0.0 Free height 11.00"
500	- 16.77	10.36	0.64
1000	- 16.27	9.86	1.14
1500	- 15.75	9.34	1.66
2000	15.27	8.86	2.14
2500	14.77	8.36	2.64
3000	14.27	7.86	3.14
3500	13.76	7.35	3.65
4000	13.28	6.87	4.13
4500	12.88	6.47	4.53
4000	13.21	6.80	4.20
3500	13.69	7.28	3.72
3000	14.16	7.75	3.25
2500	14.65	8.24	2.76
2000	15.14	8.73	2.27
1500	15.64	9.23	1.77
1000	16.16	9.75	1.25
500	16.69	10.28	.72
0	17.35	10.94	.06

Specimen Failed
Specimen Passed
NOA Written
Tested By ______ Date:
Witness ______ Date:
Sheet No. ______ of
Approved

WH-614A

DATA SHEET

WYLE LABORATORIES

Specimen Barber FSD 3

Part No.

S/N

Job No.

Report No.

Date

Test Title

Description of Test (Continued): #3

0	17.52	11.13	0.0
500	16.91	10.52	.61 Free height 11.13"
1000	16.41	10.02	1.11
1500	15.92	9.53	1.60
2000	15.46	9.07	2.06
2500	14.98	8.59	2.54
3000	14.52	8.13	3.00
3500	14.05	7.66	3.47
4000	13.58	7.19	3.94
4500	13.14	6.75	4.38
4000	13.53	7.14	3.99
3500	13.97	7.58	3.55
3000	14.43	8.04	3.09
2500	14.90	8.51	2.62
2000	15.36	8.97	2.16
1500	15.85	9.46	1.67
1000	16.33	9.94	1.19
500	16.85	10.46	0.67
0	17.45	11.06	0.07

DATA SHEET

WYLE LABORATORIES

Specimen

Part No.

S/N

Job No.

Report No.

Date

Test Title Barber FSD4

Description of Test (Continued): #4

0	17.41	11.00	0.0
500	16.81	10.40	0.6
1000	16.29	9.88	1.12 2"=2.50"
1500	15.80	9.39	1.61 Block
2000	15.33	8.92	2.08
2500	14.84	8.43	2.57
3000	14.38	7.97	3.03 11.00" Free height
3500	13.90	7.49	3.51
4000	13.42	7.01	3.99
4500	13.00	6.59	4.41
4000	13.35	6.94	4.06
3500	13.80	7.39	3.61
3000	14.27	7.86	3.14
2500	14.74	8.33	2.67
2000	15.22	8.81	2.19
1500	15.73	9.32	1.68
1000	16.23	9.82	1.18
500	16.73	10.32	0.68
0	17.34	10.93	0.07

APPENDIX B

EXAMPLE OF MILEPOST vs TIME LISTINGS

TDOP-II-FSFMS- 007

		REL DIST	ACT DIST	REL TIME	DATA RECORD NUMBER
	1	-0.030	4.970	1.265	3
	2	-0.020	4.980	3.060	9
	3	-0.010	4.990	4.885	15
ALD POST	4	-0.000	5.000	6.680	21
	5	0.000	5.000	6.685	21
	6	0.010	5.010	8.475	27
	7	0.020	5.020	10.260	33
	8	0.030	5.030	12.045	37
	9	0.040	5.040	13.830	43
	10	0.050	5.050	15.625	49
	11	0.060	5.060	17.415	55
	12	0.070	5.070	19.215	61
	13	0.080	5.080	21.015	65
	14	0.090	5.090	22.800	71
	15	0.100	5.100	24.590	77
	16	0.110	5.110	26.385	83
	17	0.120	5.120	28.185	89
	18	0.130	5.130	29.980	93
	19	0.140	5.140	31.765	99
	20	0.150	5.150	33.550	105
	21	0.160	5.160	35.330	111
	22	0.170	5.170	37.120	115
	23	0.180	5.180	38.910	121
	24	0.190	5.190	40.700	127
	25	0.200	5.200	42.485	133
	26	0.210	5.210	44.265	139
	27	0.220	5.220	46.085	145
	28	0.230	5.230	47.880	149
	29	0.240	5.240	49.665	155
	30	0.250	5.250	51.445	161
	31	0.260	5.260	53.225	167
	32	0.270	5.270	55.010	171
	33	0.280	5.280	56.810	177
	34	0.290	5.290	58.610	183
	35	0.300	5.300	60.400	189
	36	0.310	5.310	62.185	195
	37	0.320	5.320	63.975	199
	38	0.330	5.330	65.760	205
	39	0.340	5.340	67.540	211
	40	0.350	5.350	69.315	217
	41	0.360	5.360	71.105	223
	42	0.370	5.370	72.910	227
	43	0.380	5.380	74.720	233
	44	0.390	5.390	76.525	239
	45	0.400	5.400	78.320	245
	46	0.410	5.410	80.105	251
	47	0.420	5.420	81.890	255
	48	0.430	5.430	83.675	261
	49	0.440	5.440	85.465	267
	50	0.450	5.450	87.245	273
	51	0.460	5.460	89.040	279
	52	0.470	5.470	90.845	283
	53	0.480	5.480	92.645	289
	54	0.490	5.490	94.440	295
	55	0.500	5.500	96.230	301
ALD POST	56	0.502	5.502	96.605	301
	57	0.510	5.510	98.015	307
	58	0.520	5.520	99.795	311
	59	0.530	5.530	101.570	317
	60	0.540	5.540	103.360	323
	61	0.550	5.550	105.160	329
	62	0.560	5.560	106.965	335
	63	0.570	5.570	108.760	339
	64	0.580	5.580	110.550	345
	65	0.590	5.590	112.340	351
	66	0.600	5.600	114.120	357
	67	0.610	5.610	115.905	363
	68	0.620	5.620	117.700	367
	69	0.630	5.630	119.500	373
	70	0.640	5.640	121.300	379
	71	0.650	5.650	123.105	385
	72	0.660	5.660	124.915	391
	73	0.670	5.670	126.730	397
	74	0.680	5.680	128.545	401
	75	0.690	5.690	130.355	407
	76	0.700	5.700	132.155	413
	77	0.710	5.710	133.955	419
	78	0.720	5.720	135.750	425
	79	0.730	5.730	137.540	429

TDOP-II-FSFMS- 007
(Continued)

		REL DIST	ACT DIST	REL TIME	DATA RECORD NUMBER
	80	0.740	5.740	139.325	435
	81	0.750	5.750	141.105	441
	82	0.760	5.760	142.885	447
	83	0.770	5.770	144.660	453
	84	0.780	5.780	146.435	457
	85	0.790	5.790	148.215	463
	86	0.800	5.800	149.990	469
	87	0.810	5.810	151.780	475
	88	0.820	5.820	153.575	479
	89	0.830	5.830	155.370	485
	90	0.840	5.840	157.155	491
	91	0.850	5.850	158.935	497
	92	0.860	5.860	160.715	503
	93	0.870	5.870	162.490	507
	94	0.880	5.880	164.270	513
	95	0.890	5.890	166.070	519
	96	0.900	5.900	167.875	525
	97	0.910	5.910	169.675	531
	98	0.920	5.920	171.470	535
	99	0.930	5.930	173.260	541
	100	0.940	5.940	175.040	547
	101	0.950	5.950	176.815	553
	102	0.960	5.960	178.585	559
	103	0.970	5.970	180.370	563
	104	0.980	5.980	182.165	569
	105	0.990	5.990	183.980	575
	106	1.000	6.000	185.795	581
ALD POST	107	1.000	6.000	185.880	581
	108	1.010	6.010	187.605	587
	109	1.020	6.020	189.410	591
	110	1.030	6.030	191.210	597
	111	1.040	6.040	193.005	603
	112	1.050	6.050	194.795	609
	113	1.060	6.060	196.575	615
	114	1.070	6.070	198.355	619
	115	1.080	6.080	200.125	625
	116	1.090	6.090	201.890	631
	117	1.100	6.100	203.670	637
	118	1.110	6.110	205.465	643
	119	1.120	6.120	207.270	647
	120	1.130	6.130	209.080	653
	121	1.140	6.140	210.880	659
	122	1.150	6.150	212.675	665
	123	1.160	6.160	214.465	671
	124	1.170	6.170	216.250	675
	125	1.180	6.180	218.040	681
	126	1.190	6.190	219.820	687
	127	1.200	6.200	221.600	693
	128	1.210	6.210	223.395	699
	129	1.220	6.220	225.205	703
	130	1.230	6.230	227.010	709
	131	1.240	6.240	228.815	715
	132	1.250	6.250	230.620	721
	133	1.260	6.260	232.415	727
	134	1.270	6.270	234.210	731
	135	1.280	6.280	235.995	737
	136	1.290	6.290	237.785	743
	137	1.300	6.300	239.570	749
	138	1.310	6.310	241.355	755
	139	1.320	6.320	243.135	759
	140	1.330	6.330	244.910	765
	141	1.340	6.340	246.685	771
	142	1.350	6.350	248.475	777
	143	1.360	6.360	250.275	783
	144	1.370	6.370	252.065	787
	145	1.380	6.380	253.855	793
	146	1.390	6.390	255.630	799
	147	1.400	6.400	257.405	805
	148	1.410	6.410	259.180	809
	149	1.420	6.420	260.965	815
	150	1.430	6.430	262.760	821
	151	1.440	6.440	264.540	827
	152	1.450	6.450	266.315	833
	153	1.460	6.460	268.085	837
	154	1.470	6.470	269.855	843
	155	1.480	6.480	271.625	849
	156	1.490	6.490	273.390	855
	157	1.500	6.500	275.155	859
	158	1.510	6.510	276.925	865
	159	1.520	6.520	278.705	871
	160	1.530	6.530	280.485	877
	161	1.540	6.540	282.260	883
	162	1.550	6.550	284.025	887
	163	1.560	6.560	285.790	893

TDOP-II-FSFMS- 007
(Continued)

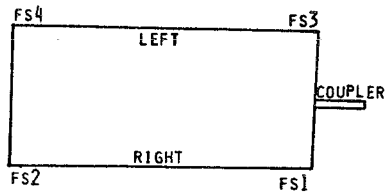
		REL DIST	ACT DIST	REL TIME	DATA RECORD NUMBER
	164	1.570	6.570	287.565	899
	165	1.580	6.580	289.350	905
	166	1.590	6.590	291.140	909
ALD POST	167	1.594	6.594	291.790	911
	168	1.600	6.600	292.930	915
	169	1.610	6.610	294.720	921
	170	1.620	6.620	296.505	927
	171	1.630	6.630	298.300	933
	172	1.640	6.640	300.105	937
	173	1.650	6.650	301.915	943
	174	1.660	6.660	303.715	949
	175	1.670	6.670	305.505	955
	176	1.680	6.680	307.295	961
	177	1.690	6.690	309.085	965
	178	1.700	6.700	310.870	971
	179	1.710	6.710	312.650	977
	180	1.720	6.720	314.430	983
	181	1.730	6.730	316.220	989
	182	1.740	6.740	318.015	993
	183	1.750	6.750	319.805	999
	184	1.760	6.760	321.585	1005
	185	1.770	6.770	323.355	1011
	186	1.780	6.780	325.115	1015
	187	1.790	6.790	326.875	1021
	188	1.800	6.800	328.640	1027
	189	1.810	6.810	330.415	1033
	190	1.820	6.820	332.185	1039
	191	1.830	6.830	333.960	1043
	192	1.840	6.840	335.735	1049
	193	1.850	6.850	337.515	1055
	194	1.860	6.860	339.290	1061
	195	1.870	6.870	341.070	1065
	196	1.880	6.880	342.845	1071
	197	1.890	6.890	344.615	1077
	198	1.900	6.900	346.395	1083
	199	1.910	6.910	348.175	1089
	200	1.920	6.920	349.970	1093
	201	1.930	6.930	351.780	1099
	202	1.940	6.940	353.600	1105
	203	1.950	6.950	355.425	1111
	204	1.960	6.960	357.235	1117
	205	1.970	6.970	359.035	1121
	206	1.980	6.980	360.820	1127
	207	1.990	6.990	362.610	1133
ALD POST	208	2.000	7.000	364.385	1139
	209	2.000	7.000	364.400	1139
	210	2.010	7.010	366.205	1145
	211	2.020	7.020	368.030	1151
	212	2.030	7.030	369.875	1155
	213	2.040	7.040	371.740	1161
	214	2.050	7.050	373.625	1167
	215	2.060	7.060	375.550	1173
	216	2.070	7.070	377.505	1179
	217	2.080	7.080	379.480	1185
	218	2.090	7.090	381.470	1193
	219	2.100	7.100	383.455	1199
	220	2.110	7.110	385.440	1205
	221	2.120	7.120	387.425	1211
	222	2.130	7.130	389.405	1217
	223	2.140	7.140	391.375	1223
	224	2.150	7.150	393.350	1229
	225	2.160	7.160	395.330	1235
	226	2.170	7.170	397.315	1241
	227	2.180	7.180	399.290	1247
	228	2.190	7.190	401.275	1253
	229	2.200	7.200	403.265	1261
	230	2.210	7.210	405.250	1267
	231	2.220	7.220	407.240	1273
	232	2.230	7.230	409.230	1279
	233	2.240	7.240	411.215	1285
	234	2.250	7.250	413.200	1291
	235	2.260	7.260	415.185	1297
	236	2.270	7.270	417.175	1303
	237	2.280	7.280	419.160	1309
	238	2.290	7.290	421.145	1317
	239	2.300	7.300	423.125	1323
	240	2.310	7.310	425.130	1329
	241	2.320	7.320	427.165	1335
	242	2.330	7.330	429.250	1341
	243	2.340	7.340	431.385	1349
	244	2.350	7.350	433.595	1355
	245	2.360	7.360	435.875	1363
	246	2.370	7.370	438.215	1369
	247	2.380	7.380	440.580	1377

TDOP-II-FSFMS- 007
(Continued)

		REL DIST	ACT DIST	REL TIME	DATA RECORD NUMBER
	248	2.390	7.390	442.945	1385
	249	2.400	7.400	445.305	1391
	250	2.410	7.410	447.645	1399
	251	2.420	7.420	449.935	1407
	252	2.430	7.430	452.175	1413
	253	2.440	7.440	454.415	1421
	254	2.450	7.450	456.675	1427
	255	2.460	7.460	458.935	1435
	256	2.470	7.470	461.195	1441
	257	2.480	7.480	463.450	1449
	258	2.490	7.490	465.715	1455
ALD POST	259	2.498	7.498	467.530	1461
	260	2.500	7.500	467.980	1463
	261	2.510	7.510	470.275	1469
	262	2.520	7.520	472.615	1477
	263	2.530	7.530	475.015	1485
	264	2.540	7.540	477.470	1493
	265	2.550	7.550	479.980	1499
	266	2.560	7.560	482.485	1507
	267	2.570	7.570	484.970	1515
	268	2.580	7.580	487.465	1523
	269	2.590	7.590	489.975	1531
	270	2.600	7.600	492.495	1539
	271	2.610	7.610	495.035	1547
	272	2.620	7.620	497.585	1555
	273	2.630	7.630	500.145	1563
	274	2.640	7.640	502.695	1571
	275	2.650	7.650	505.245	1579
	276	2.660	7.660	507.825	1587
	277	2.670	7.670	510.420	1595
	278	2.680	7.680	513.025	1603
	279	2.690	7.690	515.605	1611
	280	2.700	7.700	518.180	1619
	281	2.710	7.710	520.820	1627
	282	2.720	7.720	523.570	1637
	283	2.730	7.730	526.465	1645
	284	2.740	7.740	529.490	1655
	285	2.750	7.750	532.515	1665
	286	2.760	7.760	535.435	1673
	287	2.770	7.770	538.305	1683
	288	2.780	7.780	541.215	1691
	289	2.790	7.790	544.135	1701
	290	2.800	7.800	547.095	1709
	291	2.810	7.810	550.190	1719
	292	2.820	7.820	553.480	1729
	293	2.830	7.830	557.005	1741
	294	2.840	7.840	560.650	1753
	295	2.850	7.850	564.120	1763
	296	2.860	7.860	567.540	1773
	297	2.870	7.870	571.125	1785
	298	2.880	7.880	574.800	1797
	299	2.890	7.890	578.370	1807
	300	2.900	7.900	581.950	1819
	301	2.910	7.910	585.725	1831
	302	2.920	7.920	589.665	1843
	303	2.930	7.930	593.880	1855
	304	2.940	7.940	598.165	1869
	305	2.950	7.950	602.345	1883
	306	2.960	7.960	606.595	1895
	307	2.970	7.970	610.990	1909
	308	2.980	7.980	615.440	1923
	309	2.990	7.990	619.995	1937
	310	3.000	8.000	624.950	1953
	311	3.010	8.010	630.790	1971
	312	3.020	8.020	636.735	1989
	313	3.030	8.030	642.400	2007
	314	3.040	8.040	648.210	2025
	315	3.050	8.050	654.695	2045
	316	3.060	8.060	662.510	2071
	317	3.070	8.070	671.380	2099
	318	3.080	8.080	679.850	2125
	319	3.090	8.090	688.480	2151
	320	3.100	8.100	699.355	2185
	321	3.110	8.110	714.750	2233
	322	3.120	8.120	731.935	2287

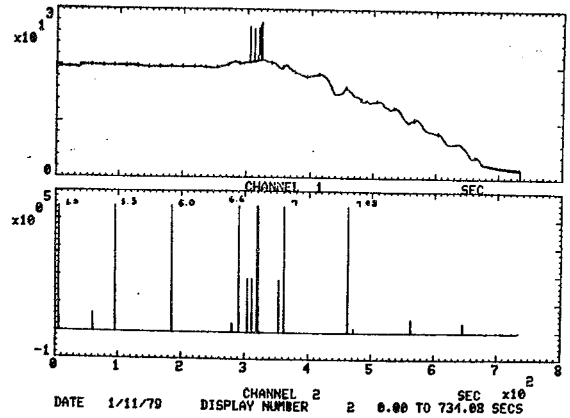
APPENDIX C
EXAMPLES OF REDUCED DATA

Parameter Definitions
(TDOP-II-FSMS-001)



Direction of Travel ——→

SPD	Speed	mph
ALD	ALD	detection
NFX	Normal force at friction snubber (FS) X	lb
LFX	Lateral force at FS X	lb
VFX	Vertical force at FS X	lb
VDR	Vertical displacement right side FS	inch
LDR	Lateral displacement right side FS	inch
PRR	Side frame/bolster pitch rotation right	degree
YRR	Side frame/bolster yaw rotation right	degree
RRR	Side frame/bolster roll rotation right	degree
XXL	Refers to previous four measurements at left side frame	
TSA	Truck/carbody bolster swivel angle	degree
TLD	Truck/carbody lateral displacement	degree
RA	Carbody roll angle	inch
CB	Carbody bounce	degree
CS	Carbody sway	G
CP	Carbody pitch	G
CY	Carbody yaw	$degree/sec^2$
CR	Carbody roll	$degree/sec^2$
		$degree/sec^2$



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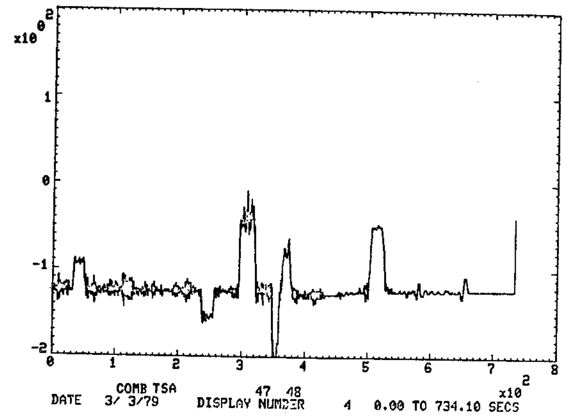

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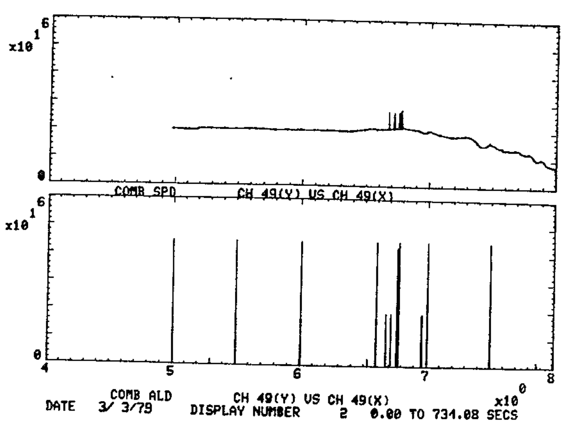

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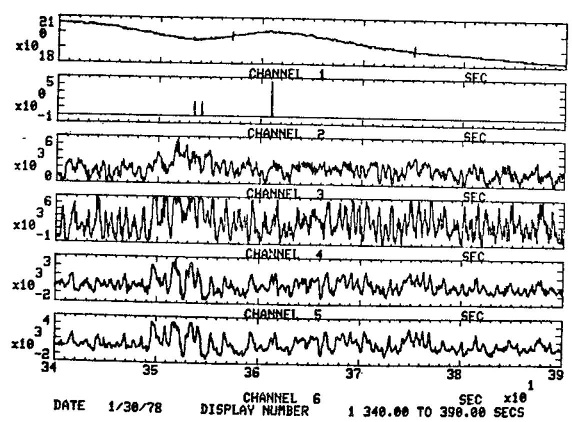

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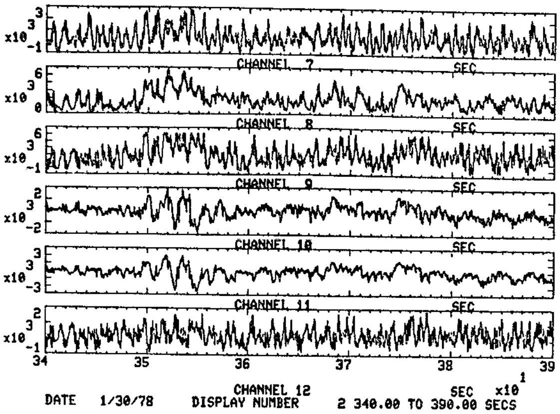

DATE 1/30/78 DISPLAY NUMBER 2 340.00 TO 390.00 SECS

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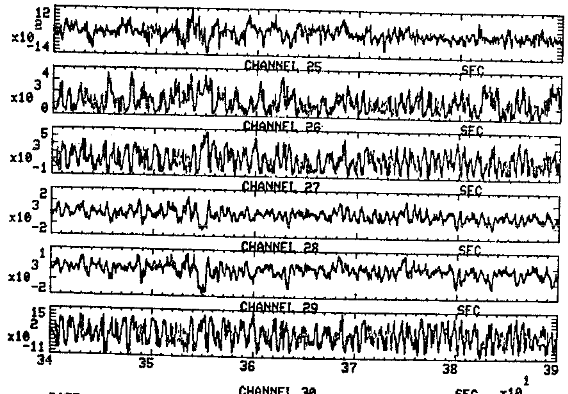

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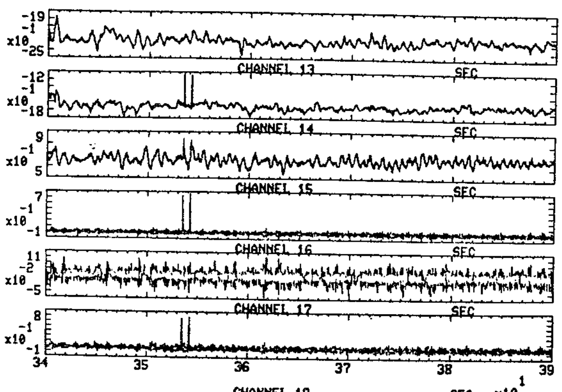

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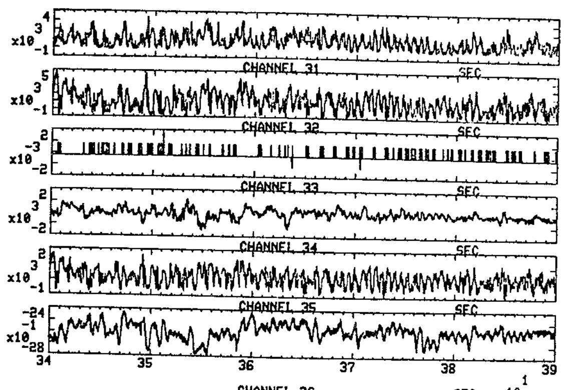

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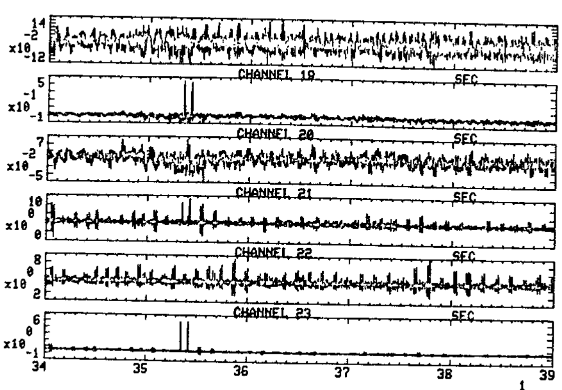

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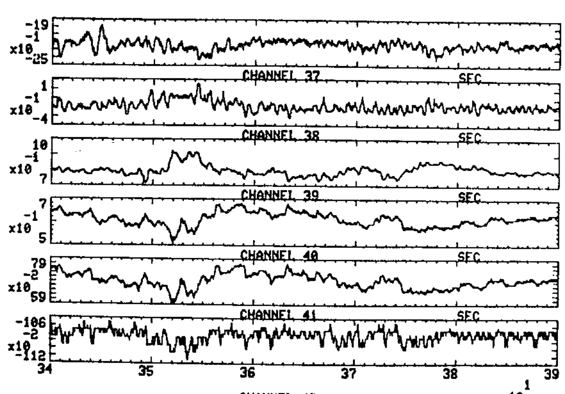

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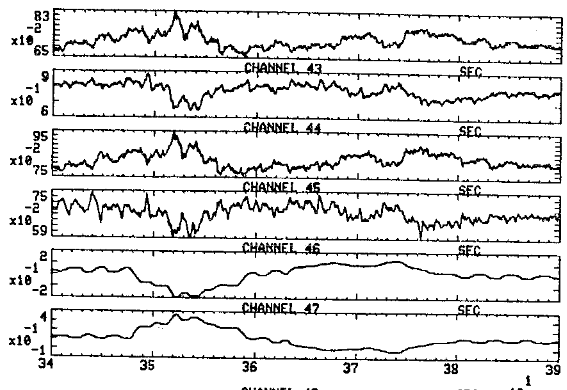

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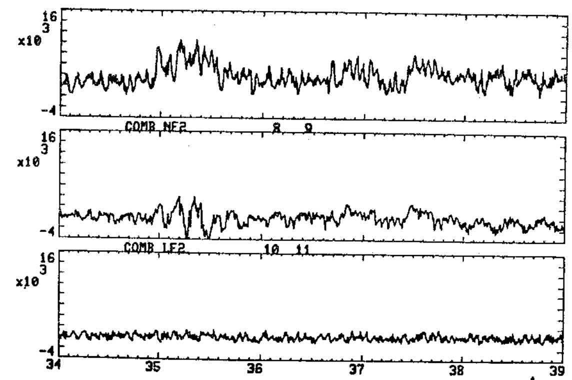

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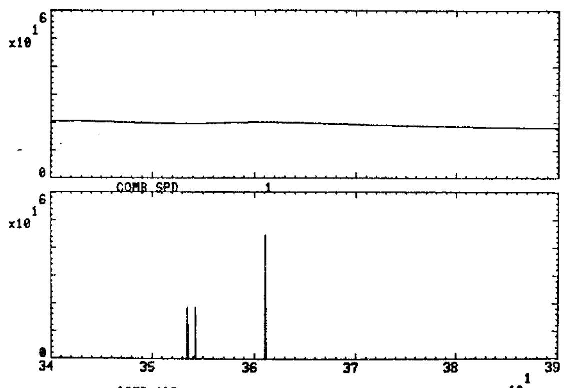

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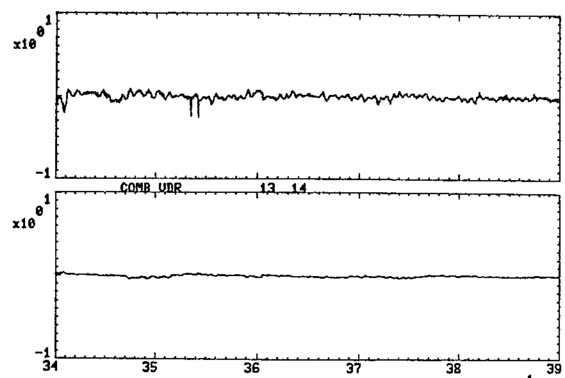
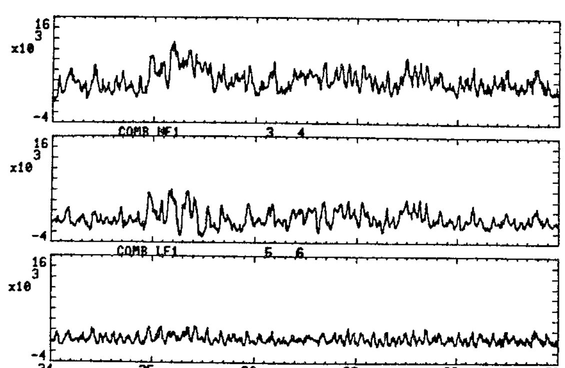


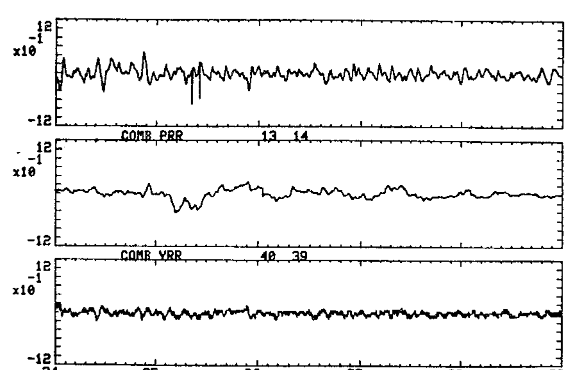
DATE 1/30/78 DISPLAY NUMBER 12 340.00 TO 390.00 SECS

TDOP-II-FSFMS- 011



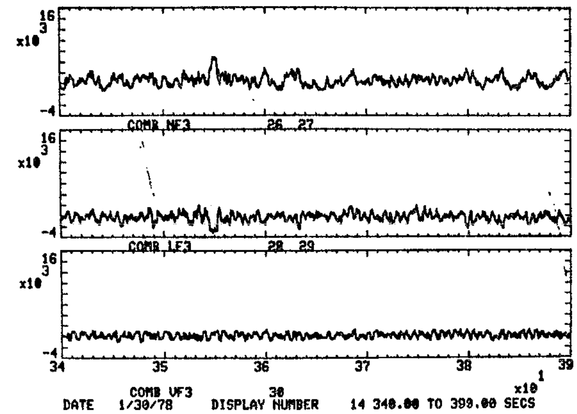
DATE 1/30/78 DISPLAY NUMBER 10 340.00 TO 390.00 SECS

TDOP-II-FSFMS- 011

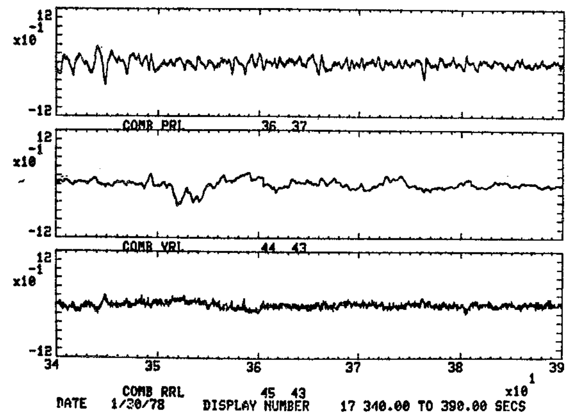


DATE 1/30/78 DISPLAY NUMBER 13 340.00 TO 390.00 SECS

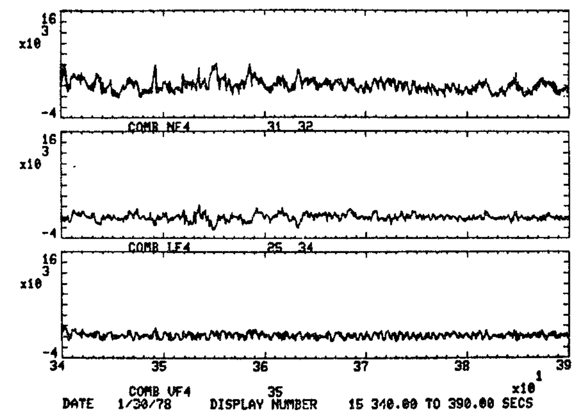
TDOP-II-FSFMS- 011



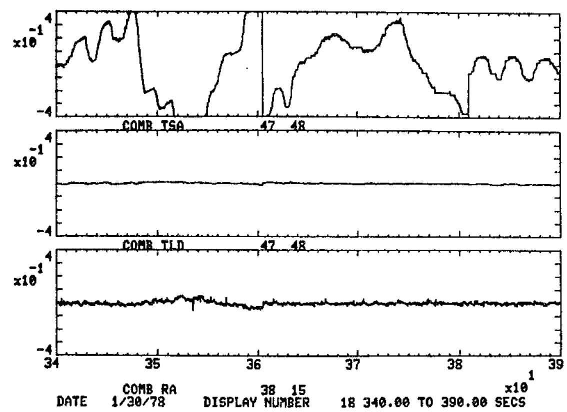
TDOP-II-FSFMS- 011



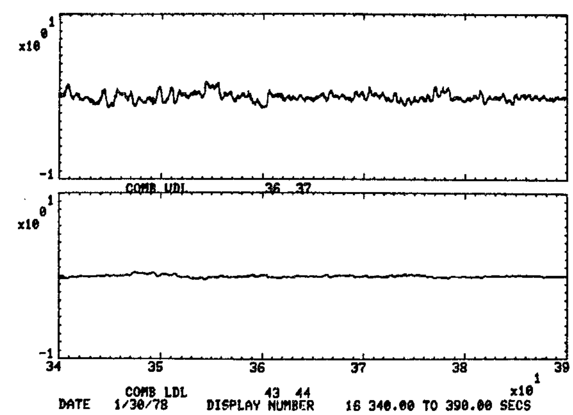
TDOP-II-FSFMS- 011



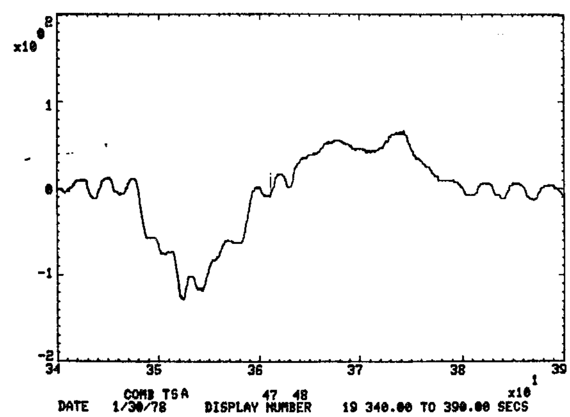
TDOP-II-FSFMS- 011



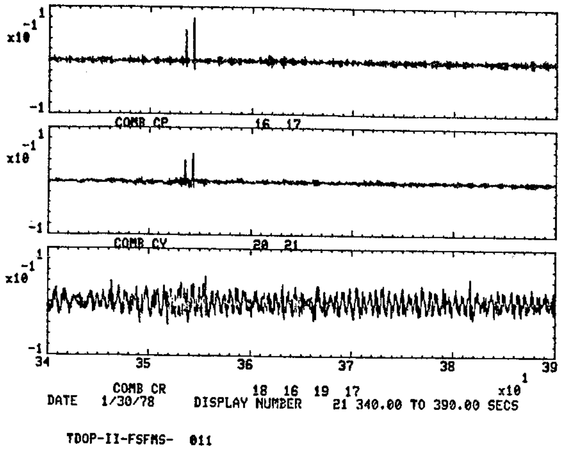
TDOP-II-FSFMS- 011

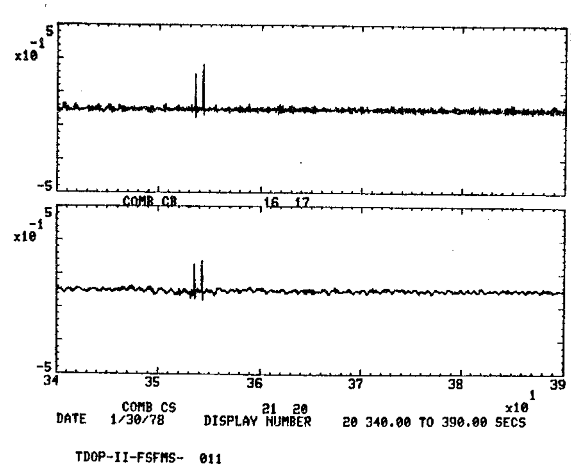


TDOP-II-FSFMS- 011



TDOP-II-FSFMS- 011


COMB CP 16 17
COMB CY 20 21
34 35 36 37 38 39
x10
COMB CR 18 16 19 17
DATE 1/30/78 DISPLAY NUMBER 21 340.00 TO 390.00 SECS
TDOP-II-FSFMS- 011


COMB CB 16 17
34 35 36 37 38 39
x10
COMB CS 21 20
DATE 1/30/78 DISPLAY NUMBER 20 340.00 TO 390.00 SECS
TDOP-II-FSFMS- 011

APPENDIX D

FRICTION COEFFICIENT CALCULATIONS

This appendix contains the detailed analysis of the friction coefficients for each truck. The section of track chosen was between mileposts 5.52 and 5.80 in test zone 1. The analysis for each friction snubber is listed on a separate page. No analysis is included for FS4 on the Barber truck because of transducer problems experienced with FS4 during this run (discussed in paragraph 3.3). The variables in the analyses are defined as follows:

FSX
: Friction snubber number X

FILT
: Cutoff frequency of analysis

NORMAL
: Cutoff level for normal force

POWER
: Cutoff level for power

FRICTION COEFFICIENT
: Mean value ± standard deviation

NUMBER
: Number of friction coefficients used in average

TOTAL ENERGY
: Total energy under curve

INCLUDED ENERGY
: Total energy under curve less than power

PERCENT INCLUDED ENERGY
: Total energy divided by included energy

Since the total energy under the curve is an arithmetic sum, positive and negative energy cancel out, and it is possible to have included energy greater than the total energy. Total friction coefficients include all the values of the friction coefficient measured during an interval, both static and dynamic. Included friction coefficients are only those which meet the normal force and power dissipation level and thus are defined as dynamic friction coefficients.

The first two column headings in the following analyses (MIN and MAX) define the range; the third and fourth columns (NUMBER and PERCENT) refer to the total friction coefficients, while NUMBER and PERCENT in the fifth and sixth columns refer to included friction coefficients.

BARBER TRUCK FS1

3/12/79 FRICTION SNUBBER FS1, FILT=8 (KTY=6)
NORMAL>100, POWER<-250 FRICTION COEFFICIENT=
0.324+/-0.088 NUMBER= 1491 TOTAL ENERGY=
-0.115E+05 IN-LB,INCLUDED ENERGY=-0.118E+05 IN-LB,
PERCENT INCLUDED=102.9

MIN	MAX	NUMBER	PERCENT	NUMBER	PERCENT
0.00	0.01	19	0.38	0	0.00
0.01	0.02	28	0.56	0	0.00
0.02	0.03	42	0.84	0	0.00
0.03	0.04	62	1.24	0	0.00
0.04	0.05	60	1.20	0	0.00
0.05	0.06	68	1.36	1	0.07
0.06	0.07	74	1.48	1	0.07
0.07	0.08	96	1.92	1	0.07
0.08	0.09	96	1.92	2	0.13
0.09	0.10	95	1.90	2	0.13
0.10	0.11	112	2.24	3	0.20
0.11	0.12	120	2.40	4	0.27
0.12	0.13	118	2.36	1	0.07
0.13	0.14	159	3.18	13	0.87
0.14	0.15	156	3.12	12	0.80
0.15	0.16	159	3.18	16	1.07
0.16	0.17	146	2.92	19	1.27
0.17	0.18	161	3.22	26	1.74
0.18	0.19	147	2.94	22	1.48
0.19	0.20	139	2.78	16	1.07
0.20	0.21	142	2.84	27	1.81
0.21	0.22	163	3.26	38	2.55
0.22	0.23	135	2.70	28	1.88
0.23	0.24	164	3.28	31	2.08
0.24	0.25	186	3.72	58	3.89
0.25	0.26	173	3.46	52	3.49
0.26	0.27	186	3.72	63	4.23
0.27	0.28	219	4.38	84	5.63
0.28	0.29	159	3.18	74	4.96
0.29	0.30	161	3.22	78	5.23
0.30	0.31	172	3.44	86	5.77
0.31	0.32	122	2.44	72	4.83
0.32	0.33	124	2.48	68	4.56
0.33	0.34	109	2.18	76	5.10
0.34	0.35	95	1.90	63	4.23
0.35	0.36	85	1.70	56	3.76
0.36	0.37	67	1.34	42	2.82
0.37	0.38	64	1.28	43	2.88
0.38	0.39	65	1.30	43	2.88
0.39	0.40	54	1.08	37	2.48
0.40	0.41	47	0.94	35	2.35
0.41	0.42	23	0.46	20	1.34
0.42	0.43	42	0.84	33	2.21
0.43	0.44	32	0.64	28	1.88
0.44	0.45	26	0.52	21	1.41
0.45	0.46	29	0.58	22	1.48
0.46	0.47	17	0.34	15	1.01
0.47	0.48	9	0.18	4	0.27
0.48	0.49	9	0.18	6	0.40
0.49	0.50	11	0.22	5	0.34
0.50	0.51	10	0.20	5	0.34
0.51	0.52	5	0.10	4	0.27
0.52	0.53	7	0.14	6	0.40
0.53	0.54	6	0.12	4	0.27
0.54	0.55	8	0.16	8	0.54
0.55	0.56	4	0.08	4	0.27
0.56	0.57	4	0.08	4	0.27
0.57	0.58	2	0.04	2	0.13
0.58	0.59	5	0.10	5	0.34
0.61	0.62	1	0.02	1	0.07
0.62	0.63	1	0.02	1	0.07

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BARBER TRUCK FS2

3/12/79 FRICTION SNUBBER FS2, FILT=8 NORMAL>100, POWER<-250 FRICTION COEFFICIENT=0.357+/-0.127 NUMBER= 1132 TOTAL ENERGY=-0.878E+04 IN-LB, INCLUDED ENERGY=-0.105E+05 IN-LB, PERCENT INCLUDED=119.6

MIN	MAX	NUMBER	PERCENT	NUMBER	PERCENT
0.00	0.01	26	0.52	0	0.00
0.01	0.02	42	0.84	0	0.00
0.02	0.03	41	0.82	0	0.00
0.03	0.04	48	0.96	0	0.00
0.04	0.05	86	1.72	0	0.00
0.05	0.06	97	1.94	1	0.09
0.06	0.07	129	2.58	0	0.00
0.07	0.08	142	2.84	3	0.27
0.08	0.09	141	2.82	2	0.18
0.09	0.10	107	2.14	6	0.53
0.10	0.11	151	3.02	8	0.71
0.11	0.12	141	2.82	11	0.97
0.12	0.13	147	2.94	10	0.88
0.13	0.14	155	3.10	12	1.06
0.14	0.15	128	2.56	16	1.41
0.15	0.16	130	2.60	13	1.15
0.16	0.17	127	2.54	16	1.41
0.17	0.18	144	2.88	12	1.06
0.18	0.19	160	3.20	16	1.41
0.19	0.20	140	2.80	17	1.50
0.20	0.21	120	2.40	17	1.50
0.21	0.22	124	2.48	18	1.59
0.22	0.23	116	2.32	20	1.77
0.23	0.24	119	2.38	31	2.74
0.24	0.25	121	2.42	36	3.18
0.25	0.26	109	2.18	23	2.03
0.26	0.27	113	2.26	24	2.12
0.27	0.28	107	2.14	23	2.03
0.28	0.29	118	2.36	35	3.09
0.29	0.30	90	1.80	32	2.83
0.30	0.31	102	2.04	33	2.92
0.31	0.32	95	1.90	37	3.27
0.32	0.33	87	1.74	36	3.18
0.33	0.34	86	1.72	35	3.09
0.34	0.35	97	1.94	43	3.80
0.35	0.36	81	1.62	39	3.45
0.36	0.37	103	2.06	44	3.89
0.37	0.38	92	1.84	31	2.74
0.38	0.39	83	1.66	37	3.27
0.39	0.40	84	1.68	36	3.18
0.40	0.41	69	1.38	28	2.47
0.41	0.42	59	1.18	25	2.21
0.42	0.43	69	1.38	29	2.56
0.43	0.44	54	1.08	32	2.83
0.44	0.45	42	0.84	21	1.86
0.45	0.46	59	1.18	30	2.65
0.46	0.47	57	1.14	31	2.74
0.47	0.48	34	0.68	19	1.68
0.48	0.49	29	0.58	19	1.68
0.49	0.50	30	0.60	15	1.33
0.50	0.51	31	0.62	19	1.68
0.51	0.52	21	0.42	11	0.97
0.52	0.53	12	0.24	6	0.53
0.53	0.54	15	0.30	9	0.80
0.54	0.55	12	0.24	7	0.62
0.55	0.56	8	0.16	3	0.27
0.56	0.57	10	0.20	5	0.44
0.57	0.58	15	0.30	12	1.06
0.58	0.59	6	0.12	4	0.35
0.59	0.60	5	0.10	4	0.35
0.60	0.61	6	0.12	5	0.44
0.61	0.62	2	0.04	1	0.09
0.62	0.63	3	0.06	2	0.18
0.63	0.64	1	0.02	0	0.00
0.64	0.65	2	0.04	2	0.18
0.66	0.67	4	0.08	4	0.35
0.67	0.68	2	0.04	2	0.18
0.68	0.69	2	0.04	2	0.18
0.70	0.71	1	0.02	1	0.09
0.73	0.74	4	0.08	4	0.35
0.76	0.77	1	0.02	1	0.09
0.79	0.80	1	0.02	1	0.09
0.80	0.81	1	0.02	1	0.09
0.86	0.87	1	0.02	1	0.09
0.87	0.88	1	0.02	1	0.09
0.98	0.99	2	0.04	2	0.18

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BARBER TRUCK FS3

3/12/79 FRICTION SNUBBER FS3, FILT=8 NORMAL>100, POWER<-250 FRICTION COEFFICIENT=0.308+/-0.070 NUMBER= 1613 TOTAL ENERGY=-0.122E+05 IN-LB, INCLUDED ENERGY=-0.146E+05 IN-LB, PERCENT INCLUDED=119.8

MIN	MAX	NUMBER	PERCENT	NUMBER	PERCENT
0.00	0.01	11	0.22	0	0.00
0.01	0.02	20	0.40	0	0.00
0.02	0.03	39	0.78	0	0.00
0.03	0.04	46	0.92	0	0.00
0.04	0.05	47	0.94	0	0.00
0.05	0.06	66	1.32	1	0.06
0.06	0.07	77	1.54	1	0.06
0.07	0.08	84	1.68	2	0.12
0.08	0.09	90	1.80	4	0.25
0.09	0.10	78	1.56	0	0.00
0.10	0.11	112	2.24	9	0.56
0.11	0.12	113	2.26	4	0.25
0.12	0.13	140	2.80	10	0.62
0.13	0.14	106	2.12	8	0.50
0.14	0.15	115	2.30	12	0.74
0.15	0.16	109	2.18	20	1.24
0.16	0.17	117	2.34	16	0.99
0.17	0.18	119	2.38	18	1.12
0.18	0.19	145	2.90	20	1.24
0.19	0.20	123	2.46	33	2.05
0.20	0.21	152	3.04	26	1.61
0.21	0.22	154	3.08	33	2.05
0.22	0.23	137	2.74	35	2.17
0.23	0.24	149	2.98	45	2.79
0.24	0.25	143	2.86	42	2.60
0.25	0.26	182	3.64	72	4.46
0.26	0.27	157	3.14	60	3.72
0.27	0.28	184	3.68	74	4.59
0.28	0.29	210	4.20	91	5.64
0.29	0.30	233	4.66	127	7.87
0.30	0.31	202	4.04	109	6.76
0.31	0.32	243	4.86	124	7.69
0.32	0.33	215	4.30	115	7.13
0.33	0.34	136	2.72	76	4.71
0.34	0.35	143	2.86	69	4.28
0.35	0.36	124	2.48	67	4.15
0.36	0.37	98	1.96	54	3.35
0.37	0.38	91	1.82	55	3.41
0.38	0.39	77	1.54	49	3.04
0.39	0.40	79	1.58	46	2.85
0.40	0.41	48	0.96	30	1.86
0.41	0.42	25	0.50	17	1.05
0.42	0.43	14	0.28	6	0.37
0.43	0.44	15	0.30	14	0.87
0.44	0.45	12	0.24	10	0.62
0.45	0.46	5	0.10	4	0.25
0.46	0.47	5	0.10	0	0.00
0.47	0.48	1	0.02	1	0.06
0.48	0.49	2	0.04	0	0.00
0.49	0.50	1	0.02	0	0.00
0.50	0.51	1	0.02	1	0.06
0.51	0.52	1	0.02	0	0.00
0.53	0.54	2	0.04	1	0.06
0.54	0.55	2	0.04	2	0.12

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ASF TRUCK FS1

3/13/79 FS1, FILTER=8, NORMAL>100, POWER<-250 FRICTION COEFFICIENT=0.464+/-0.105 NUMBER= 1208 TOTAL ENERGY=-0.910E+04 IN-LB, INCLUDED ENERGY= -0.968E+04 IN-LB, PERCENT INCLUDED=106.3

MIN	MAX	NUMBER	PERCENT	NUMBER	PERCENT
0.00	0.01	13	0.26	0	0.00
0.01	0.02	16	0.32	0	0.00
0.02	0.03	17	0.34	0	0.00
0.03	0.04	16	0.32	0	0.00
0.04	0.05	33	0.66	0	0.00
0.05	0.06	26	0.52	0	0.00

ASF TRUCK FS1
(Continued)

MIN	MAX	NUMBER	PERCENT	NUMBER	PERCENT
0.06	0.07	27	0.54	0	0.00
0.07	0.08	48	0.96	0	0.00
0.08	0.09	31	0.62	0	0.00
0.09	0.10	46	0.92	0	0.00
0.10	0.11	45	0.90	0	0.00
0.11	0.12	51	1.02	0	0.00
0.12	0.13	66	1.32	0	0.00
0.13	0.14	58	1.16	0	0.00
0.14	0.15	61	1.22	1	0.08
0.15	0.16	66	1.32	1	0.08
0.16	0.17	76	1.52	1	0.08
0.17	0.18	76	1.52	0	0.00
0.18	0.19	81	1.62	2	0.17
0.19	0.20	94	1.88	5	0.41
0.20	0.21	97	1.94	6	0.50
0.21	0.22	99	1.98	3	0.25
0.22	0.23	94	1.88	7	0.58
0.23	0.24	120	2.40	7	0.58
0.24	0.25	128	2.56	4	0.33
0.25	0.26	114	2.28	11	0.91
0.26	0.27	109	2.18	9	0.75
0.27	0.28	113	2.26	10	0.83
0.28	0.29	107	2.14	10	0.83
0.29	0.30	87	1.74	7	0.58
0.30	0.31	95	1.90	12	0.99
0.31	0.32	105	2.10	22	1.82
0.32	0.33	113	2.26	20	1.66
0.33	0.34	118	2.36	32	2.65
0.34	0.35	109	2.18	17	1.41
0.35	0.36	136	2.72	24	1.99
0.36	0.37	109	2.18	26	2.15
0.37	0.38	131	2.62	36	2.98
0.38	0.39	110	2.20	29	2.40
0.39	0.40	111	2.22	27	2.24
0.40	0.41	127	2.54	48	3.97
0.41	0.42	139	2.78	56	4.64
0.42	0.43	130	2.60	46	3.81
0.43	0.44	127	2.54	47	3.89
0.44	0.45	108	2.16	44	3.64
0.45	0.46	104	2.08	59	4.88
0.46	0.47	107	2.14	48	3.97
0.47	0.48	122	2.44	52	4.30
0.48	0.49	111	2.22	62	5.13
0.49	0.50	88	1.76	47	3.89
0.50	0.51	91	1.82	36	2.98
0.51	0.52	71	1.42	38	3.15
0.52	0.53	67	1.34	35	2.90
0.53	0.54	63	1.26	32	2.65
0.54	0.55	85	1.70	51	4.22
0.55	0.56	58	1.16	30	2.48
0.56	0.57	32	0.64	17	1.41
0.57	0.58	33	0.66	22	1.82
0.58	0.59	17	0.34	9	0.75
0.59	0.60	18	0.36	9	0.75
0.60	0.61	27	0.54	19	1.57
0.61	0.62	17	0.34	10	0.83
0.62	0.63	15	0.30	9	0.75
0.63	0.64	11	0.22	3	0.25
0.64	0.65	10	0.20	6	0.50
0.65	0.66	4	0.08	4	0.33
0.66	0.67	5	0.10	2	0.17
0.67	0.68	10	0.20	8	0.66
0.68	0.69	7	0.14	7	0.58
0.69	0.70	1	0.02	1	0.08
0.70	0.71	9	0.18	3	0.25
0.71	0.72	7	0.14	2	0.17
0.72	0.73	2	0.04	1	0.08
0.73	0.74	4	0.08	4	0.33
0.74	0.75	3	0.06	3	0.25
0.75	0.76	2	0.04	1	0.08
0.76	0.77	3	0.06	1	0.08
0.77	0.78	2	0.04	2	0.17
0.78	0.79	1	0.02	1	0.08
0.79	0.80	2	0.04	2	0.17
0.80	0.81	1	0.02	1	0.08
0.81	0.82	1	0.02	0	0.00
0.82	0.83	1	0.02	0	0.00
0.83	0.84	1	0.02	0	0.00
0.85	0.86	1	0.02	1	0.08
0.87	0.88	1	0.02	0	0.00
0.88	0.89	2	0.04	0	0.00

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ASF TRUCK FS2

3/13/79 FS2, FILTER=8, NORMAL>100, POWER<-250
FRICTION COEFFICIENT=0.366+/-0.106 NUMBER=874
TOTAL ENERGY=-0.588E+04 IN-LB, INCLUDED ENERGY=
-0.477E+04 IN-LB, PERCENT INCLUDED= 81

MIN	MAX	NUMBER	PERCENT	NUMBER	PERCENT
0.00	0.01	26	0.52	0	0.00
0.01	0.02	22	0.44	0	0.00
0.02	0.03	27	0.54	0	0.00
0.03	0.04	54	1.08	0	0.00
0.04	0.05	59	1.18	0	0.00
0.05	0.06	52	1.04	0	0.00
0.06	0.07	69	1.38	0	0.00
0.07	0.08	81	1.62	1	0.11
0.08	0.09	87	1.74	0	0.00
0.09	0.10	122	2.44	4	0.46
0.10	0.11	82	1.64	3	0.34
0.11	0.12	95	1.90	1	0.11
0.12	0.13	91	1.82	3	0.34
0.13	0.14	130	2.60	7	0.80
0.14	0.15	94	1.88	7	0.80
0.15	0.16	109	2.18	8	0.92
0.16	0.17	94	1.88	7	0.80
0.17	0.18	104	2.08	8	0.92
0.18	0.19	115	2.30	12	1.37
0.19	0.20	99	1.98	12	1.37
0.20	0.21	123	2.46	16	1.83
0.21	0.22	125	2.50	13	1.49
0.22	0.23	153	3.06	22	2.52
0.23	0.24	131	2.62	15	1.72
0.24	0.25	133	2.66	11	1.26
0.25	0.26	140	2.80	25	2.86
0.26	0.27	135	2.70	15	1.72
0.27	0.28	112	2.24	15	1.72
0.28	0.29	155	3.10	20	2.29
0.29	0.30	116	2.32	19	2.17
0.30	0.31	134	2.68	21	2.40
0.31	0.32	137	2.74	30	3.43
0.32	0.33	126	2.52	29	3.32
0.33	0.34	126	2.52	33	3.78
0.34	0.35	144	2.88	39	4.46
0.35	0.36	127	2.54	34	3.89
0.36	0.37	117	2.34	47	5.38
0.37	0.38	112	2.24	39	4.46
0.38	0.39	112	2.24	34	3.89
0.39	0.40	82	1.64	21	2.40
0.40	0.41	97	1.94	34	3.89
0.41	0.42	75	1.50	33	3.78
0.42	0.43	66	1.32	27	3.09
0.43	0.44	50	1.00	16	1.83
0.44	0.45	72	1.44	29	3.32
0.45	0.46	53	1.06	18	2.06
0.46	0.47	51	1.02	13	1.49
0.47	0.48	53	1.06	14	1.60
0.48	0.49	51	1.02	26	2.97
0.49	0.50	46	0.92	20	2.29
0.50	0.51	44	0.88	17	1.95
0.51	0.52	27	0.54	9	1.03
0.52	0.53	29	0.58	8	0.92
0.53	0.54	25	0.50	11	1.26
0.54	0.55	9	0.18	2	0.23
0.55	0.56	20	0.40	7	0.80
0.56	0.57	17	0.34	5	0.57
0.57	0.58	9	0.18	1	0.11
0.58	0.59	13	0.26	5	0.57
0.59	0.60	6	0.12	2	0.23
0.60	0.61	5	0.10	1	0.11
0.61	0.62	7	0.14	1	0.11
0.62	0.63	6	0.12	1	0.11
0.63	0.64	9	0.18	1	0.11
0.65	0.66	2	0.04	1	0.11
0.67	0.68	1	0.02	1	0.11
0.72	0.73	1	0.02	0	0.00
0.73	0.74	1	0.02	0	0.00
0.74	0.75	1	0.02	0	0.00
0.78	0.79	1	0.02	0	0.00
0.81	0.82	1	0.02	0	0.00

TDOP-II-FSFMS-011

ASF TRUCK FS3

3/13/79 FS3, FILTER=8, NORMAL>100, POWER<-250
FRICTION COEFFICIENT=0.408+/-0.078 NUMBER= 1244
TOTAL ENERGY=-0.763E+04 IN-LB, INCLUDED ENERGY=
-0.779E+04 IN-LB, PERCENT INCLUDED=102.1

MIN	MAX	NUMBER	PERCENT	NUMBER	PERCENT
0.00	0.01	8	0.16	0	0.00
0.01	0.02	7	0.14	0	0.00
0.02	0.03	11	0.22	0	0.00
0.03	0.04	23	0.46	0	0.00
0.04	0.05	20	0.40	0	0.00
0.05	0.06	19	0.38	0	0.00
0.06	0.07	15	0.30	0	0.00
0.07	0.08	32	0.64	0	0.00
0.08	0.09	33	0.66	0	0.00
0.09	0.10	30	0.60	0	0.00
0.10	0.11	29	0.58	1	0.08
0.11	0.12	46	0.92	0	0.00
0.12	0.13	47	0.94	1	0.08
0.13	0.14	36	0.72	0	0.00
0.14	0.15	56	1.12	1	0.08
0.15	0.16	63	1.26	1	0.08
0.16	0.17	64	1.28	0	0.00
0.17	0.18	59	1.18	0	0.00
0.18	0.19	57	1.14	1	0.08
0.19	0.20	61	1.22	4	0.32
0.20	0.21	76	1.52	1	0.08
0.21	0.22	85	1.70	2	0.16
0.22	0.23	82	1.64	4	0.32
0.23	0.24	71	1.42	4	0.32
0.24	0.25	77	1.54	3	0.24
0.25	0.26	91	1.82	6	0.48
0.26	0.27	95	1.90	5	0.40
0.27	0.28	109	2.18	9	0.72
0.28	0.29	109	2.18	11	0.88
0.29	0.30	113	2.26	7	0.56
0.30	0.31	146	2.92	16	1.29
0.31	0.32	166	3.32	26	2.09
0.32	0.33	159	3.18	43	3.46
0.33	0.34	188	3.76	39	3.14
0.34	0.35	179	3.58	66	5.31
0.35	0.36	219	4.38	79	6.35
0.36	0.37	192	3.84	85	6.83
0.37	0.38	187	3.74	65	5.23
0.38	0.39	169	3.38	61	4.90
0.39	0.40	214	4.28	50	4.02
0.40	0.41	162	3.24	68	5.47
0.41	0.42	158	3.16	67	5.39
0.42	0.43	157	3.14	69	5.55
0.43	0.44	142	2.84	66	5.31
0.44	0.45	137	2.74	53	4.26
0.45	0.46	116	2.32	54	4.34
0.46	0.47	107	2.14	51	4.10
0.47	0.48	82	1.64	45	3.62
0.48	0.49	76	1.52	34	2.73
0.49	0.50	58	1.16	24	1.93
0.50	0.51	64	1.28	22	1.77
0.51	0.52	47	0.94	24	1.93
0.52	0.53	32	0.64	14	1.13
0.53	0.54	30	0.60	5	0.40
0.54	0.55	21	0.42	6	0.48
0.55	0.56	29	0.58	4	0.32
0.56	0.57	21	0.42	10	0.80
0.57	0.58	16	0.32	6	0.48
0.58	0.59	13	0.26	8	0.64
0.59	0.60	10	0.20	3	0.24
0.60	0.61	15	0.30	4	0.32
0.61	0.62	9	0.18	4	0.32
0.62	0.63	8	0.16	3	0.24
0.63	0.64	8	0.16	1	0.08
0.64	0.65	5	0.10	2	0.16
0.65	0.66	3	0.06	0	0.00
0.66	0.67	4	0.08	0	0.00
0.67	0.68	6	0.12	2	0.16
0.68	0.69	5	0.10	0	0.00
0.69	0.70	6	0.12	0	0.00
0.71	0.72	2	0.04	2	0.16
0.72	0.73	2	0.04	0	0.00
0.73	0.74	1	0.02	0	0.00
0.79	0.80	1	0.02	0	0.00
0.86	0.87	1	0.02	0	0.00
0.94	0.95	1	0.02	1	0.08
1.00	1.01	2	0.04	0	0.00
				1	0.08

TDOP-II-FSFMS-011

ASF TRUCK FS4

3/13/79 FS4, FILTER=8, NORMAL>100, POWER<-250
FRICTION COEFFICIENT=0.488+/-0.262 NUMBER= 844
TOTAL ENERGY=-0.444E+04 IN-LB, INCLUDED ENERGY=
-0.468E+04 IN-LB, PERCENT INCLUDED=105.5

MIN	MAX	NUMBER	PERCENT	NUMBER	PERCENT
0.00	0.01	38	0.76	0	0.00
0.01	0.02	8	0.16	0	0.00
0.02	0.03	12	0.24	0	0.00
0.03	0.04	22	0.44	0	0.00
0.04	0.05	23	0.46	0	0.00
0.05	0.06	23	0.46	0	0.00
0.06	0.07	33	0.66	0	0.00
0.07	0.08	32	0.64	0	0.00
0.08	0.09	30	0.60	0	0.00
0.09	0.10	38	0.76	0	0.00
0.10	0.11	44	0.88	0	0.00
0.11	0.12	46	0.92	0	0.00
0.12	0.13	46	0.92	1	0.12
0.13	0.14	56	1.12	0	0.00
0.14	0.15	62	1.24	0	0.00
0.15	0.16	49	0.98	0	0.00
0.16	0.17	57	1.14	0	0.00
0.17	0.18	89	1.78	3	0.36
0.18	0.19	73	1.46	1	0.12
0.19	0.20	71	1.42	6	0.71
0.20	0.21	83	1.66	2	0.24
0.21	0.22	87	1.74	0	0.00
0.22	0.23	78	1.56	3	0.36
0.23	0.24	98	1.96	5	0.59
0.24	0.25	80	1.60	9	1.07
0.25	0.26	100	2.00	4	0.47
0.26	0.27	91	1.82	7	0.83
0.27	0.28	118	2.36	5	0.59
0.28	0.29	114	2.28	10	1.18
0.29	0.30	118	2.36	5	0.59
0.30	0.31	112	2.24	7	0.83
0.31	0.32	125	2.50	9	1.07
0.32	0.33	132	2.64	10	1.18
0.33	0.34	139	2.78	12	1.42
0.34	0.35	133	2.66	25	2.96
0.35	0.36	161	3.22	20	2.37
0.36	0.37	184	3.68	45	5.33
0.37	0.38	159	3.18	71	8.41
0.38	0.39	151	3.02	72	8.53
0.39	0.40	91	1.82	64	7.58
0.40	0.41	115	2.30	36	4.27
0.41	0.42	95	1.90	44	5.21
0.42	0.43	79	1.58	23	2.73
0.43	0.44	77	1.54	20	2.37
0.44	0.45	79	1.58	13	1.54
0.45	0.46	70	1.40	14	1.66
0.46	0.47	73	1.46	17	2.01
0.47	0.48	60	1.20	19	2.25
0.48	0.49	49	0.98	18	2.13
0.49	0.50	47	0.94	9	1.07
0.50	0.51	39	0.78	12	1.42
0.51	0.52	40	0.80	10	1.18
0.52	0.53	44	0.88	16	1.90
0.53	0.54	38	0.76	15	1.78
0.54	0.55	46	0.92	10	1.18
0.55	0.56	36	0.72	20	2.37
0.56	0.57	24	0.48	12	1.42
0.57	0.58	23	0.46	3	0.36
0.58	0.59	17	0.34	4	0.47
0.59	0.60	16	0.32	5	0.59
0.60	0.61	21	0.42	5	0.59
0.61	0.62	21	0.42	6	0.71
0.62	0.63	16	0.32	5	0.59
0.63	0.64	18	0.36	3	0.36
0.64	0.65	18	0.36	3	0.36
0.65	0.66	19	0.38	5	0.59
0.66	0.67	24	0.48	6	0.71
0.67	0.68	15	0.30	7	0.83
0.68	0.69	10	0.20	1	0.12
0.69	0.70	14	0.28	2	0.24
0.70	0.71	12	0.24	2	0.24
0.71	0.72	12	0.24	2	0.24
0.72	0.73	7	0.14	3	0.36
0.73	0.74	8	0.16	3	0.36
0.74	0.75	5	0.10	2	0.24
0.75	0.76	15	0.30	0	0.00
0.76	0.77	19	0.38	1	0.12
0.77	0.78	11	0.22	1	0.12
0.78	0.79	12	0.24	2	0.24
				2	0.24

ASF TRUCK FS4
(Continued)

MIN	MAX	NUMBER	PERCENT	NUMBER	PERCENT
0.79	0.80	12	0.24	3	0.36
0.80	0.81	16	0.32	3	0.36
0.81	0.82	6	0.12	2	0.24
0.82	0.83	7	0.14	1	0.12
0.83	0.84	12	0.24	1	0.12
0.84	0.85	12	0.24	0	0.00
0.85	0.86	11	0.22	3	0.36
0.86	0.87	12	0.24	2	0.24
0.87	0.88	10	0.20	0	0.00
0.88	0.89	9	0.18	0	0.00
0.89	0.90	14	0.28	3	0.36
0.90	0.91	5	0.10	1	0.12
0.91	0.92	11	0.22	1	0.12
0.92	0.93	11	0.22	0	0.00
0.93	0.94	10	0.20	1	0.12
0.94	0.95	7	0.14	2	0.24
0.95	0.96	6	0.12	1	0.12
0.96	0.97	3	0.06	0	0.00
0.97	0.98	7	0.14	2	0.24
0.98	0.99	4	0.08	1	0.12
0.99	1.00	15	0.30	3	0.36
1.00	1.01	250	5.00	37	4.38

TDOP-II-FSFMS-011