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THE YAW STABILITY OF TRACTOR-SEMITRAILERS DURING CORNERING

APPENDICES

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16. Abstract

The yaw stability of tractor-semitrailers in steering-only maneuvers is examined by means of computer simulation and full-scale tests. The tests included as-designed vehicles as well as vehicles modified with frame and front suspension stiffening elements installed. Results show that while tractor yaw instability can occur well below the rollover threshold for certain vehicles, modified stiffness parameters can eliminate such premature yaw instability.

Simulation study of the influence of design and operating variables on tractor yaw stability served to classify the relative importance of different suspension stiffness options, as well as tire mix, fifth wheel placement, and trailer loading practices. Results show that remarkably low levels of tractor yaw stability are possible with certain combinations of design and in-use variables.

A set of measurements of tractor-semitrailer ride vibrations is also reported as an add-on task to this study.

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Appendices

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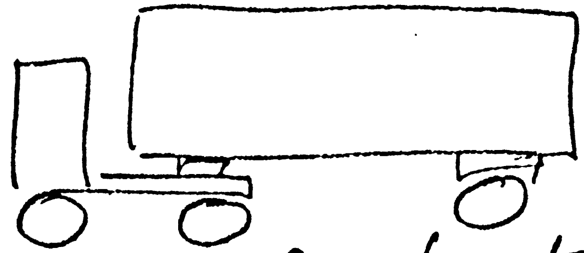
APPENDIX I

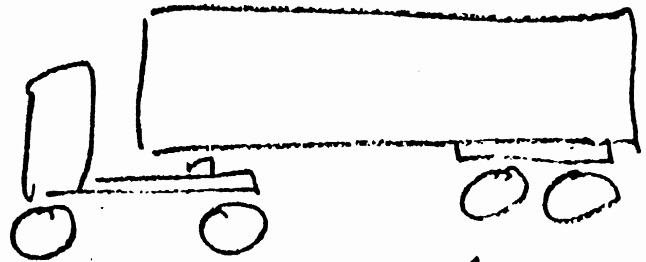
SURVEY OF ACCIDENT DATA

In this appendix are presented accident data summarizing the content of the BMCS data file for 1976, as sorted for tractor-semitrailer combinations, only. The data are presented to show the jackknife (JK), overturn (OT), other, and total accidents occurring for trailer body type and cargo type for each of four possible combinations of tractor and trailer axle arrangements. Separate tables are provided for each of the configurations: (2/1), (2/2), (3/1), and (3/2), representing $\frac{\text{no. of tractor axles}}{\text{no. of semitrailer axles}}$. For each three-line row of data, the top line lists the number of accidents of the JK, OT, and Other type represented in the file, the second line (called Row %) lists the percentage of that vehicle's total accidents which were of the JK, OT, or Other type, and the third line lists the percentage of all JK, OT, or Other accidents in which that particular vehicle category was involved.



Comb. Config. (2/1)
- by Trailer Type

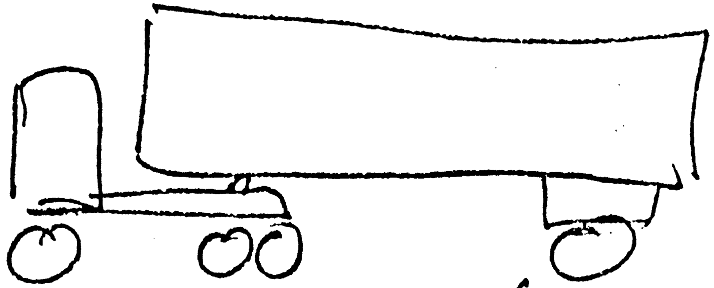
		(1) JK	(2) OT	(3) OTHER	(TOTAL)
	(1)	30	73	896	999
Van	(ROW %)	3.0	7.3	89.7	100.0
	(COL %)	85.7	78.5	81.2	81.1
	(2)	0	5	60	65
Flat	(ROW %)	0.0	7.7	92.3	100.0
	(COL %)	0.0	5.4	5.4	5.3
	(3)	1	3	23	27
Tank	(ROW %)	3.7	11.1	85.2	100.0
	(COL %)	2.9	3.2	2.1	2.2
	(4)	0	0	28	28
Auto Carrier	(ROW %)	0.0	0.0	100.0	100.0
	(COL %)	0.0	0.0	2.5	2.3
	(6)	0	0	2	2
Dump	(ROW %)	0.0	0.0	100.0	100.0
	(COL %)	0.0	0.0	0.2	0.2
	(7)	4	6	68	78
Unknown	(ROW %)	5.1	7.7	87.2	100.0
	(COL %)	11.4	6.5	6.2	6.3
	(8)	0	6	27	33
Other	(ROW %)	0.0	18.2	81.8	100.0
	(COL %)	0.0	6.5	2.4	2.7
	(TOTAL)	35	93	1104	1232
	(ROW %)	2.8	7.5	89.6	100.0
	(COL %)	100.0	100.0	102.0	100.0



Comb. Config. (2/2)
-by Trailer Type

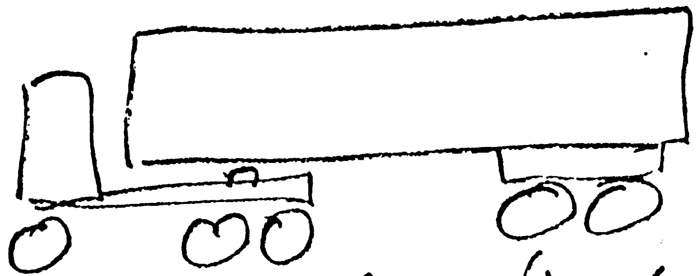
		(1) JK	(2) OT	(3) OTHER	(TOTAL)
Van	(1)	76	59	1342	1477
	(ROW %)	5.1	4.0	90.9	100.0
	(COL %)	73.8	77.6	76.5	76.4
Flat	(2)	6	4	116	126
	(ROW %)	4.8	3.2	92.1	100.0
	(COL %)	5.8	5.3	6.6	6.5
Tank	(3)	4	5	80	89
	(ROW %)	4.5	5.6	89.9	100.0
	(COL %)	3.9	6.6	4.6	4.6
Auto Carrier	(4)	0	0	27	27
	(ROW %)	0.0	0.0	100.0	100.0
	(COL %)	0.0	0.0	1.5	1.4
Refrigerated	(5)	0	0	1	1
	(ROW %)	0.0	0.0	100.0	100.0
	(COL %)	0.0	0.0	0.1	0.1
Dump	(6)	0	0	7	7
	(ROW %)	0.0	0.0	100.0	100.0
	(COL %)	0.0	0.0	0.4	0.4
Unknown	(7)	14	4	140	158
	(ROW %)	8.9	2.5	88.6	100.0
	(COL %)	13.6	5.3	8.0	8.2
Other	(8)	3	4	42	49
	(ROW %)	6.1	8.2	85.7	100.0
	(COL %)	2.9	5.3	2.4	2.5
	(TOTAL)	103	76	1755	1934
	(ROW %)	5.3	3.9	90.7	100.0
	(COL %)	100.0	100.0	100.0	100.0

		(1) JK	(2) OT	(3) OTHEP	(TOTAL)
	(1)	3	6	81	90
Van	(ROW %)	3.3	6.7	90.0	100.0
	(COL %)	60.0	85.7	52.9	54.5
	(2)	0	0	15	15
Flat	(ROW %)	0.0	0.0	100.0	100.0
	(COL %)	0.0	0.0	9.8	9.1
	(3)	0	0	6	6
Tank	(ROW %)	0.0	0.0	100.0	100.0
	(COL %)	0.0	0.0	3.9	3.6
	(4)	0	0	28	28
Auto Carrier	(ROW %)	0.0	0.0	100.0	100.0
	(COL %)	0.0	0.0	18.3	17.0
	(7)	1	1	13	15
Unknown	(ROW %)	6.7	6.7	86.7	100.0
	(COL %)	20.0	14.3	8.5	9.1
	(8)	1	0	10	11
Other	(ROW %)	9.1	0.0	90.9	100.0
	(COL %)	20.0	0.0	6.5	6.7
	(TOTAL)	5	7	153	165
	(ROW %)	3.0	4.2	92.7	100.0
	(COL %)	100.0	100.0	100.0	100.0



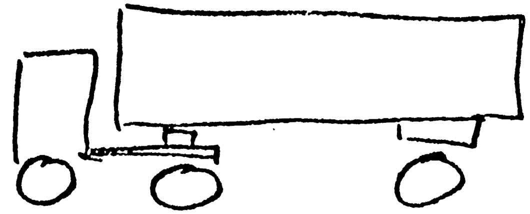
Comb. Config. (3/1)
- by Trailer Type

		(1) JK	(2) OT	(3) OTHER	(TOTAL)
Van	(1)	280	471	5867	6,618
	(ROW %)	4.2	7.1	88.7	100.0
	(COL %)	64.7	50.3	52.3	52.6
Flat	(2)	41	199	2213	2453
	(ROW %)	1.7	8.1	90.2	100.0
	(COL %)	9.5	21.3	19.7	19.5
Tank	(3)	59	156	1487	1702
	(ROW %)	3.5	9.2	87.4	100.0
	(COL %)	13.6	16.7	13.3	13.5
Auto Carrier	(4)	1	5	387	393
	(ROW %)	0.3	1.3	98.5	100.0
	(COL %)	0.2	0.5	3.5	3.1
Refrigerated	(5)	11	16	185	212
	(ROW %)	5.2	7.5	87.3	100.0
	(COL %)	2.5	1.7	1.7	1.7
Dump	(6)	1	10	62	73
	(ROW %)	1.4	13.7	84.9	100.0
	(COL %)	0.2	1.1	0.6	0.6
Unknown	(7)	27	55	692	774
	(ROW %)	3.5	7.1	89.4	100.0
	(COL %)	6.2	5.9	6.2	6.2
Other	(8)	13	24	315	352
	(ROW %)	3.7	6.8	89.5	100.0
	(COL %)	3.0	2.6	2.8	2.8
	(TOTAL)	433	936	11208	12577
	(ROW %)	3.4	7.4	89.1	100.0
	(COL %)	100.0	100.0	100.0	100.0



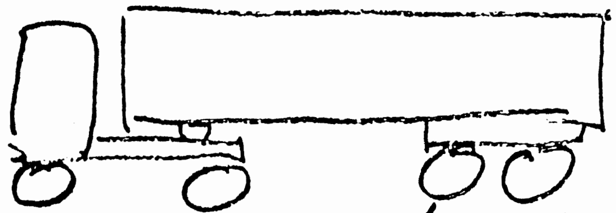
Comb. Config. (3/2)
-by Trailer Type

		(1) JK	(2) OT	(3) OTHER	(TOTAL)
Empty	(1)	5	2	188	195
	(ROW %)	2.6	1.0	96.4	100.0
	(COL %)	14.3	2.2	17.0	15.8
Bulk Frt.	(2)	29	83	864	976
	(ROW %)	3.0	8.5	88.5	100.0
	(COL %)	82.9	89.2	78.3	79.2
Metal, Hvy. Mach.	(3)	0	5	17	22
	(ROW %)	0.0	22.7	77.3	100.0
	(COL %)	0.0	5.4	1.5	1.8
Motor Vehicles	(4)	1	0	18	19
	(ROW %)	5.3	0.0	94.7	100.0
	(COL %)	2.9	0.0	1.6	1.5
Bulk Liquids	(6)	0	2	11	13
	(ROW %)	0.0	15.4	84.6	100.0
	(COL %)	0.0	2.2	1.0	1.1
Misc.	(7)	0	1	3	4
	(ROW %)	0.0	25.0	75.0	100.0
	(COL %)	0.0	1.1	0.3	0.3
Unknown	(8)	0	0	3	3
	(ROW %)	0.0	0.0	100.0	100.0
	(COL %)	0.0	0.0	0.3	0.2
	(TOTAL)	35	93	1104	1232
	(ROW %)	2.8	7.5	89.6	100.0
	(COL %)	100.0	100.0	100.0	100.0

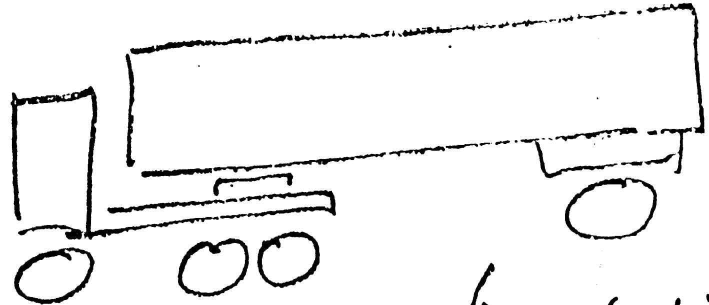


Comb. Config. (2/1)
- by Trailer Cargo Type

		(1) JK	(2) OT	(3) OTHER	(TOTAL)
Empty	(1)	44	2	314	360
	(ROW %)	12.2	0.6	87.2	100.0
	(COL %)	42.7	2.6	17.9	18.6
Bulk Frt.	(2)	56	67	1321	1444
	(ROW %)	3.9	4.6	91.5	100.0
	(COL %)	54.4	88.2	75.3	74.7
Metal, Hvy. Mach.	(3)	2	2	39	43
	(ROW %)	4.7	4.7	90.7	100.0
	(COL %)	1.9	2.6	2.2	2.2
Motor Vehicles	(4)	0	0	26	26
	(ROW %)	0.0	0.0	100.0	100.0
	(COL %)	0.0	0.0	1.5	1.3
Draway/ Towaway	(5)	0	0	1	1
	(ROW %)	0.0	0.0	100.0	100.0
	(COL %)	0.0	0.0	0.1	0.1
Bulk Liquids	(6)	0	5	44	49
	(ROW %)	0.0	10.2	89.8	100.0
	(COL %)	0.0	6.6	2.5	2.5
Misc.	(7)	0	0	3	3
	(ROW %)	0.0	0.0	100.0	100.0
	(COL %)	0.0	0.0	0.2	0.2
Unknown	(8)	1	0	7	8
	(ROW %)	12.5	0.0	87.5	100.0
	(COL %)	1.0	0.0	0.4	0.4
	(TOTAL)	103	76	1755	1934
	(ROW %)	5.3	3.9	90.7	100.0
	(COL %)	100.0	100.0	100.0	100.0



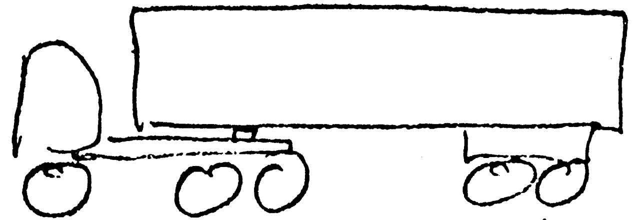
Comb. Config (2/2)
-by Trailer Cargo Type



Comb. Config. (3/1)
– by Trailer Cargo Type

		(1) JK	(2) OT	(3) OTHER	(TOTAL)
Empty	(1)	0	0	26	26
	(ROW %)	0.0	0.0	100.0	100.0
	(COL %)	0.0	0.0	17.0	15.8
Bulk Frt.	(2)	4	7	85	96
	(ROW %)	4.2	7.3	88.5	100.0
	(COL %)	80.0	100.0	55.6	58.2
Metal, Hvy. Mach.	(3)	1	0	8	9
	(ROW %)	11.1	0.0	88.9	100.0
	(COL %)	20.0	0.0	5.2	5.5
Motor Vehicles	(4)	0	0	30	30
	(ROW %)	0.0	0.0	100.0	100.0
	(COL %)	0.0	0.0	19.6	18.2
Bulk Liquids	(6)	0	0	2	2
	(ROW %)	0.0	0.0	100.0	100.0
	(COL %)	0.0	0.0	1.3	1.2
Misc.	(7)	0	0	1	1
	(ROW %)	0.0	0.0	100.0	100.0
	(COL %)	0.0	0.0	0.7	0.6
Unknown	(8)	0	0	1	1
	(ROW %)	0.0	0.0	100.0	100.0
	(COL %)	0.0	0.0	0.7	0.6
	(TOTAL)	5	7	153	165
	(ROW %)	3.0	4.2	92.7	100.0
	(COL %)	100.0	100.0	100.0	100.0

		(1) JK	(2) OT	(3) OTHER	(TOTAL)
Empty	(1)	199	18	2484	2701
	(ROW %)	7.4	0.7	92.0	100.0
	(COL %)	46.0	1.9	22.2	21.5
Bulk Frt.	(2)	211	663	6330	7204
	(ROW %)	2.9	9.2	87.9	100.0
	(COL %)	48.7	70.8	56.5	57.3
Metal, Hvy. Mach.	(3)	9	101	1208	1318
	(ROW %)	0.7	7.7	91.7	100.0
	(COL %)	2.1	10.8	10.8	10.5
Motor Vehicles	(4)	0	6	306	312
	(ROW %)	0.0	1.9	98.1	100.0
	(COL %)	0.0	0.6	2.7	2.5
Draway/ Towaway	(5)	1	0	1	2
	(ROW %)	50.0	0.0	50.0	100.0
	(COL %)	0.2	0.0	0.0	0.0
Bulk Liquids	(6)	7	133	782	922
	(ROW %)	0.8	14.4	84.8	100.0
	(COL %)	1.6	14.2	7.0	7.3
Misc.	(7)	4	11	65	80
	(ROW %)	5.0	13.8	81.3	100.0
	(COL %)	0.9	1.2	0.6	0.6
Unknown	(8)	2	4	32	38
	(ROW %)	5.3	10.5	84.2	100.0
	(COL %)	0.5	0.4	0.3	0.3
	(TOTAL)	433	936	11208	12577
	(ROW %)	3.4	7.4	89.1	100.0
	(COL %)	100.0	100.0	100.0	100.0



Comb. Config. (3/2)
–by Trailer Cargo Type

APPENDIX II

VEHICLE PARAMETER LISTINGS

Listed in this appendix are the parameters used for the purpose of simulating the directional response of tractor-semitrailer-type vehicles using the Phase II simulation [1]*. The eight sets of parameters listings included here correspond to the baseline configuration of each vehicle combination for which a parameter variation study was conducted. The eight vehicle combinations are described below:

1) International Harvester tractor/Fruehauf van trailer
2) Ford tractor/Fruehauf van trailer
3) Ford tractor/Trailmobile flat-bed trailer
4) 110" wheelbase, two-axle, C.O.E. tractor/single-axle, 40' van trailer
5) 140" wheelbase, two-axle, C.O.E. tractor/single-axle, 40' van trailer
6) 145" wheelbase, three-axle, C.O.E. tractor/tandem-axle, 45' van trailer
7) 165" wheelbase, three-axle, conventional tractor/tandem-axle, 45' van trailer
8) 200" wheelbase, three-axle, conventional tractor/tandem-axle, 45' van trailer

Additional explanation of the meaning of each parameter is given in the Phase II technical report [1].

Tire Data

The tire data (which turns out to be very lengthy if listed for each tire mounted on a vehicle) has not been included in the main listings of

*Numbers in brackets refer to references provided in this appendix at the conclusion of the explanatory text.

each set of vehicle parameters. Rather, the specific tires employed with each vehicle configuration are simply identified by manufacturer and size. Tire parameters, themselves, are then listed for each of the identified tires at the conclusion of the presentation of all vehicle parameters.

With reference to the tire data, it should be noted that the parameters describing the cornering stiffness characteristics were obtained by curve-fitting the measured lateral force-sideslip angle data. A detailed description of the tire model and the definition of the curve-fitting parameters is given in Appendix B of [2].

Parameters Values Used in the Parameter Variation Study

The first three data sets were used for the purpose of studying the sensitivity of tractor yaw stability to changes in tractor roll stiffness distribution. The two parameters that are varied are the tractor frame stiffness, TTC, and the auxiliary roll stiffness at the tractor front axle, KRS(1). For each vehicle combination, the parameter TTC was varied from 20,000 in-lb/deg (for the baseline case) to 140,000 in-lb/deg, in steps of 20,000 in-lb/deg; while the parameter KRS(1) was varied from 0.0 in-lb/deg (for the baseline case) to 150,000 in-lb/deg in steps of 25,000 in-lb/deg. For cases in which the tires on the tractor rear axles are replaced by lug tires, tire data corresponding to the Uniroyal 10x20 Fleetmaster Superlug were used.

The data sets four through eight were used for the purpose of studying the influence of the following parameters on the yaw divergency and rollover behavior of tractor-semitrailers:

K1 - Tractor front axle suspension stiffness (lb/in)

K2 - Tractor rear axle suspension stiffness (lb/in)

K3 - Trailer suspension stiffness (lb/in)

BB - Longitudinal distance of fifth wheel from the midpoint of the tractor tandem (in)

PZ - Height of payload center of gravity above ground level (in)

The values of these five parameters for each of the 24 configurations are given in Table II.1. Once again, for cases in which the tractor rear tires are replaced by lug tires, tire data corresponding to the Uniroyal 10x20 Fleetmaster Superlug were used.

Estimation of Frame Compliance Parameters TTC and TRSTF

In the modified version of the Phase II tractor-semitrailer model the roll compliances of the tractor and trailer frame are represented by the lumped-stiffness parameters TTC and TRSTF, respectively. In reality, both the mass and compliance pertaining to the sprung masse elements are distributed along the length of the tractor and trailer frames. Hence, unless proper care is taken in estimating these parameters, the calculations made using the model can be in error (especially for the cases in which the structures are highly compliant). The method adopted for calculating these parameters is presented in the following paragraphs.

Tractor Frame Stiffness Parameter TTC. Typical layouts of engines and transmissions of commercial tractors cause the sprung mass of the tractor to be located near the front axle. Typical torsional compliance values for the portion of the tractor frame that extends from the tractor sprung mass center to the front axle are small, and thus can be neglected for the purposes of these simulations. The tractor frame stiffness parameter, TTC, can thus be defined as the measured (or estimated) torsional stiffness of the entire length of the frame from tractor front axle to the tractor rear axle.

Trailer Frame Stiffness Parameter TRSTF. Unlike the tractor, the trailer frame compliance and mass are more evenly distributed along the length of the frame. Hence, two problems arise with regard to representing the trailer as a lumped parameter model.

1) Due to the distributed nature of both the mass and the frame compliance, the measured (or estimated) static torsional frame stiffness cannot be used directly as the value for the lumped stiffness parameter TRSTF (as was possible for TTC).

Table II.1

		Tractor suspension: Typ front, typ rear (K1 & K2)												Tractor suspension: Low front, high rear (K1 & K2)											
	BB	5th wheel forward						5th wheel over tractor rear axle						5th wheel forward						5th wheel over tractor rear axle					
Trailer susp. stiffness	K3	Typical			Low			Typical			Low			Typical			Low			Typical			Low		
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
110" W.B., 2 AXLE,	K1	1100	—*	—	—	—	—	—	—	—	—	—	—	850	850	850	850	850	850	850	850	850	850	850	850
C.O.E. TRACTOR –	K2	8000	—	—	—	—	—	—	—	—	—	—	—	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000
	BB	21.0	—	—	—	—	—	0.0	0.0	0.0	0.0	0.0	0.0	—	—	—	—	—	—	0.0	0.0	0.0	0.0	0.0	0.0
SINGLE AXLE	K3	8000	—	—	5000	5000	5000	—	—	—	5000	5000	5000	—	—	—	5000	5000	5000	—	—	—	5000	5000	5000
40' TRAILER	P2	68	78	88	68	78	88	68	78	88	68	78	88	68	78	88	68	78	88	68	78	88	68	78	88
140" W.B., 2 AXLE,	K1	1100	—	—	—	—	—	—	—	—	—	—	—	850	850	850	850	850	850	850	850	850	850	850	850
C.O.E. TRACTOR –	K2	8000	—	—	—	—	—	—	—	—	—	—	—	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000
	BB	22.5	—	—	—	—	—	0.0	0.0	0.0	0.0	0.0	0.0	—	—	—	—	—	—	0.0	0.0	0.0	0.0	0.0	0.0
SINGLE AXLE	K3	8000	—	—	5000	5000	5000	—	—	—	5000	5000	5000	—	—	—	5000	5000	5000	—	—	—	5000	5000	5000
40' TRAILER	P2	68	78	88	68	78	88	68	78	88	68	78	88	68	78	88	68	78	88	68	78	88	68	78	88
145" W.B., 3 AXLE,	K1	1300	—	—	—	—	—	—	—	—	—	—	—	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100
C.O.E. TRACTOR –	K2	10000	—	—	—	—	—	—	—	—	—	—	—	16000	16000	16000	16000	16000	16000	16000	16000	16000	16000	16000	16000
	BB	18.8	—	—	—	—	—	0.0	0.0	0.0	0.0	0.0	0.0	—	—	—	—	—	—	0.0	0.0	0.0	0.0	0.0	0.0
TANDEM AXLE	K3	16000	—	—	8000	8000	8000	—	—	—	8000	8000	8000	—	—	—	8000	8000	8000	—	—	—	8000	8000	8000
45' TRAILER	P2	68	78	88	68	78	88	68	78	88	68	78	88	68	78	88	68	78	88	68	78	88	68	78	88
165" W.B., 3 AXLE	K1	1300	—	—	—	—	—	—	—	—	—	—	—	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100
CONV. TRACTOR –	K2	10000	—	—	—	—	—	—	—	—	—	—	—	16000	16000	16000	16000	16000	16000	16000	16000	16000	16000	16000	16000
	BB	24.7	—	—	—	—	—	0.0	0.0	0.0	0.0	0.0	0.0	—	—	—	—	—	—	0.0	0.0	0.0	0.0	0.0	0.0
TANDEM AXLE	K3	16000	—	—	8000	8000	8000	—	—	—	8000	8000	8000	—	—	—	8000	8000	8000	—	—	—	8000	8000	8000
45' TRAILER	P2	68	78	88	68	78	88	68	78	88	68	78	88	68	78	88	68	78							
200" W.B., 3 AXLE	K1	1300	—	—	—	—	—	—	—	—	—	—	—	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100
CONV. TRACTOR –	K2	10000	—	—	—	—	—	—	—	—	—	—	—	16000	16000	16000	16000	16000	16000	16000	16000	16000	16000	16000	16000
	BB	24.4	—	—	—	—	—	0.0	0.0	0.0	0.0	0.0	0.0	—	—	—	—	—	—	0.0	0.0	0.0	0.0	0.0	0.0
TANDEM AXLE	K3	16000	—	—	8000	8000	8000	—	—	—	8000	8000	8000	—	—	—	8000	8000	8000	—	—	—	8000	8000	8000
45' TRAILER	P2	68	78	88	68	78	88	68	78	88	68	78	88	68	78	88	68	78	88	68	78	88	68	78	88

Baseline: All rib or rib/lug

* NOTE: '—' denotes, value same as that in column (1)

2) There is no provision in the model for incorporating the compliance of that portion of the frame which extends from the trailer sprung mass center to the trailer rear axles.

With reference to Figure II.1, we note that a steady turn of lateral acceleration, a_y, causes a total roll moment of $(M \cdot a_y \cdot h_T)$ to act on the frame. If the mass and stiffness are uniformly distributed, it can be shown that the twist deflection, ϕ, at the midpoint of the frame with respect to the ends is given by

$$\phi = \frac{M h_T a_y}{8K} \tag{1}$$

If the trailer is to be represented by a lumped parameter model and if an authentic deflection, ϕ, is to take place, then the springs that connect the sprung mass to the fifth wheel and to the rear suspension should have a torsional stiffness of 4K each. Therefore, the value used for TRSTF is four times the measured (or estimated) stiffness of the trailer frame.

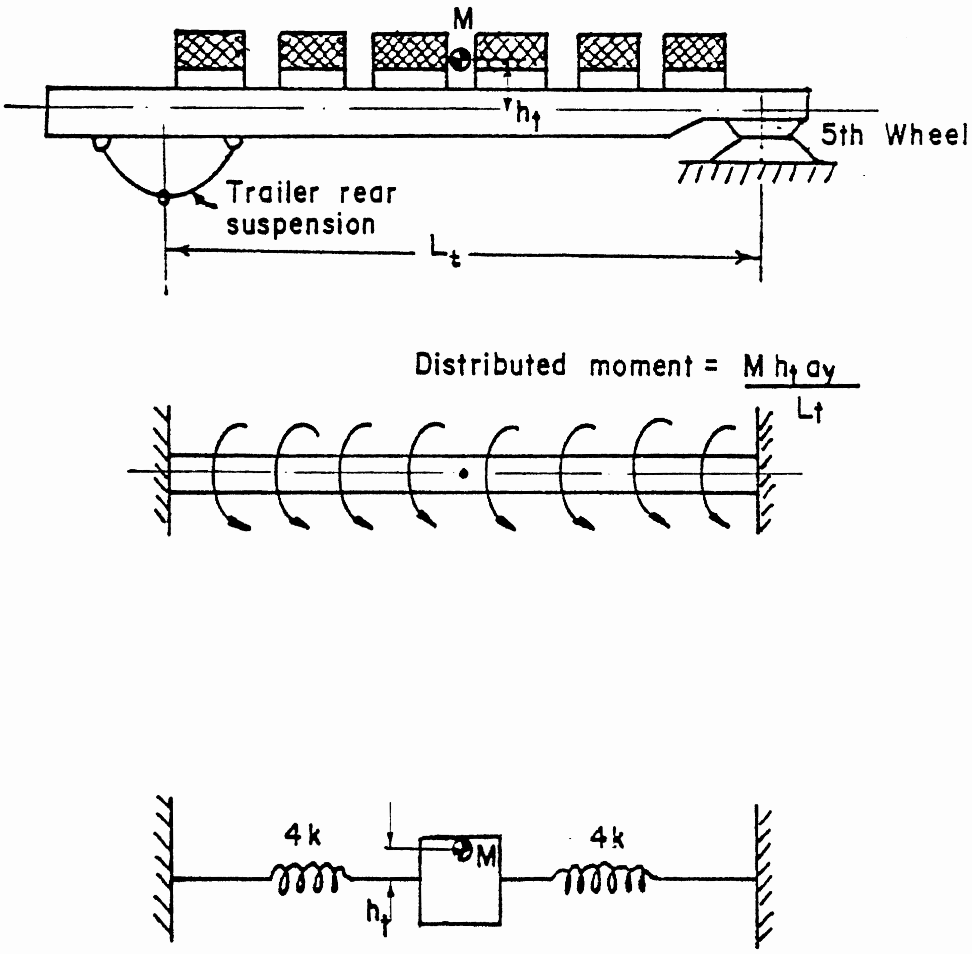
Next, the influence of the compliance in the trailer frame, which extends from the sprung mass c.g. to the trailer suspension, is accounted for by using suitable values for the trailer suspension roll center height and roll stiffness.

A schematic view of the rear section of the trailer is shown in Figure II.2. From static equilibrium, it can be shown that the moment, T, transmitted to the trailer sprung mass from the trailer rear suspension is given by the expression:

$$T = SMY\left(h_2 + \frac{K_2 h_1}{(K_1+K_2)}\right) + \frac{K_1 K_2}{K_1+K_2} \quad (\phi_1 - \phi_3)$$

$$= SMY \cdot h_{eq} + K_{eq} \cdot (\phi_1 - \phi_3)$$

or



h_t = height of sprung mass c.g. above the frame compliance axis

M = Sprung mass of the trailer

a_y = Lateral acceleration of the turn

k = Static stiffness of the trailer

Figure II.1

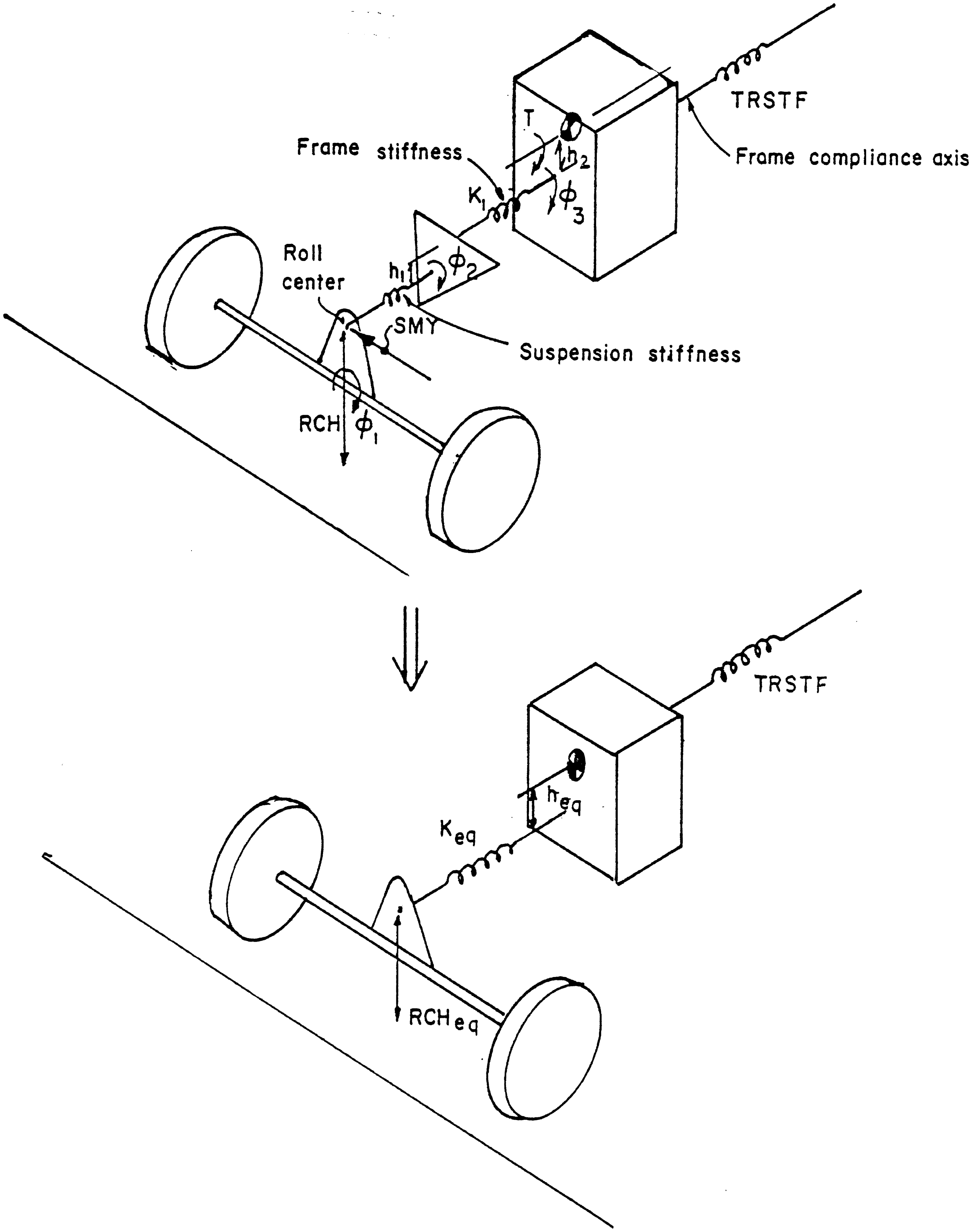

TRSTF
Frame compliance axis
Frame stiffness
T
h_2
K_1
ϕ_3
Roll
center
h_1
ϕ_2
SMY
Suspension stiffness
RCH
ϕ_1
TRSTF
h_{eq}
K_{eq}
RCH_{eq}

Figure II.2

$$RCH_{eq} = RCH + h_1 + h_2 - h_{eq}$$

$$RCH_{eq} = RCH + \frac{h_1 K_1}{(K_1+K_2)}$$

$$K_{eq} = \frac{K_1 K_2}{K_1+K_2}$$

$$KRS = K_{eq} - K_1$$

$$KRS = \frac{-K_1{}^2}{(K_1+K_2)}$$

Therefore, the actual roll center height, RCH, of the trailer suspension is replaced by the equivalent roll center height, RCH_{eq}. The reduction in the effective stiffness of the trailer suspension is accounted for by using a negative auxiliary roll stiffness of $-K_1^2/(K_1+K_2)$.

The above method was adopted for computing the parameters, TRSTF, KRS(3), and RCH(3) for the flat-bed trailer in this study. The stiffness of the van trailer frame was found to be sufficiently high (almost four times the stiffness of the trailer suspension) that no correction was found necessary.

References

1. Bernard, J.E., Winkler, C.B., and Fancher, P.S. "A Computer-Based Mathematical Method for Predicting the Directional Response of Trucks and Tractor-Trailers." Phase II Technical Report: Motor Truck Braking and Handling Performance Study, Report No. UM-HSRI-PF-73-1, Highway Safety Research Institute, University of Michigan, June 1, 1973.

2. Moncarz, H., Bernard, J.E., Gupta, R., and Fancher, P.S. "Vehicle-In-Use Limit Performance and Tire Factors, Appendix B." Final Report, Contract No. DOT-HS-031-3-693, Report No. UM-HSRI-PF-75-1-3, Highway Safety Research Institute, University of Michigan, January 31, 1975.

VEHICLE PARAMETER LISTINGS

IHC-TRACTOR VAN TRLER LOADED,10X22, 10X20 FIRESTONE-TIRES *1A3 1B3*

INPUT PARAMETER TABLE

SYMBOL	DESCRIPTION	INITIAL VALUE
KEY(1)	TRACTOR AXLE KEY: 0 FOR SINGLE AXLE 1 FOR WALKING BEAM 2 FOR 4 ELLIPTIC LEAF	2
KEY(2)	TRAILER AXLE KEY	2
AA1	HORIZONTAL DISTANCE FORM TRACTOR FRONT LEAF-FRAME CONTACT TO AXLE CENTER (IN)	24.00
AA2	HORIZONTAL DISTANCE FROM TRACTOR REAR LEAF-FRAME CONTACT TO AXLE CENTER (IN)	24.00
AA4	HORIZONTAL DISTANCE FROM TRACTOR FRONT LEAF-FRAME CONTACT TO LOAD LEVELER PIN (IN	1.00
AA5	HORIZONTAL DISTANCE FROM TRACTOR REAR LEAF-FRAME CONTACT TO LOAD LEVELER PIN (IN	1.00
AA6	VERTICAL DISTANCE FROM AXLE DOWN TO TRACTOR TORQUE ROD (IN)	0.0
AA7	ANGLE BETWEEN TRACTOR TORQUE ROD AND HORIZONTAL (DEG)	0.0
AA8	HORIZONTAL DISTANCE FROM AXLE CENTER FORWARD TO TRACTOR TORQUE ROD (IN)	0.0
AA9	HORIZONTAL DISTANCE FROM TRAILER FRONT LEAF-FRAME CONTACT TO AXLE CENTER (IN)	18.50
AA10	HORIZONTAL DISTANCE FROM TRAILER REAR LEAF-FRAME CONTACT TO AXLE CENTER (IN)	18.50
AA12	HORIZONTAL DISTANCE FROM TRAILER FRONT LEAF-FRAME CONTACT TO LOAD LEVELER PIN (IN	6.25
AA13	HORIZONTAL DISTANCE FROM TRAILER REAR LEAF-FRAME CONTACT TO LOAD LEVELER PIN (IN	6.25
AA14	VERTICAL DISTANCE FROM AXLE DOWN TO TRAILER TORQUE ROD (IN)	7.00
AA15	ANGLE BETWEEN TRAILER TORQUE ROD AND HORIZONTAL (DEG)	15.01
AA16	HORIZONTAL DISTANCE FROM AXLE CENTER FORWARD TO TRAILER TORQUE ROD (IN)	5.50
A1	HORIZONTAL DISTANCE FROM TRACTOR CG TO CENTER OF TRACTOR FRONT SUSPENSION (IN)	35.90
A2	HORIZONTAL DISTANCE FROM TRACTOR CG TO CENTER OF TRACTOR REAR SUSPENSION (IN)	106.10
A3	HORIZONTAL DISTANCE FROM TRAILER CG TO 5TH WHEEL (IN)	230.50
A4	HORIZONTAL DISTANCE FROM TRAILER CG TO CENTER OF TRAILER SUSPENSION (IN)	179.50
ALPHA1	STATIC DISTANCE, TRACTOR FRONT AXLE TO GROUND (IN)	20.30
ALPHA2	STATIC DISTANCE, TRACTOR REAR AXLE(S) TO GROUND (IN)	20.30
ALPHA3	STATIC DISTANCE, TRAILER AXLE(S) TO GROUND (IN)	19.50
AN1	TIRE PRESSURE DIST. FUNCTION FOR TRACTOR FRONT TIRES	0.250
AN2	TIRE PRESSURE DIST. FUNCTION FOR TRACTOR FRONT TANDEM TIRES	0.250
AN3	TIRE PRESSURE DIST. FUNCTION FOR TRACTOR REAR TANDEM TIRES	0.250
AN4	TIRE PRESSURE DIST. FUNCTION FOR TRAILOR FRONT TANDEM TIRES	0.250
AN5	TIRE PRESSURE DIST. FUNCTION FOR TRAILOR REAR TANDEM TIRES	0.250
BB	HORIZONTAL DISTANCE FROM 5TH WHEEL TO MIDPOINT OF TRACTOR REAR SUSPENSION (IN)	0.0
C1	VISCOUS DAMPING: JOUNCE ON TRACTOR FRONT SUSPENSION (LB-SEC/IN)	10.00
C2	VISCOUS DAMPING: REBOUND ON TRACTOR FRONT SUSPENSION (LB-SEC/IN)	20.00
C3	VISCOUS DAMPING: JOUNCE ON TRACTOR REAR SUSPENSION (LB-SEC/IN)	10.00
C4	VISCOUS DAMPING: REBOUND ON TRACTOR REAR SUSPENSION (LB-SEC/IN)	20.00
C5	VISCOUS DAMPING: JOUNCE ON TRAILER SUSPENSION (LB-SEC/IN)	10.00
C6	VISCOUS DAMPING: REBOUND ON TRAILER SUSPENSION (LB-SEC/IN)	20.00

CALF1	LATERAL STIFFNESS, TRACTOR FRONT TIRES (LBS/DEG)	-1.00
CF1	MAXIMUM COULOMB FRICTION, TRACTOR FRONT SUSPENSION (LB)	500.00
CF2	MAXIMUM COULOMB FRICTION, TRACTOR REAR SUSPENSION (LB)	500.00
CF3	MAXIMUM COULOMB FRICTION, TRAILER SUSPENSION (LB)	1500.00
CS1	LONGITUDINAL STIFFNESS, TRACTOR FRONT TIRES (LBS)	-1.00
CS2	LONGITUDINAL STIFFNESS, TRACTOR FRONT TANDEM TIRES (LBS)	-1.00
CS3	LONGITUDINAL STIFFNESS, TRACTOR REAR TANDEM TIRES (LBS)	-1.00
CS4	LONGITUDINAL STIFFNESS, TRAILER FRONT TANDEM TIRES (LBS)	-1.00
CS5	LONGITUDINAL STIFFNESS, TRAILER REAR TANDEM TIRES (LBS)	-1.00
D	VERTICAL DISTANCE FROM 5TH WHEEL CONNECTION TO TRACTOR CG (IN)	8.80
DELTA1	STATIC VERTICAL DISTANCE, TRACTOR CG TO TRACTOR FRONT AXLE (IN)	19.40
DELTA3	STATIC VERTICAL DISTANCE, TRAILER CG TO TRAILER AXLE (IN)	49.50
DT2	DISTANCE BETWEEN DUAL TIRES, TRACTOR REAR SUSPENSION (IN)	13.00
DT3	DISTANCE BETWEEN DUAL TIRES, TRAILER SUSPENSION (IN)	13.00
FA1	FRICTION REDUCTION PARAMETER FOR TRACTOR FRONT TIRES	0.002
FA2	FRICTION REDUCTION PARAMETER FOR TRACTOR FRONT TANDEM TIRES	0.002
FA3	FRICTION REDUCTION PARAMETER FOR TRACTOR REAR TANDEM TIRES	0.002
FA4	FRICTION REDUCTION PARAMETER FOR TRAILER FRONT TANDEM TIRES	0.0
FA5	FRICTION REDUCTION PARAMETER FOR TRAILER REAR TANDEM TIRES	0.0
IXX	TRACTOR SPRUNG MASS ROLL MOMENT OF INERTIA (IN-LB-SEC**2)	18166.00
IYY	TRACTOR SPRUNG MASS PITCH MOMENT OF INERTIA (IN-LB-SEC**2)	69955.00
IZZ	TRACTOR YAW MOMENT OF INERTIA (IN-LB-SEC**2)	69955.00
IXZ	TRACTOR PITCH PLANE CROSS MOMENT (IN-LB-SEC**2)	0.0
ITXX	TRAILER SPRUNG MASS ROLL MOMENT OF INERTIA (IN-LB-SEC**2)	73000.00
ITYY	(IN-LB-SEC**2) MASS PITCH MOMENT OF INER	789869.00
ITZZ	TRAILER YAW MOMENT OF INERTIA (IN-LB-SEC**2)	789869.00
ITXZ	TRAILER PITCH PLANE CROSS MOMENT (IN-LB-SEC**2)	0.0
JA1	ROLL MOMENT OF TRACTOR FRONT AXLE (IN-LB-SEC**2)	3719.00
JA2	ROLL MOMENT OF TRACTOR FRONT TANDEM AXLE (IN-LB-SEC**2)	4458.00
JA3	ROLL MOMENT OF TRAILER FRONT TANDEM AXLE (IN-LB-SEC**2)	4100.00
JS1	POLAR MOMENT OF TRACTOR FRONT WHEELS (IN-LB-SEC**2)	103.00
JS2	POLAR MOMENT OF TRACTOR FRONT TANDEM WHEELS (IN-LB-SEC**2)	231.00
JS3	POLAR MOMENT OF TRACTOR REAR TANDEM WHEELS (IN-LB-SEC**2)	231.00
JS4	POLAR MOMENT OF TRAILER FRONT TANDEM WHEELS (IN-LB-SEC**2)	231.00
JS5	POLAR MOMENT OF TRAILER REAR TANDEM WHEELS (IN-LB-SEC**2)	231.00
K1	SPRING RATE, TRACTOR FRONT SUSPENSION (LB/IN)	1012.50
K2	SPRING RATE, TRACTOR REAR SUSPENSION (LB/IN)	3000.00
K3	SPRING RATE, TRAILER SUSPENSION (LB/IN)	19175.00

KRS1	FRONT AUXILIARY ROLL STIFFNESS(IN-LB/DEG	0.0
KRS2	REAR AUXILIARY ROLL STIFFNESS(IN-LB/DEG	0.0
KRS3	TRAILER AUXILIARY ROLL STIFFNESS(IN-LB/DEG	0.0
AKRS	TRACTOR TR TANDEM AUX ROLL STIFFNESS(IN-LB/DEG)	78000.00
KT1	SPRING RATE, TRACTOR FRONT TIRES (LB/IN)	5700.00
KT2	SPRING RATE, TRACTOR FRONT TANDEM TIRES (LB/IN)	5700.00
KT3	SPRING RATE, TRACTOR REAR TANDEM TIRES (LB/IN)	5700.00
KT4	SPRING RATE, TRAILER FRONT TANDEM TIRES (LB/IN)	5300.00
KT5	SPRING RATE, TRAILER REAR TANDEM TIRES (LB/IN)	5300.00

FIFTH WHEEL SPRING RATE

ROTATION WH5DFL (DEG)	SPRING RATE MC5 (IN-LBS/DEG)
0.0	0.20000E+08

TRACTOR FRAME ROLL SPRING RATE

ROTATION TTDFL(DEG)	SPRING RATE TTC(IN-LBS/DEG)
0.0	0.20000E+05

TRSTF	TRAILER FRAME ROLL STIFFNESS(IN-LB/DEG)	1500000.00
PW	WEIGHT OF PAYLOAD (LBS)	40600.00
PJ1	POLL MOMENT OF INERTIA OF PAYLOAD (IN-LB-SEC**2)	37500.00
PJ2	PITCH MOMENT OF INERTIA OF PAYLOAD (IN-LB-SEC**2)	1727000.00
PJ3	YAW MOMENT OF INERTIA OF PAYLOAD (IN-LB-SEC**2)	1727000.00
PX	HORIZONTAL DISTANCE FROM MIDPOINT OF REAR SUSPENSION TO PAYLOAD MASS CENTER (IN)	182.00
PZ	VERTICAL DISTANCE FROM GROUND TO PAYLOAD MASS CENTER (IN)	64.50
RCH1	ROLL CENTER HEIGHT, TRACTOR FRONT SUSPENSION (IN)	24.55
RCH2	ROLL CENTER HEIGHT, TRACTOR REAR SUSPENSION (IN)	22.00
RCH3	ROLL CENTER HEIGHT, TRAILER SUSPENSION (IN	25.60
RS1	COMPLIANCE STEER (DEG/IN)	0.0
RSC1	ROLL STEER COEFFICIENT, TRACTOR FRONT SUSPENSION	0.0
RSC2	ROLL STEER COEFFICIENT, TRACTOR REAR SUSPENSION	0.10
RSC3	ROLL STEER COEFFICIENT, TRAILER SUSPENSION	0.10
SY1	HORIZONTAL DISTANCE FROM TRACTOR BODY X-AXIS TO TRACTOR FRONT SUSPENSION (IN)	16.30
SY2	HORIZONTAL DISTANCE FROM TRACTOR BODY X-AXIS TO TRACTOR REAR SUSPENSION (IN)	17.50
SY3	HORIZONTAL DISTANCE FROM TRAILER BODY X-AXIS TO TRAILER SUSPENSION (IN)	19.00
TIMF	MAXIMUM REAL TIME FOR SIMULATION (SEC)	4.00
TRA1	HALF TRACK, TRACTOR FRONT AXLE (IN)	40.25
TRA2	HALF TRACK, TRACTOR REAR AXLE(S) (IN)	36.00
TRA3	HALF TRACK, TRAILER AXLE(S) (IN)	36.00
VEL	INITIAL VELOCITY (FT/SEC)	73.33
W1	SPRUNG WEIGHT OF TRACTOR (LBS)	10316.00
W2	SPRUNG WEIGHT OF TRAILER (LBS)	14281.00
WS1	WEIGHT OF TRACTOR FRONT SUSPENSION (LBS)	1190.00
WS2	WEIGHT OF TRACTOR FRONT TANDEM SUSPENSION (LBS)	2340.00
WS3	WEIGHT OF TRACTOR REAR TANDEM SUSPENSION (LBS)	2170.00
WS4	WEIGHT OF TRAILER FRONT TANDEM SUSPENSION (LBS)	1520.00
WS5	WEIGHT OF TRAILER REAR TANDEM SUSPENSION (LBS)	1520.00

```
BRAKE PARAMETERS: TQ(1,1,1) = 0.050 TQ(1,1,2) = 0.270
                  TQ(1,2,1) = 0.050 TQ(1,2,2) = 0.270
                  TQ(2,1,1) = 0.075 TQ(2,1,2) = 0.245
                  TQ(2,2,1) = 0.075 TQ(2,2,2) = 0.245
                  TQ(3,1,1) = 0.075 TQ(3,1,2) = 0.245
                  TQ(3,2,1) = 0.075 TQ(3,2,2) = 0.245
                  TQ(4,1,1) = 0.175 TQ(4,1,2) = 0.303
                  TQ(4,2,1) = 0.175 TQ(4,2,2) = 0.303
                  TQ(5,1,1) = 0.175 TQ(5,1,2) = 0.303
                  TQ(5,2,1) = 0.175 TQ(5,2,2) = 0.303

    TABLE 1: TIME VS PRESSURE (PSI)
             NO. OF POINTS:  2
          0.0            0.0
          0.0500         0.0

    INPUT PARAMETER TABLE FOR BRAKE FORCE CALCULATION SUBROUTINE
    SYMBOL      DESCRIPTION                          INITIAL VALUE
                                  AXLE 1, LEFT SIDE
    IBRT        BRAKE TYPE                                     NONE
                                  AXLE 2, LEFT SIDE
    IBRT        BRAKE TYPE                                     NONE
                                  AXLE 3, LEFT SIDE
    IBRT        BRAKE TYPE                                     NONE
                                  AXLE 4, LEFT SIDE
    IBRT        BRAKE TYPE                                     NONE
                                  AXLE 5, LEFT SIDE
    IBRT        BRAKE TYPE                                     NONE

    TABLE  2: TIME VS STEER ANGLE (DEG)
              LEFT SIDE
              NO. OF POINTS:  2
          0.0            0.0
          8.0000        12.0000


    TABLE  3: TIME VS STEER ANGLE (DEG)
              RIGHT SIDE
              NO. OF POINTS:  2
          0.0            0.0
          8.0000        12.0000


    PARAMETERS FOR INCLINE SURFACE:
          G1          GRAVITY X COMPONENT            0.0
          G2          GRAVITY Y COMPONENT            0.0
          G3          GRAVITY Z COMPONENT            1.000

    THERE WILL BE NO WIND THIS RUN

THE ANTILOCK SYSTEM WILL NOT BE USED THIS RUN

     *** END INPUT ***
```

	EMPTY	LOADED
DISTANCE FROM TRAILER SPRUNG MASS CENTER TO TRAILER REAR AXLE CENTERLINE (IN)	179.500	181.349
DISTANCE FROM TRAILER SPRUNG MASS CENTER TO GROUND (IN)	69.000	65.671
ROLL MOMENT OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	72999.938	111054.063
PITCH MOMENT OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	789868.500	2517592.000
YAW MOMENT OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	789868.500	2517038.000

THE STATIC LOADS ON THE TIRES ARE

AXLE NUMBER	LOAD
1	8897.938
2	15781.398
3	15611.398
4	16823.133
5	16823.133
TOTAL	73937.000

THE TRACTOR TOTAL SPRUNG MASS CENTER IS 62.844 INCHES BEHIND THE FRONT AXLE,
THE TOTAL YAW MOMENT OF INERTIA IS 192914.500 IN LB SEC**2.

THE TRAILER MASS CENTER IS 238.169 INCHES BEHIND THE FIFTH WHEEL,
THE TOTAL YAW MOMENT OF INERTIA IS 2775432.000 IN LB SEC**2

TIME INCREMENT TO BE PRINTED OUT IS 0.10

TRACTOR FRONT TIRES : FIRESTONE 10X22 RIB
TRACTOR LEADING TANDEM TIRES : FIRESTONE 10X22 RIB
TRACTOR TRAILING TANDEM TIRES : FIRESTONE 10X22 RIB

TRAILER LEADING TANDEM TIRES : FIRESTONE 10X20 RIB
TRAILER TRAILING TANDEM TIRES : FIRESTONE 10X20 RIB

*** BEGIN OUTPUT ***

FORD TRACTOR-VAN TRAILER LOADED, FIRESTONE-10X20 RIB *1A2 1B2*

INPUT PARAMETER TABLE

SYMBOL	DESCRIPTION	INITIAL VALUE
KEY(1)	TRACTOR AXLE KEY: 0 FOR SINGLE AXLE 1 FOR WALKING BEAM 2 FOR 4 ELLIPTIC LEAF	0
KEY(2)	TRAILER AXLE KEY	2
AA9	HORIZONTAL DISTANCE FROM TRAILER FRONT LEAF-FRAME CONTACT TO AXLE CENTER (IN)	18.50
AA10	HORIZONTAL DISTANCE FROM TRAILER REAR LEAF-FRAME CONTACT TO AXLE CENTER (IN)	18.50
AA12	HORIZONTAL DISTANCE FROM TRAILER FRONT LEAF-FRAME CONTACT TO LOAD LEVELER PIN (IN	6.25
AA13	HORIZONTAL DISTANCE FROM TRAILER REAR LEAF-FRAME CONTACT TO LOAD LEVELER PIN (IN	6.25
AA14	VERTICAL DISTANCE FROM AXLE DOWN TO TRAILER TORQUE ROD (IN)	7.00
AA15	ANGLE BETWEEN TRAILER TORQUE ROD AND HORIZONTAL (DEG)	15.00
AA16	HORIZONTAL DISTANCE FROM AXLE CENTER FORWARD TO TRAILER TORQUE ROD (IN)	5.50
A1	HORIZONTAL DISTANCE FROM TRACTOR CG TO CENTER OF TRACTOR FRONT SUSPENSION (IN)	36.00
A2	HORIZONTAL DISTANCE FROM TRACTOR CG TO CENTER OF TRACTOR REAR SUSPENSION (IN)	98.50
A3	HORIZONTAL DISTANCE FROM TRAILER CG TO 5TH WHEEL (IN)	230.50
A4	HORIZONTAL DISTANCE FROM TRAILER CG TO CENTER OF TRAILER SUSPENSION (IN)	179.50
ALPHA1	STATIC DISTANCE, TRACTOR FRONT AXLE TO GROUND (IN)	19.50
ALPHA2	STATIC DISTANCE, TRACTOR REAR AXLE(S) TO GROUND (IN)	19.50
ALPHA3	STATIC DISTANCE, TRAILER AXLE(S) TO GROUND (IN)	19.50
AN1	TIRE PRESSURE DIST. FUNCTION FOR TRACTOR FRONT TIRES	0.250
AN2	TIRE PRESSURE DIST. FUNCTION FOR TRACTOR REAR TIRES	0.250
AN3	TIRE PRESSURE DIST. FUNCTION FOR TRAILOR FRONT TANDEM TIRES	0.250
AN4	TIRE PRESSURE DIST. FUNCTION FOR TRAILOR REAR TANDEM TIRES	0.250
BB	HORIZONTAL DISTANCE FROM 5TH WHEEL TO MIDPOINT OF TRACTOR REAR SUSPENSION (IN)	0.0
C1	VISCOUS DAMPING: JOUNCE ON TRACTOR FRONT SUSPENSION (LB-SEC/IN)	10.00
C2	VISCOUS DAMPING: REBOUND ON TRACTOR FRONT SUSPENSION (LB-SEC/IN)	20.00
C3	VISCOUS DAMPING: JOUNCE ON TRACTOR REAR SUSPENSION (LB-SEC/IN)	10.00
C4	VISCOUS DAMPING: REBOUND ON TRACTOR REAR SUSPENSION (LB-SEC/IN)	20.00
C5	VISCOUS DAMPING: JOUNCE ON TRAILER SUSPENSION (LB-SEC/IN)	10.00
C6	VISCOUS DAMPING: REBOUND ON TRAILER SUSPENSION (LB-SEC/IN)	20.00
CALF1	LATERAL STIFFNESS, TRACTOR FRONT TIRES (LBS/DEG)	-1.00
CF1	MAXIMUM COULOMB FRICTION, TRACTOR FRONT SUSPENSION (LB)	500.00
CF2	MAXIMUM COULOMB FRICTION, TRACTOR REAR SUSPENSION (LB)	750.00
CF3	MAXIMUM COULOMB FRICTION, TRAILER SUSPENSION (LB)	1500.00
CS1	LONGITUDINAL STIFFNESS, TRACTOR FRONT TIRES (LBS)	28000.00
CS2	LONGITUDINAL STIFFNESS, TRACTOR REAR TIRES (LBS)	28000.00
CS3	LONGITUDINAL STIFFNESS, TRAILER FRONT TANDEM TIRES (LBS)	28000.00
CS4	LONGITUDINAL STIFFNESS, TRAILER REAR TANDEM TIRES (LBS)	28000.00

D	VERTICAL DISTANCE FROM 5TH WHEEL CONNECTION TO TRACTOR CG (IN)	4.80
DELTA1	STATIC VERTICAL DISTANCE, TRACTOR CG TO TRACTOR FRONT AXLE (IN)	24.18
DELTA3	STATIC VERTICAL DISTANCE, TRAILER CG TO TRAILER AXLE (IN)	49.50
DT2	DISTANCE BETWEEN DUAL TIRES, TRACTOR REAR SUSPENSION (IN)	13.00
DT3	DISTANCE BETWEEN DUAL TIRES, TRAILER SUSPENSION (IN)	13.00
FA1	FRICTION REDUCTION PARAMETER FOR TRACTOR FRONT TIRES	0.0
FA2	FRICTION REDUCTION PARAMETER FOR TRACTOR REAR TIRES	0.0
FA3	FRICTION REDUCTION PARAMETER FOR TRAILER FRONT TANDEM TIRES	0.0
FA4	FRICTION REDUCTION PARAMETER FOR TRAILER REAR TANDEM TIRES	0.0
IXX	TRACTOR SPRUNG MASS ROLL MOMENT OF INERTIA (IN-LB-SEC**2)	18000.00
IYY	TRACTOR SPRUNG MASS PITCH MOMENT OF INERTIA (IN-LB-SEC**2)	74174.00
IZZ	TRACTOR YAW MOMENT OF INERTIA (IN-LB-SEC**2)	74174.00
IXZ	TRACTOR PITCH PLANE CROSS MOMENT (IN-LB-SEC**2)	0.0
ITXX	TRAILER SPRUNG MASS ROLL MOMENT OF INERTIA (IN-LB-SEC**2)	73000.00
ITYY	(IN-LB-SEC**2) MASS PITCH MOMENT OF INER	789869.00
ITZZ	TRAILER YAW MOMENT OF INERTIA (IN-LB-SEC**2)	789869.00
ITXZ	TRAILER PITCH PLANE CROSS MOMENT (IN-LB-SEC**2)	0.0
JA1	ROLL MOMENT OF TRACTOR FRONT AXLE (IN-LB-SEC**2)	3719.00
JA2	ROLL MOMENT OF TRACTOR REAR AXLE (IN-LB-SEC**2)	4458.00
JA3	ROLL MOMENT OF TRAILER REAR AXLE (IN-LB-SEC**2)	4100.00
JS1	POLAR MOMENT OF TRACTOR FRONT WHEELS (IN-LB-SEC**2)	103.00
JS2	POLAR MOMENT OF TRACTOR REAR WHEELS (IN-LB-SEC**2)	231.00
JS3	POLAR MOMENT OF TRAILER FRONT TANDEM WHEELS (IN-LB-SEC**2)	231.00
JS4	POLAR MOMENT OF TRAILER REAR TANDEM WHEELS (IN-LB-SEC**2)	231.00
K1	SPRING RATE, TRACTOR FRONT SUSPENSION (LB/IN)	917.50
K2	SPRING RATE, TRACTOR REAR SUSPENSION (LB/IN)	11000.00
K3	SPRING RATE, TRAILER SUSPENSION (LB/IN)	19175.00
KRS1	FRONT AUXILIARY ROLL STIFFNESS(IN-LB/DEG	0.0
KRS2	REAR AUXILIARY ROLL STIFFNESS(IN-LB/DEG	0.0
KRS3	TRAILER AUXILIARY ROLL STIFFNESS(IN-LB/DEG	0.0
KT1	SPRING RATE, TRACTOR FRONT TIRES (LB/IN)	5300.00
KT2	SPRING RATE, TRACTOR REAR TIRES (LB/IN)	5300.00
KT3	SPRING RATE, TRAILER FRONT TANDEM TIRES (LB/IN)	5300.00
KT4	SPRING RATE, TRAILER REAR TANDEM TIRES (LB/IN)	5300.00

FIFTH WHEEL SPRING RATE

ROTATION WH5DFL (DEG)	SPRING RATE MC5 (IN-LBS/DEG)
0.0	0.20000E+08

TRACTOR FRAME ROLL SPRING RATE

ROTATION TTDFL(DEG)	SPRING RATE TTC(IN-LBS/DEG)
0.0	0.20000E+05

TRSTF	TRAILER FRAME ROLL STIFFNESS(IN-LB/DEG)	1500000.00

PW	WEIGHT OF PAYLOAD (LBS)	30200.00
PJ1	POLL MOMENT OF INERTIA OF PAYLOAD (IN-LB-SEC**2)	25636.00
PJ2	PITCH MOMENT OF INERTIA OF PAYLOAD (IN-LB-SEC**2)	728816.00
PJ3	YAW MOMENT OF INERTIA OF PAYLOAD (IN-LB-SEC**2)	728816.00
PX	HORIZONTAL DISTANCE FROM MIDPOINT OF REAR SUSPENSION TO PAYLOAD MASS CENTER (IN)	105.50
PZ	VERTICAL DISTANCE FROM GROUND TO PAYLOAD MASS CENTER (IN)	64.50
RCH1	ROLL CENTER HEIGHT, TRACTOR FRONT SUSPENSION (IN)	21.00
RCH2	ROLL CENTER HEIGHT, TRACTOR REAR SUSPENSION (IN)	31.00
RCH3	ROLL CENTER HEIGHT, TRAILER SUSPENSION (IN	25.60
RS1	COMPLIANCE STEER (DEG/IN)	0.0
RSC1	ROLL STEER COEFFICIENT, TRACTOR FRONT SUSPENSION	0.14
RSC2	ROLL STEER COEFFICIENT, TRACTOR REAR SUSPENSION	-0.02
RSC3	ROLL STEER COEFFICIENT, TRAILER SUSPENSION	0.10
SY1	HORIZONTAL DISTANCE FROM TRACTOR BODY X-AXIS TO TRACTOR FRONT SUSPENSION (IN)	17.00
SY2	HORIZONTAL DISTANCE FROM TRACTOR BODY X-AXIS TO TRACTOR REAR SUSPENSION (IN)	20.00
SY3	HORIZONTAL DISTANCE FROM TRAILER BODY X-AXIS TO TRAILER SUSPENSION (IN)	19.00
TIMF	MAXIMUM REAL TIME FOR SIMULATION (SEC)	0.10
TRA1	HALF TRACK, TRACTOR FRONT AXLE (IN)	38.50
TRA2	HALF TRACK, TRACTOR REAR AXLE(S) (IN)	36.00
TRA3	HALF TRACK, TRAILER AXLE(S) (IN)	36.00
VEL	INITIAL VELOCITY (FT/SEC)	73.33
W1	SPRUNG WEIGHT OF TRACTOR (LBS)	10331.00
W2	SPRUNG WEIGHT OF TRAILER (LBS)	14281.00
WS1	WEIGHT OF TRACTOR FRONT SUSPENSION (LBS)	1190.00
WS2	WEIGHT OF TRACTOR REAR SUSPENSION (LBS)	2340.00
WS3	WEIGHT OF TRAILER FRONT TANDEM SUSPENSION (LBS)	1520.00
WS4	WEIGHT OF TRAILER REAR TANDEM SUSPENSION (LBS)	1520.00

BRAKE PARAMETERS:

TQ(1,1,1) = 0.050	TQ(1,1,2) = 0.270
TQ(1,2,1) = 0.050	TQ(1,2,2) = 0.270
TQ(2,1,1) = 0.075	TQ(2,1,2) = 0.245
TQ(2,2,1) = 0.075	TQ(2,2,2) = 0.245
TQ(3,1,1) = 0.175	TQ(3,1,2) = 0.303
TQ(3,2,1) = 0.175	TQ(3,2,2) = 0.303
TQ(4,1,1) = 0.175	TQ(4,1,2) = 0.303
TQ(4,2,1) = 0.175	TQ(4,2,2) = 0.303

TABLE 1: TIME VS PRESSURE (PSI)
NO. OF POINTS: 2

0.0	0.0
0.0500	0.0

INPUT PARAMETER TABLE FOR BRAKE FORCE CALCULATION SUBROUTINE

SYMBOL	DESCRIPTION		INITIAL VALUE
IBRT	BRAKE TYPE	AXLE 1, LEFT SIDE	NONE
IBRT	BRAKE TYPE	AXLE 2, LEFT SIDE	NONE
IBRT	BRAKE TYPE	AXLE 3, LEFT SIDE	NONE
IBRT	BRAKE TYPE	AXLE 4, LEFT SIDE	NONE

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TABLE  2: TIME VS STEER ANGLE (DEG)
          LEFT SIDE
          NO. OF POINTS:  2
     0.0             0.0
     8.0000         12.0000


TABLE  3: TIME VS STEER ANGLE (DEG)
          RIGHT SIDE
          NO. OF POINTS:  2
     0.0             0.0
     8.0000         12.0000


PARAMETERS FOR INCLINE SURFACE:
     G1          GRAVITY X COMPONENT          0.0
     G2          GRAVITY Y COMPONENT          0.0
     G3          GRAVITY Z COMPONENT          1.000

THERE WILL BE NO WIND THIS RUN

THE ANTILOCK SYSTEM WILL NOT BE USED THIS RUN

*** END INPUT ***
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	EMPTY	LOADED
DISTANCE FROM TRAILER SPRUNG MASS CENTER TO TRAILER REAR AXLE CENTERLINE (IN)	179.500	129.258
DISTANCE FROM TRAILER SPRUNG MASS CENTER TO GROUND (IN)	69.000	65.945
ROLL MOMENT OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	72999.938	99144.500
PITCH MOMENT OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	789868.500	1656718.000
YAW MOMENT OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	789868.500	1656210.000

THE STATIC LOADS ON THE TIRES ARE

AXLE NUMBER	LOAD
1	8755.832
2	19128.434
3	16748.867
4	16748.867
TOTAL	61382.000

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THE TRACTOR TOTAL SPRUNG MASS CENTER IS      49.538 INCHES BEHIND THE FRONT AXLE,
THE TOTAL YAW MOMENT OF INERTIA IS   138571.500 IN LB SEC**2.

THE TRAILER MASS CENTER IS      289.010 INCHES BEHIND THE FIFTH WHEEL,
THE TOTAL YAW MOMENT OF INERTIA IS  1792376.000 IN LB SEC**2

TIME INCREMENT TO BE PRINTED OUT IS 0.10

     TRACTOR FRONT TIRES              : FIRESTONE 10X20 RIB
     TRACTOR REAR TIRES               : FIRESTONE 10X20 RIB

     TRAILER LEADING TANDEM TIRES     : FIRESTONE 10X20 RIB
     TRAILER TRAILING TANDEM TIRES    : FIRESTONE 10X20 RIB

*** BEGIN OUTPUT ***
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FORD TRACTOR-FLAT-BED-TRAILER-FIRESTONE 10.00X20 RIB *1A2 1B2*
INPUT PARAMETER TABLE

SYMBOL	DESCRIPTION	INITIAL VALUE
KEY(1)	TRACTOR AXLE KEY: 0 FOR SINGLE AXLE 1 FOR WALKING BEAM 2 FOR 4 ELLIPTIC LEAF	0
KEY(2)	TRAILER AXLE KEY	2
AA9	HORIZONTAL DISTANCE FROM TRAILER FRONT LEAF-FRAME CONTACT TO AXLE CENTER (IN)	18.50
AA10	HORIZONTAL DISTANCE FROM TRAILER REAR LEAF-FRAME CONTACT TO AXLE CENTER (IN)	18.50
AA12	HORIZONTAL DISTANCE FROM TRAILER FRONT LEAF-FRAME CONTACT TO LOAD LEVELER PIN (IN	6.25
AA13	HORIZONTAL DISTANCE FROM TRAILER REAR LEAF-FRAME CONTACT TO LOAD LEVELER PIN (IN	6.25
AA14	VERTICAL DISTANCE FROM AXLE DOWN TO TRAILER TORQUE ROD (IN)	7.00
AA15	ANGLE BETWEEN TRAILER TORQUE ROD AND HORIZONTAL (DEG)	15.00
AA16	HORIZONTAL DISTANCE FROM AXLE CENTER FORWARD TO TRAILER TORQUE ROD (IN)	5.50
A1	HORIZONTAL DISTANCE FROM TRACTOR CG TO CENTER OF TRACTOR FRONT SUSPENSION (IN)	36.00
A2	HORIZONTAL DISTANCE FROM TRACTOR CG TO CENTER OF TRACTOR REAR SUSPENSION (IN)	98.50
A3	HORIZONTAL DISTANCE FROM TRAILER CG TO 5TH WHEEL (IN)	232.00
A4	HORIZONTAL DISTANCE FROM TRAILER CG TO CENTER OF TRAILER SUSPENSION (IN)	176.00
ALPHA1	STATIC DISTANCE, TRACTOR FRONT AXLE TO GROUND (IN)	19.50
ALPHA2	STATIC DISTANCE, TRACTOR REAR AXLE(S) TO GROUND (IN)	19.50
ALPHA3	STATIC DISTANCE, TRAILER AXLE(S) TO GROUND (IN)	19.50
AN1	TIRE PRESSURE DIST. FUNCTION FOR TRACTOR FRONT TIRES	0.250
AN2	TIRE PRESSURE DIST. FUNCTION FOR TRACTOR REAR TIRES	0.250
AN3	TIRE PRESSURE DIST. FUNCTION FOR TRAILOR FRONT TANDEM TIRES	0.250
AN4	TIRE PRESSURE DIST. FUNCTION FOR TRAILOR REAR TANDEM TIRES	0.250
BB	HORIZONTAL DISTANCE FROM 5TH WHEEL TO MIDPOINT OF TRACTOR REAR SUSPENSION (IN)	0.0
C1	VISCOUS DAMPING: JOUNCE ON TRACTOR FRONT SUSPENSION (LB-SEC/IN)	10.00
C2	VISCOUS DAMPING: REBOUND ON TRACTOR FRONT SUSPENSION (LB-SEC/IN)	20.00
C3	VISCOUS DAMPING: JOUNCE ON TRACTOR REAR SUSPENSION (LB-SEC/IN)	10.00
C4	VISCOUS DAMPING: REBOUND ON TRACTOR REAR SUSPENSION (LB-SEC/IN)	20.00
C5	VISCOUS DAMPING: JOUNCE ON TRAILER SUSPENSION (LB-SEC/IN)	10.00
C6	VISCOUS DAMPING: REBOUND ON TRAILER SUSPENSION (LB-SEC/IN)	20.00
CALF1	LATERAL STIFFNESS, TRACTOR FRONT TIRES (LBS/DEG)	-1.00
CF1	MAXIMUM COULOMB FRICTION, TRACTOR FRONT SUSPENSION (LB)	500.00
CF2	MAXIMUM COULOMB FRICTION, TRACTOR REAR SUSPENSION (LB)	750.00
CF3	MAXIMUM COULOMB FRICTION, TRAILER SUSPENSION (LB)	1500.00
CS1	LONGITUDINAL STIFFNESS, TRACTOR FRONT TIRES (LBS)	28000.00
CS2	LONGITUDINAL STIFFNESS, TRACTOR REAR TIRES (LBS)	28000.00
CS3	LONGITUDINAL STIFFNESS, TRAILER FRONT TANDEM TIRES (LBS)	28000.00
CS4	LONGITUDINAL STIFFNESS, TRAILER REAR TANDEM TIRES (LBS)	28000.00

D	VERTICAL DISTANCE FROM 5TH WHEEL CONNECTION TO TRACTOR CG (IN)	4.80
DELTA1	STATIC VERTICAL DISTANCE, TRACTOR CG TO TRACTOR FRONT AXLE (IN)	24.18
DELTA3	STATIC VERTICAL DISTANCE, TRAILER CG TO TRAILER AXLE (IN)	25.00
DT2	DISTANCE BETWEEN DUAL TIRES, TRACTOR REAR SUSPENSION (IN)	13.00
DT3	DISTANCE BETWEEN DUAL TIRES, TRAILER SUSPENSION (IN)	13.00
FA1	FRICTION REDUCTION PARAMETER FOR TRACTOR FRONT TIRES	0.0
FA2	FRICTION REDUCTION PARAMETER FOR TRACTOR REAR TIRES	0.0
FA3	FRICTION REDUCTION PARAMETER FOR TRAILER FRONT TANDEM TIRES	0.0
FA4	FRICTION REDUCTION PARAMETER FOR TRAILER REAR TANDEM TIRES	0.0
IXX	TRACTOR SPRUNG MASS ROLL MOMENT OF INERTIA (IN-LB-SEC**2)	18000.00
IYY	TRACTOR SPRUNG MASS PITCH MOMENT OF INERTIA (IN-LB-SEC**2)	74174.00
IZZ	TRACTOR YAW MOMENT OF INERTIA (IN-LB-SEC**2)	74174.00
IXZ	TRACTOR PITCH PLANE CROSS MOMENT (IN-LB-SEC**2)	0.0
ITXX	TRAILER SPRUNG MASS ROLL MOMENT OF INERTIA (IN-LB-SEC**2)	69029.00
ITYY	(IN-LB-SEC**2) MASS PITCH MOMENT OF INER	587432.00
ITZZ	TRAILER YAW MOMENT OF INERTIA (IN-LB-SEC**2)	587432.00
ITXZ	TRAILER PITCH PLANE CROSS MOMENT (IN-LB-SEC**2)	0.0
JA1	ROLL MOMENT OF TRACTOR FRONT AXLE (IN-LB-SEC**2)	3719.00
JA2	ROLL MOMENT OF TRACTOR REAR AXLE (IN-LB-SEC**2)	4458.00
JA3	ROLL MOMENT OF TRAILER REAR AXLE (IN-LB-SEC**2)	4100.00
JS1	POLAR MOMENT OF TRACTOR FRONT WHEELS (IN-LB-SEC**2)	103.00
JS2	POLAR MOMENT OF TRACTOR REAR WHEELS (IN-LB-SEC**2)	231.00
JS3	POLAR MOMENT OF TRAILER FRONT TANDEM WHEELS (IN-LB-SEC**2)	231.00
JS4	POLAR MOMENT OF TRAILER REAR TANDEM WHEELS (IN-LB-SEC**2)	231.00
K1	SPRING RATE, TRACTOR FRONT SUSPENSION (LB/IN)	917.50
K2	SPRING RATE, TRACTOR REAR SUSPENSION (LB/IN)	11000.00
K3	SPRING RATE, TRAILER SUSPENSION (LB/IN)	8887.00
KRS1	FRONT AUXILIARY ROLL STIFFNESS(IN-LB/DEG	0.0
KRS2	REAR AUXILIARY ROLL STIFFNESS(IN-LB/DEG	0.0
KRS3	TRAILER AUXILIARY ROLL STIFFNESS(IN-LB/DEG	-68015.00
KT1	SPRING RATE, TRACTOR FRONT TIRES (LB/IN)	5300.00
KT2	SPRING RATE, TRACTOR REAR TIRES (LB/IN)	5300.00
KT3	SPRING RATE, TRAILER FRONT TANDEM TIRES (LB/IN)	5300.00
KT4	SPRING RATE, TRAILER REAR TANDEM TIRES (LB/IN)	5300.00

FIFTH WHEEL SPRING RATE

ROTATION WH5DFL (DEG)	SPRING RATE MC5 (IN-LBS/DEG)
0.0	0.20000E+08

TRACTOR FRAME ROLL SPRING RATE

ROTATION TTDFL(DEG)	SPRING RATE TTC(IN-LBS/DEG)
0.0	0.20000E+05

TRSTF	TRAILER FRAME ROLL STIFFNESS(IN-LB/DEG)	48000.00

PW	WEIGHT OF PAYLOAD (LBS)	31200.00
PJ1	POLL MOMENT OF INERTIA OF PAYLOAD (IN-LB-SEC**2)	27045.00
PJ2	PITCH MOMENT OF INERTIA OF PAYLOAD (IN-LB-SEC**2)	761736.00
PJ3	YAW MOMENT OF INERTIA OF PAYLOAD (IN-LB-SEC**2)	761736.00
PX	HORIZONTAL DISTANCE FROM MIDPOINT OF REAR SUSPENSION TO PAYLOAD MASS CENTER (IN)	109.40
PZ	VERTICAL DISTANCE FROM GROUND TO PAYLOAD MASS CENTER (IN)	67.50
RCH1	ROLL CENTER HEIGHT, TRACTOR FRONT SUSPENSION (IN)	21.00
RCH2	ROLL CENTER HEIGHT, TRACTOR REAR SUSPENSION (IN)	31.00
RCH3	ROLL CENTER HEIGHT, TRAILER SUSPENSION (IN	41.10
RS1	COMPLIANCE STEER (DEG/IN)	0.0
RSC1	ROLL STEER COEFFICIENT, TRACTOR FRONT SUSPENSION	0.14
RSC2	ROLL STEER COEFFICIENT, TRACTOR REAR SUSPENSION	-0.02
RSC3	ROLL STEER COEFFICIENT, TRAILER SUSPENSION	0.10
SY1	HORIZONTAL DISTANCE FROM TRACTOR BODY X-AXIS TO TRACTOR FRONT SUSPENSION (IN)	17.00
SY2	HORIZONTAL DISTANCE FROM TRACTOR BODY X-AXIS TO TRACTOR REAR SUSPENSION (IN)	20.00
SY3	HORIZONTAL DISTANCE FROM TRAILER BODY X-AXIS TO TRAILER SUSPENSION (IN)	19.00
TIMF	MAXIMUM REAL TIME FOR SIMULATION (SEC)	0.10
TRA1	HALF TRACK, TRACTOR FRONT AXLE (IN)	38.50
TRA2	HALF TRACK, TRACTOR REAR AXLE(S) (IN)	36.00
TRA3	HALF TRACK, TRAILER AXLE(S) (IN)	36.00
VEL	INITIAL VELOCITY (FT/SEC)	73.33
W1	SPRUNG WEIGHT OF TRACTOR (LBS)	10331.00
W2	SPRUNG WEIGHT OF TRAILER (LBS)	10383.00
WS1	WEIGHT OF TRACTOR FRONT SUSPENSION (LBS)	1190.00
WS2	WEIGHT OF TRACTOR REAR SUSPENSION (LBS)	2340.00
WS3	WEIGHT OF TRAILER FRONT TANDEM SUSPENSION (LBS)	1520.00
WS4	WEIGHT OF TRAILER REAR TANDEM SUSPENSION (LBS)	1520.00

BRAKE PARAMETERS:

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TQ(1,1,1) = 0.050 TQ(1,1,2) = 0.270
TQ(1,2,1) = 0.050 TQ(1,2,2) = 0.270
TQ(2,1,1) = 0.075 TQ(2,1,2) = 0.245
TQ(2,2,1) = 0.075 TQ(2,2,2) = 0.245
TQ(3,1,1) = 0.175 TQ(3,1,2) = 0.303
TQ(3,2,1) = 0.175 TQ(3,2,2) = 0.303
TQ(4,1,1) = 0.175 TQ(4,1,2) = 0.303
TQ(4,2,1) = 0.175 TQ(4,2,2) = 0.303
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TABLE 1: TIME VS PRESSURE (PSI)

NO. OF POINTS: 2

0.0	0.0
0.0500	0.0

INPUT PARAMETER TABLE FOR BRAKE FORCE CALCULATION SUBROUTINE

SYMBOL	DESCRIPTION		INITIAL VALUE
IBRT	BRAKE TYPE	AXLE 1, LEFT SIDE	NONE
IBRT	BRAKE TYPE	AXLE 2, LEFT SIDE	NONE
IBRT	BRAKE TYPE	AXLE 3, LEFT SIDE	NONE
IBRT	BRAKE TYPE	AXLE 4, LEFT SIDE	NONE

TABLE 2: TIME VS STEER ANGLE (DEG)
LEFT SIDE
NO. OF POINTS: 2

0.0	0.0
8.0000	12.0000

TABLE 3: TIME VS STEER ANGLE (DEG)
RIGHT SIDE
NO. OF POINTS: 2

0.0	0.0
8.0000	12.0000

PARAMETERS FOR INCLINE SURFACE:

G1	GRAVITY X COMPONENT	0.0
G2	GRAVITY Y COMPONENT	0.0
G3	GRAVITY Z COMPONENT	1.000

THERE WILL BE NO WIND THIS RUN

THE ANTILOCK SYSTEM WILL NOT BE USED THIS RUN

*** END INPUT ***

	EMPTY	LOADED
DISTANCE FROM TRAILER SPRUNG MASS CENTER TO TRAILER REAR AXLE CENTERLINE (IN)	176.000	126.030
DISTANCE FROM TRAILER SPRUNG MASS CENTER TO GROUND (IN)	44.500	61.757
ROLL MOMENT OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	69028.938	106748.438
PITCH MOMENT OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	587431.938	1449345.000
YAW MOMENT OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	587431.938	1438671.000

THE STATIC LOADS ON THE TIRES ARE

AXLE NUMBER	LOAD
1	8755.832
2	17949.996
3	15889.086
4	15889.086
TOTAL	58484.000

THE TRACTOR TOTAL SPRUNG MASS CENTER IS 49.538 INCHES BEHIND THE FRONT AXLE,
THE TOTAL YAW MOMENT OF INERTIA IS 138571.500 IN LB SEC**2.

THE TRAILER MASS CENTER IS 290.556 INCHES BEHIND THE FIFTH WHEEL,
THE TOTAL YAW MOMENT OF INERTIA IS 1568243.000 IN LB SEC**2

TIME INCREMENT TO BE PRINTED OUT IS 0.10

TRACTOR FRONT TIRES	: FIRESTONE 10X20 RIB
TRACTOR REAR TIRES	: FIRESTONE 10X20 RIB
TRAILER LEADING TANDEM TIRES	: FIRESTONE 10X20 RIB
TRAILER TRAILING TANDEM TIRES	: FIRESTONE 10X20 RIB

*** BEGIN OUTPUT ***

2AXLE 110 IN. WHEEL BASE TRACTOR-VAN TRAILER RUN# 1

INPUT PARAMETER TABLE

SYMBOL	DESCRIPTION	INITIAL VALUE
KEY(1)	TRACTOR AXLE KEY: 0 FOR SINGLE AXLE 1 FOR WALKING BEAM 2 FOR 4 ELLIPTIC LEAF	0
KEY(2)	TRAILER AXLE KEY	0
A1	HORIZONTAL DISTANCE FROM TRACTOR CG TO CENTER OF TRACTOR FRONT SUSPENSION (IN)	31.90
A2	HORIZONTAL DISTANCE FROM TRACTOR CG TO CENTER OF TRACTOR REAR SUSPENSION (IN)	78.10
A3	HORIZONTAL DISTANCE FROM TRAILER CG TO 5TH WHEEL (IN)	212.20
A4	HORIZONTAL DISTANCE FROM TRAILER CG TO CENTER OF TRAILER SUSPENSION (IN)	195.80
ALPHA1	STATIC DISTANCE, TRACTOR FRONT AXLE TO GROUND (IN)	19.50
ALPHA2	STATIC DISTANCE, TRACTOR REAR AXLE(S) TO GROUND (IN)	19.50
ALPHA3	STATIC DISTANCE, TRAILER AXLE(S) TO GROUND (IN)	19.50
AN1	TIRE PRESSURE DIST. FUNCTION FOR TRACTOR FRONT TIRES	0.250
AN2	TIRE PRESSURE DIST. FUNCTION FOR TRACTOR REAR TIRES	0.250
AN3	TIRE PRESSURE DIST. FUNCTION FOR TRAILOR TIRES	0.250
BB	HORIZONTAL DISTANCE FROM 5TH WHEEL TO MIDPOINT OF TRACTOR REAR SUSPENSION (IN)	21.00
C1	VISCOUS DAMPING: JOUNCE ON TRACTOR FRONT SUSPENSION (LB-SEC/IN)	10.00
C2	VISCOUS DAMPING: REBOUND ON TRACTOR FRONT SUSPENSION (LB-SEC/IN)	20.00
C3	VISCOUS DAMPING: JOUNCE ON TRACTOR REAR SUSPENSION (LB-SEC/IN)	10.00
C4	VISCOUS DAMPING: REBOUND ON TRACTOR REAR SUSPENSION (LB-SEC/IN)	20.00
C5	VISCOUS DAMPING: JOUNCE ON TRAILER SUSPENSION (LB-SEC/IN)	10.00
C6	VISCOUS DAMPING: REBOUND ON TRAILER SUSPENSION (LB-SEC/IN)	20.00
CALF1	LATERAL STIFFNESS, TRACTOR FRONT TIRES (LBS/DEG)	-1.00
CF1	MAXIMUM COULOMB FRICTION, TRACTOR FRONT SUSPENSION (LB)	500.00
CF2	MAXIMUM COULOMB FRICTION, TRACTOR REAR SUSPENSION (LB)	750.00
CF3	MAXIMUM COULOMB FRICTION, TRAILER SUSPENSION (LB)	750.00
CS1	LONGITUDINAL STIFFNESS, TRACTOR FRONT TIRES (LBS)	28000.00
CS2	LONGITUDINAL STIFFNESS, TRACTOR REAR TIRES (LBS)	28000.00
CS3	LONGITUDINAL STIFFNESS, TRAILER TIRES (LBS)	28000.00
D	VERTICAL DISTANCE FROM 5TH WHEEL CONNECTION TO TRACTOR CG (IN)	4.50
DELTA1	STATIC VERTICAL DISTANCE, TRACTOR CG TO TRACTOR FRONT AXLE (IN)	24.50
DELTA3	STATIC VERTICAL DISTANCE, TRAILER CG TO TRAILER AXLE (IN)	37.80
DT2	DISTANCE BETWEEN DUAL TIRES, TRACTOR REAR SUSPENSION (IN)	13.00
DT3	DISTANCE BETWEEN DUAL TIRES, TRAILER SUSPENSION (IN)	13.00
FA1	FRICTION REDUCTION PARAMETER FOR TRACTOR FRONT TIRES	0.0
FA2	FRICTION REDUCTION PARAMETER FOR TRACTOR REAR TIRES	0.0
FA3	FRICTION REDUCTION PARAMETER FOR TRAILER TIRES	0.0

IXX	TRACTOR SPRUNG MASS ROLL MOMENT OF INERTIA (IN-LB-SEC**2)	11906.00
IYY	TRACTOR SPRUNG MASS PITCH MOMENT OF INERTIA (IN-LB-SEC**2)	49440.00
IZZ	TRACTOR YAW MOMENT OF INERTIA (IN-LB-SEC**2)	49440.00
IXZ	TRACTOR PITCH PLANE CROSS MOMENT (IN-LB-SEC**2)	0.0
ITXX	TRAILER SPRUNG MASS ROLL MOMENT OF INERTIA (IN-LB-SEC**2)	14843.00
ITYY	(IN-LB-SEC**2) MASS PITCH MOMENT OF INER	422207.00
ITZZ	TRAILER YAW MOMENT OF INERTIA (IN-LB-SEC**2)	422207.00
ITXZ	TRAILER PITCH PLANE CROSS MOMENT (IN-LB-SEC**2)	0.0
JA1	ROLL MOMENT OF TRACTOR FRONT AXLE (IN-LB-SEC**2)	3719.00
JA2	ROLL MOMENT OF TRACTOR REAR AXLE (IN-LB-SEC**2)	4458.00
JA3	ROLL MOMENT OF TRAILER AXLE (IN-LB-SEC**2)	4100.00
JS1	POLAR MOMENT OF TRACTOR FRONT WHEELS (IN-LB-SEC**2)	103.00
JS2	POLAR MOMENT OF TRACTOR REAR WHEELS (IN-LB-SEC**2)	231.00
JS3	POLAR MOMENT OF TRAILER WHEELS (IN-LB-SEC**2)	231.00
K1	SPRING RATE, TRACTOR FRONT SUSPENSION (LB/IN)	1100.00
K2	SPRING RATE, TRACTOR REAR SUSPENSION (LB/IN)	8000.00
K3	SPRING RATE, TRAILER SUSPENSION (LB/IN)	8000.00
KRS1	FRONT AUXILIARY ROLL STIFFNESS(IN-LB/DEG	0.0
KRS2	REAR AUXILIARY ROLL STIFFNESS(IN-LB/DEG	0.0
KRS3	TRAILER AUXILIARY ROLL STIFFNESS(IN-LB/DEG	0.0
KT1	SPRING RATE, TRACTOR FRONT TIRES (LB/IN)	5300.00
KT2	SPRING RATE, TRACTOR REAR TIRES (LB/IN)	5300.00
KT3	SPRING RATE, TRAILER TIRES (LB/IN)	5300.00

FIFTH WHEEL SPRING RATE

ROTATION WH5DFL (DEG)	SPRING RATE MC5 (IN-LBS/DEG)
0.0	0.20000E+08

TRACTOR FRAME ROLL SPRING RATE

ROTATION TTDFL(DEG)	SPRING RATE TTC(IN-LBS/DEG)
0.0	0.25450E+05

TRSTF	TRAILER FRAME ROLL STIFFNESS(IN-LB/DEG)	1500000.00
PW	WEIGHT OF PAYLOAD (LBS)	29010.00
PJ1	POLL MOMENT OF INERTIA OF PAYLOAD (IN-LB-SEC**2)	50659.00
PJ2	PITCH MOMENT OF INERTIA OF PAYLOAD (IN-LB-SEC**2)	1421650.00
PJ3	YAW MOMENT OF INERTIA OF PAYLOAD (IN-LB-SEC**2)	1421650.00
PX	HORIZONTAL DISTANCE FROM MIDPOINT OF REAR SUSPENSION TO PAYLOAD MASS CENTER (IN)	210.00
PZ	VERTICAL DISTANCE FROM GROUND TO PAYLOAD MASS CENTER (IN)	68.00
RCH1	ROLL CENTER HEIGHT, TRACTOR FRONT SUSPENSION (IN)	24.00
RCH2	ROLL CENTER HEIGHT, TRACTOR REAR SUSPENSION (IN)	30.00
RCH3	ROLL CENTER HEIGHT, TRAILER SUSPENSION (IN	30.00

RS1	COMPLIANCE STEER (DEG/IN)	0.0
RSC1	ROLL STEER COEFFICIENT, TRACTOR FRONT SUSPENSION	0.0
RSC2	ROLL STEER COEFFICIENT, TRACTOR REAR SUSPENSION	0.10
RSC3	ROLL STEER COEFFICIENT, TRAILER SUSPENSION	0.10
SY1	HORIZONTAL DISTANCE FROM TRACTOR BODY X-AXIS TO TRACTOR FRONT SUSPENSION (IN)	17.00
SY2	HORIZONTAL DISTANCE FROM TRACTOR BODY X-AXIS TO TRACTOR REAR SUSPENSION (IN)	20.00
SY3	HORIZONTAL DISTANCE FROM TRAILER BODY X-AXIS TO TRAILER SUSPENSION (IN)	20.00
TIMF	MAXIMUM REAL TIME FOR SIMULATION (SEC)	4.00
TRA1	HALF TRACK, TRACTOR FRONT AXLE (IN)	38.50
TRA2	HALF TRACK, TRACTOR REAR AXLE(S) (IN)	36.00
TRA3	HALF TRACK, TRAILER AXLE(S) (IN)	36.00
VEL	INITIAL VELOCITY (FT/SEC)	73.33
W1	SPRUNG WEIGHT OF TRACTOR (LBS)	7990.00
W2	SPRUNG WEIGHT OF TRAILER (LBS)	8500.00
WS1	WEIGHT OF TRACTOR FRONT SUSPENSION (LBS)	1200.00
WS2	WEIGHT OF TRACTOR REAR SUSPENSION (LBS)	2300.00
WS3	WEIGHT OF TRAILER SUSPENSION (LBS)	1500.00

```
BRAKE PARAMETERS: TQ(1,1,1) = 0.050 TQ(1,1,2) = 0.270
                  TQ(1,2,1) = 0.050 TQ(1,2,2) = 0.270
                  TQ(2,1,1) = 0.075 TQ(2,1,2) = 0.245
                  TQ(2,2,1) = 0.075 TQ(2,2,2) = 0.245
                  TQ(3,1,1) = 0.175 TQ(3,1,2) = 0.303
                  TQ(3,2,1) = 0.175 TQ(3,2,2) = 0.303
```

TABLE 1: TIME VS PRESSURE (PSI)
NO. OF POINTS: 2

0.0	0.0
0.0500	0.0

INPUT PARAMETER TABLE FOR BRAKE FORCE CALCULATION SUBROUTINE

SYMBOL	DESCRIPTION		INITIAL VALUE
		AXLE 1, LEFT SIDE	
IBRT	BRAKE TYPE		NONE
		AXLE 2, LEFT SIDE	
IBRT	BRAKE TYPE		NONE
		AXLE 3, LEFT SIDE	
IBRT	BRAKE TYPE		NONE

TABLE 2: TIME VS STEER ANGLE (DEG)
LEFT SIDE
NO. OF POINTS: 2

0.0	0.0
8.0000	08.0000

TABLE 3: TIME VS STEER ANGLE (DEG)
RIGHT SIDE
NO. OF POINTS: 2

0.0	0.0
8.0000	08.0000

PARAMETERS FOR INCLINE SURFACE:

G1	GRAVITY X COMPONENT	0.0
G2	GRAVITY Y COMPONENT	0.0
G3	GRAVITY Z COMPONENT	1.000

THERE WILL BE NO WIND THIS RUN

THE ANTILOCK SYSTEM WILL NOT BE USED THIS RUN

*** END INPUT ***

	EMPTY	LOADED
DISTANCE FROM TRAILER SPRUNG MASS CENTER TO TRAILER REAR AXLE CENTERLINE (IN)	195.800	206.782
DISTANCE FROM TRAILER SPRUNG MASS CENTER TO GROUND (IN)	57.300	65.575
ROLL MOMENT OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	14842.996	67451.438
PITCH MOMENT OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	422206.938	1849239.000
YAW MOMENT OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	422206.938	1847289.000

THE STATIC LOADS ON THE TIRES ARE

AXLE NUMBER	LOAD
1	10502.242
2	19998.539
3	19999.219
TOTAL	50500.000

THE TRACTOR TOTAL SPRUNG MASS CENTER IS 44.202 INCHES BEHIND THE FRONT AXLE,
THE TOTAL YAW MOMENT OF INERTIA IS 92614.000 IN LB SEC**2.

THE TRAILER MASS CENTER IS 209.169 INCHES BEHIND THE FIFTH WHEEL,
THE TOTAL YAW MOMENT OF INERTIA IS 2011131.000 IN LB SEC**2

TIME INCREMENT TO BE PRINTED OUT IS 0.10

TRACTOR FRONT TIRES : FIRESTONE 10X20 RIB
TRACTOR REAR TIRES : FIRESTONE 10X20 RIB

TRAILER TIRES : FIRESTONE 10X20 RIB

*** BEGIN OUTPUT ***

2AXLE 140 IN. WHEEL BASE TRACTOR-VAN TRAILER RUN# 49

INPUT PARAMETER TABLE

SYMBOL	DESCRIPTION	INITIAL VALUE
KEY(1)	TRACTOR AXLE KEY: 0 FOR SINGLE AXLE 1 FOR WALKING BEAM 2 FOR 4 ELLIPTIC LEAF	0
KEY(2)	TRAILER AXLE KEY	0
A1	HORIZONTAL DISTANCE FROM TRACTOR CG TO CENTER OF TRACTOR FRONT SUSPENSION (IN)	36.40
A2	HORIZONTAL DISTANCE FROM TRACTOR CG TO CENTER OF TRACTOR REAR SUSPENSION (IN)	103.60
A3	HORIZONTAL DISTANCE FROM TRAILER CG TO 5TH WHEEL (IN)	212.20
A4	HORIZONTAL DISTANCE FROM TRAILER CG TO CENTER OF TRAILER SUSPENSION (IN)	195.80
ALPHA1	STATIC DISTANCE, TRACTOR FRONT AXLE TO GROUND (IN)	19.50
ALPHA2	STATIC DISTANCE, TRACTOR REAR AXLE(S) TO GROUND (IN)	19.50
ALPHA3	STATIC DISTANCE, TRAILER AXLE(S) TO GROUND (IN)	19.50
AN1	TIRE PRESSURE DIST. FUNCTION FOR TRACTOR FRONT TIRES	0.250
AN2	TIRE PRESSURE DIST. FUNCTION FOR TRACTOR REAR TIRES	0.250
AN3	TIRE PRESSURE DIST. FUNCTION FOR TRAILOR TIRES	0.250
BB	HORIZONTAL DISTANCE FROM 5TH WHEEL TO MIDPOINT OF TRACTOR REAR SUSPENSION (IN)	22.50
C1	VISCOUS DAMPING: JOUNCE ON TRACTOR FRONT SUSPENSION (LB-SEC/IN)	10.00
C2	VISCOUS DAMPING: REBOUND ON TRACTOR FRONT SUSPENSION (LB-SEC/IN)	20.00
C3	VISCOUS DAMPING: JOUNCE ON TRACTOR REAR SUSPENSION (LB-SEC/IN)	10.00
C4	VISCOUS DAMPING: REBOUND ON TRACTOR REAR SUSPENSION (LB-SEC/IN)	20.00
C5	VISCOUS DAMPING: JOUNCE ON TRAILER SUSPENSION (LB-SEC/IN)	10.00
C6	VISCOUS DAMPING: REBOUND ON TRAILER SUSPENSION (LB-SEC/IN)	20.00
CALF1	LATERAL STIFFNESS, TRACTOR FRONT TIRES (LBS/DEG)	-1.00
CF1	MAXIMUM COULOMB FRICTION, TRACTOR FRONT SUSPENSION (LB)	500.00
CF2	MAXIMUM COULOMB FRICTION, TRACTOR REAR SUSPENSION (LB)	750.00
CF3	MAXIMUM COULOMB FRICTION, TRAILER SUSPENSION (LB)	750.00
CS1	LONGITUDINAL STIFFNESS, TRACTOR FRONT TIRES (LBS)	28000.00
CS2	LONGITUDINAL STIFFNESS, TRACTOR REAR TIRES (LBS)	28000.00
CS3	LONGITUDINAL STIFFNESS, TRAILER TIRES (LBS)	28000.00
D	VERTICAL DISTANCE FROM 5TH WHEEL CONNECTION TO TRACTOR CG (IN)	4.50
DELTA1	STATIC VERTICAL DISTANCE, TRACTOR CG TO TRACTOR FRONT AXLE (IN)	24.50
DELTA3	STATIC VERTICAL DISTANCE, TRAILER CG TO TRAILER AXLE (IN)	37.80
DT2	DISTANCE BETWEEN DUAL TIRES, TRACTOR REAR SUSPENSION (IN)	13.00
DT3	DISTANCE BETWEEN DUAL TIRES, TRAILER SUSPENSION (IN)	13.00
FA1	FRICTION REDUCTION PARAMETER FOR TRACTOR FRONT TIRES	0.0
FA2	FRICTION REDUCTION PARAMETER FOR TRACTOR REAR TIRES	0.0
FA3	FRICTION REDUCTION PARAMETER FOR TRAILER TIRES	0.0

IXX	TRACTOR SPRUNG MASS ROLL MOMENT OF INERTIA (IN-LB-SEC**2)	12772.00
IYY	TRACTOR SPRUNG MASS PITCH MOMENT OF INERTIA (IN-LB-SEC**2)	67527.00
IZZ	TRACTOR YAW MOMENT OF INERTIA (IN-LB-SEC**2)	67527.00
IXZ	TRACTOR PITCH PLANE CROSS MOMENT (IN-LB-SEC**2)	0.0
ITXX	TRAILER SPRUNG MASS ROLL MOMENT OF INERTIA (IN-LB-SEC**2)	14843.00
ITYY	(IN-LB-SEC**2) MASS PITCH MOMENT OF INER	422207.00
ITZZ	TRAILER YAW MOMENT OF INERTIA (IN-LB-SEC**2)	422207.00
ITXZ	TRAILER PITCH PLANE CROSS MOMENT (IN-LB-SEC**2)	0.0
JA1	ROLL MOMENT OF TRACTOR FRONT AXLE (IN-LB-SEC**2)	3719.00
JA2	ROLL MOMENT OF TRACTOR REAR AXLE (IN-LB-SEC**2)	4458.00
JA3	ROLL MOMENT OF TRAILER AXLE (IN-LB-SEC**2)	4100.00
JS1	POLAR MOMENT OF TRACTOR FRONT WHEELS (IN-LB-SEC**2)	103.00
JS2	POLAR MOMENT OF TRACTOR REAR WHEELS (IN-LB-SEC**2)	231.00
JS3	POLAR MOMENT OF TRAILER WHEELS (IN-LB-SEC**2)	231.00
K1	SPRING RATE, TRACTOR FRONT SUSPENSION (LB/IN)	1100.00
K2	SPRING RATE, TRACTOR REAR SUSPENSION (LB/IN)	8000.00
K3	SPRING RATE, TRAILER SUSPENSION (LB/IN)	8000.00
KRS1	FRONT AUXILIARY ROLL STIFFNESS(IN-LB/DEG	0.0
KRS2	REAR AUXILIARY ROLL STIFFNESS(IN-LB/DEG	0.0
KRS3	TRAILER AUXILIARY ROLL STIFFNESS(IN-LB/DEG	0.0
KT1	SPRING RATE, TRACTOR FRONT TIRES (LB/IN)	5300.00
KT2	SPRING RATE, TRACTOR REAR TIRES (LB/IN)	5300.00
KT3	SPRING RATE, TRAILER TIRES (LB/IN)	5300.00

FIFTH WHEEL SPRING RATE

ROTATION WH5DFL (DEG)	SPRING RATE MC5 (IN-LBS/DEG)
0.0	0.20000E+08

TRACTOR FRAME ROLL SPRING RATE

ROTATION TTDFL(DEG)	SPRING RATE TTC(IN-LBS/DEG)
0.0	0.20000E+05

TRSTF	TRAILER FRAME ROLL STIFFNESS(IN-LB/DEG)	1500000.00
PW	WEIGHT OF PAYLOAD (LBS)	28430.00
PJ1	POLL MOMENT OF INERTIA OF PAYLOAD (IN-LB-SEC**2)	49646.00
PJ2	PITCH MOMENT OF INERTIA OF PAYLOAD (IN-LB-SEC**2)	1438368.00
PJ3	YAW MOMENT OF INERTIA OF PAYLOAD (IN-LB-SEC**2)	1438368.00
PX	HORIZONTAL DISTANCE FROM MIDPOINT OF REAR SUSPENSION TO PAYLOAD MASS CENTER (IN)	206.00
PZ	VERTICAL DISTANCE FROM GROUND TO PAYLOAD MASS CENTER (IN)	68.00
RCH1	ROLL CENTER HEIGHT, TRACTOR FRONT SUSPENSION (IN)	24.00
RCH2	ROLL CENTER HEIGHT, TRACTOR REAR SUSPENSION (IN)	30.00
RCH3	ROLL CENTER HEIGHT, TRAILER SUSPENSION (IN	30.00

RS1	COMPLIANCE STEER (DEG/IN)	0.0
RSC1	ROLL STEER COEFFICIENT, TRACTOR FRONT SUSPENSION	0.0
RSC2	ROLL STEER COEFFICIENT, TRACTOR REAR SUSPENSION	0.10
RSC3	ROLL STEER COEFFICIENT, TRAILER SUSPENSION	0.10
SY1	HORIZONTAL DISTANCE FROM TRACTOR BODY X-AXIS TO TRACTOR FRONT SUSPENSION (IN)	17.00
SY2	HORIZONTAL DISTANCE FROM TRACTOR BODY X-AXIS TO TRACTOR REAR SUSPENSION (IN)	20.00
SY3	HORIZONTAL DISTANCE FROM TRAILER BODY X-AXIS TO TRAILER SUSPENSION (IN)	20.00
TIMF	MAXIMUM REAL TIME FOR SIMULATION (SEC)	4.00
TRA1	HALF TRACK, TRACTOR FRONT AXLE (IN)	38.50
TRA2	HALF TRACK, TRACTOR REAR AXLE(S) (IN)	36.00
TRA3	HALF TRACK, TRAILER AXLE(S) (IN)	36.00
VEL	INITIAL VELOCITY (FT/SEC)	73.33
W1	SPRUNG WEIGHT OF TRACTOR (LBS)	8570.00
W2	SPRUNG WEIGHT OF TRAILER (LBS)	8500.00
WS1	WEIGHT OF TRACTOR FRONT SUSPENSION (LBS)	1200.00
WS2	WEIGHT OF TRACTOR REAR SUSPENSION (LBS)	2300.00
WS3	WEIGHT OF TRAILER SUSPENSION (LBS)	1500.00

```
BRAKE PARAMETERS: TQ(1,1,1) = 0.050 TQ(1,1,2) = 0.270
                  TQ(1,2,1) = 0.050 TQ(1,2,2) = 0.270
                  TQ(2,1,1) = 0.075 TQ(2,1,2) = 0.245
                  TQ(2,2,1) = 0.075 TQ(2,2,2) = 0.245
                  TQ(3,1,1) = 0.175 TQ(3,1,2) = 0.303
                  TQ(3,2,1) = 0.175 TQ(3,2,2) = 0.303
```

TABLE 1: TIME VS PRESSURE (PSI)
NO. OF POINTS: 2

0.0	0.0
0.0500	0.0

INPUT PARAMETER TABLE FOR BRAKE FORCE CALCULATION SUBROUTINE

SYMBOL	DESCRIPTION		INITIAL VALUE
		AXLE 1, LEFT SIDE	
IBRT	BRAKE TYPE		NONE
		AXLE 2, LEFT SIDE	
IBRT	BRAKE TYPE		NONE
		AXLE 3, LEFT SIDE	
IBRT	BRAKE TYPE		NONE

TABLE 2: TIME VS STEER ANGLE (DEG)
LEFT SIDE
NO. OF POINTS: 2

0.0	0.0
8.0000	08.0000

TABLE 3: TIME VS STEER ANGLE (DEG)
RIGHT SIDE
NO. OF POINTS: 2

0.0	0.0
8.0000	08.0000

PARAMETERS FOR INCLINE SURFACE:

G1	GRAVITY X COMPONENT	0.0
G2	GRAVITY Y COMPONENT	0.0
G3	GRAVITY Z COMPONENT	1.000

THERE WILL BE NO WIND THIS RUN

THE ANTILOCK SYSTEM WILL NOT BE USED THIS RUN

*** END INPUT ***

	EMPTY	LOADED
DISTANCE FROM TRAILER SPRUNG MASS CENTER TO TRAILER REAR AXLE CENTERLINE (IN)	195.800	203.652
DISTANCE FROM TRAILER SPRUNG MASS CENTER TO GROUND (IN)	57.300	65.537
ROLL MOMENT OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	14842.996	66429.375
PITCH MOMENT OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	422206.938	1864278.000
YAW MOMENT OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	422206.938	1862337.000

THE STATIC LOADS ON THE TIRES ARE

AXLE NUMBER	LOAD
1	10504.336
2	19999.180
3	19996.484
TOTAL	50500.000

THE TRACTOR TOTAL SPRUNG MASS CENTER IS 52.523 INCHES BEHIND THE FRONT AXLE,
THE TOTAL YAW MOMENT OF INERTIA IS 135636.750 IN LB SEC**2.

THE TRAILER MASS CENTER IS 212.297 INCHES BEHIND THE FIFTH WHEEL,
THE TOTAL YAW MOMENT OF INERTIA IS 2021286.000 IN LB SEC**2

TIME INCREMENT TO BE PRINTED OUT IS 0.10

TRACTOR FRONT TIRES : FIRESTONE 10X20 RIB
TRACTOR REAR TIRES : FIRESTONE 10X20 RIB

TRAILER TIRES : FIRESTONE 10X20 RIB

*** BEGIN OUTPUT ***

145 INCH WHEEL BASE 3AXLE TRACTOR,VAN TRAILER RUN# 97

INPUT PARAMETER TABLE

SYMBOL	DESCRIPTION	INITIAL VALUE
KEY(1)	TRACTOR AXLE KEY: 0 FOR SINGLE AXLE 1 FOR WALKING BEAM 2 FOR 4 ELLIPTIC LEAF	2
KEY(2)	TRAILER AXLE KEY	2
AA1	HORIZONTAL DISTANCE FORM TRACTOR FRONT LEAF-FRAME CONTACT TO AXLE CENTER (IN)	24.00
AA2	HORIZONTAL DISTANCE FROM TRACTOR REAR LEAF-FRAME CONTACT TO AXLE CENTER (IN)	24.00
AA4	HORIZONTAL DISTANCE FROM TRACTOR FRONT LEAF-FRAME CONTACT TO LOAD LEVELER PIN (IN	1.00
AA5	HORIZONTAL DISTANCE FROM TRACTOR REAR LEAF-FRAME CONTACT TO LOAD LEVELER PIN (IN	1.00
AA6	VERTICAL DISTANCE FROM AXLE DOWN TO TRACTOR TORQUE ROD (IN)	0.0
AA7	ANGLE BETWEEN TRACTOR TORQUE ROD AND HORIZONTAL (DEG)	0.0
AA8	HORIZONTAL DISTANCE FROM AXLE CENTER FORWARD TO TRACTOR TORQUE ROD (IN)	0.0
AA9	HORIZONTAL DISTANCE FROM TRAILER FRONT LEAF-FRAME CONTACT TO AXLE CENTER (IN)	18.50
AA10	HORIZONTAL DISTANCE FROM TRAILER REAR LEAF-FRAME CONTACT TO AXLE CENTER (IN)	18.50
AA12	HORIZONTAL DISTANCE FROM TRAILER FRONT LEAF-FRAME CONTACT TO LOAD LEVELER PIN (IN	6.25
AA13	HORIZONTAL DISTANCE FROM TRAILER REAR LEAF-FRAME CONTACT TO LOAD LEVELER PIN (IN	6.25
AA14	VERTICAL DISTANCE FROM AXLE DOWN TO TRAILER TORQUE ROD (IN)	7.00
AA15	ANGLE BETWEEN TRAILER TORQUE ROD AND HORIZONTAL (DEG)	15.01
AA16	HORIZONTAL DISTANCE FROM AXLE CENTER FORWARD TO TRAILER TORQUE ROD (IN)	5.50
A1	HORIZONTAL DISTANCE FROM TRACTOR CG TO CENTER OF TRACTOR FRONT SUSPENSION (IN)	37.70
A2	HORIZONTAL DISTANCE FROM TRACTOR CG TO CENTER OF TRACTOR REAR SUSPENSION (IN)	107.30
A3	HORIZONTAL DISTANCE FROM TRAILER CG TO 5TH WHEEL (IN)	230.50
A4	HORIZONTAL DISTANCE FROM TRAILER CG TO CENTER OF TRAILER SUSPENSION (IN)	179.50
ALPHA1	STATIC DISTANCE, TRACTOR FRONT AXLE TO GROUND (IN)	19.50
ALPHA2	STATIC DISTANCE, TRACTOR REAR AXLE(S) TO GROUND (IN)	19.50
ALPHA3	STATIC DISTANCE, TRAILER AXLE(S) TO GROUND (IN)	19.50
AN1	TIRE PRESSURE DIST. FUNCTION FOR TRACTOR FRONT TIRES	0.250
AN2	TIRE PRESSURE DIST. FUNCTION FOR TRACTOR FRONT TANDEM TIRES	0.250
AN3	TIRE PRESSURE DIST. FUNCTION FOR TRACTOR REAR TANDEM TIRES	0.250
AN4	TIRE PRESSURE DIST. FUNCTION FOR TRAILOR FRONT TANDEM TIRES	0.250
AN5	TIRE PRESSURE DIST. FUNCTION FOR TRAILOR REAR TANDEM TIRES	0.250
BB	HORIZONTAL DISTANCE FROM 5TH WHEEL TO MIDPOINT OF TRACTOR REAR SUSPENSION (IN)	18.80
C1	VISCOUS DAMPING: JOUNCE ON TRACTOR FRONT SUSPENSION (LB-SEC/IN)	10.00
C2	VISCOUS DAMPING: REBOUND ON TRACTOR FRONT SUSPENSION (LB-SEC/IN)	20.00
C3	VISCOUS DAMPING: JOUNCE ON TRACTOR REAR SUSPENSION (LB-SEC/IN)	10.00
C4	VISCOUS DAMPING: REBOUND ON TRACTOR REAR SUSPENSION (LB-SEC/IN)	20.00
C5	VISCOUS DAMPING: JOUNCE ON TRAILER SUSPENSION (LB-SEC/IN)	10.00
C6	VISCOUS DAMPING: REBOUND ON TRAILER SUSPENSION (LB-SEC/IN)	20.00

CALF1	LATERAL STIFFNESS, TRACTOR FRONT TIRES (LBS/DEG)	-1.00
CF1	MAXIMUM COULOMB FRICTION, TRACTOR FRONT SUSPENSION (LB)	500.00
CF2	MAXIMUM COULOMB FRICTION, TRACTOR REAR SUSPENSION (LB)	1500.00
CF3	MAXIMUM COULOMB FRICTION, TRAILER SUSPENSION (LB)	1500.00
CS1	LONGITUDINAL STIFFNESS, TRACTOR FRONT TIRES (LBS)	28000.00
CS2	LONGITUDINAL STIFFNESS, TRACTOR FRONT TANDEM TIRES (LBS)	28000.00
CS3	LONGITUDINAL STIFFNESS, TRACTOR REAR TANDEM TIRES (LBS)	28000.00
CS4	LONGITUDINAL STIFFNESS, TRAILER FRONT TANDEM TIRES (LBS)	28000.00
CS5	LONGITUDINAL STIFFNESS, TRAILER REAR TANDEM TIRES (LBS)	28000.00
D	VERTICAL DISTANCE FROM 5TH WHEEL CONNECTION TO TRACTOR CG (IN)	4.50
DELTA1	STATIC VERTICAL DISTANCE, TRACTOR CG TO TRACTOR FRONT AXLE (IN)	24.50
DELTA3	STATIC VERTICAL DISTANCE, TRAILER CG TO TRAILER AXLE (IN)	37.80
DT2	DISTANCE BETWEEN DUAL TIRES, TRACTOR REAR SUSPENSION (IN)	13.00
DT3	DISTANCE BETWEEN DUAL TIRES, TRAILER SUSPENSION (IN)	13.00
FA1	FRICTION REDUCTION PARAMETER FOR TRACTOR FRONT TIRES	0.0
FA2	FRICTION REDUCTION PARAMETER FOR TRACTOR FRONT TANDEM TIRES	0.0
FA3	FRICTION REDUCTION PARAMETER FOR TRACTOR REAR TANDEM TIRES	0.0
FA4	FRICTION REDUCTION PARAMETER FOR TRAILER FRONT TANDEM TIRES	0.0
FA5	FRICTION REDUCTION PARAMETER FOR TRAILER REAR TANDEM TIRES	0.0
IXX	TRACTOR SPRUNG MASS ROLL MOMENT OF INERTIA (IN-LB-SEC**2)	13630.00
IYY	TRACTOR SPRUNG MASS PITCH MOMENT OF INERTIA (IN-LB-SEC**2)	97371.00
IZZ	TRACTOR YAW MOMENT OF INERTIA (IN-LB-SEC**2)	97371.00
IXZ	TRACTOR PITCH PLANE CROSS MOMENT (IN-LB-SEC**2)	0.0
ITXX	TRAILER SPRUNG MASS ROLL MOMENT OF INERTIA (IN-LB-SEC**2)	21100.00
ITYY	(IN-LB-SEC**2) MASS PITCH MOMENT OF INER	759480.00
ITZZ	TRAILER YAW MOMENT OF INERTIA (IN-LB-SEC**2)	759480.00
ITXZ	TRAILER PITCH PLANE CROSS MOMENT (IN-LB-SEC**2)	0.0
JA1	ROLL MOMENT OF TRACTOR FRONT AXLE (IN-LB-SEC**2)	3719.00
JA2	ROLL MOMENT OF TRACTOR FRONT TANDEM AXLE (IN-LB-SEC**2)	4458.00
JA3	ROLL MOMENT OF TRAILER FRONT TANDEM AXLE (IN-LB-SEC**2)	4100.00
JS1	POLAR MOMENT OF TRACTOR FRONT WHEELS (IN-LB-SEC**2)	103.00
JS2	POLAR MOMENT OF TRACTOR FRONT TANDEM WHEELS (IN-LB-SEC**2)	231.00
JS3	POLAR MOMENT OF TRACTOR REAR TANDEM WHEELS (IN-LB-SEC**2)	231.00
JS4	POLAR MOMENT OF TRAILER FRONT TANDEM WHEELS (IN-LB-SEC**2)	231.00
JS5	POLAR MOMENT OF TRAILER REAR TANDEM WHEELS (IN-LB-SEC**2)	231.00
K1	SPRING RATE, TRACTOR FRONT SUSPENSION (LB/IN)	1300.00
K2	SPRING RATE, TRACTOR REAR SUSPENSION (LB/IN)	10000.00
K3	SPRING RATE, TRAILER SUSPENSION (LB/IN)	16000.00

KRS1	FRONT AUXILIARY ROLL STIFFNESS(IN-LB/DEG	0.0
KRS2	REAR AUXILIARY ROLL STIFFNESS(IN-LB/DEG	0.0
KRS3	TRAILER AUXILIARY ROLL STIFFNESS(IN-LB/DEG	0.0
AKRS	TRACTOR TR TANDEM AUX ROLL STIFFNESS(IN-LB/DEG)	0.0
KT1	SPRING RATE, TRACTOR FRONT TIRES (LB/IN)	5700.00
KT2	SPRING RATE, TRACTOR FRONT TANDEM TIRES (LB/IN)	5700.00
KT3	SPRING RATE, TRACTOR REAR TANDEM TIRES (LB/IN)	5700.00
KT4	SPRING RATE, TRAILER FRONT TANDEM TIRES (LB/IN)	5300.00
KT5	SPRING RATE, TRAILER REAR TANDEM TIRES (LB/IN)	5300.00

FIFTH WHEEL SPRING RATE

ROTATION WH5DFL (DEG)	SPRING RATE MC5 (IN-LBS/DEG)
0.0	0.20000E+08

TRACTOR FRAME ROLL SPRING RATE

ROTATION TTDFL(DEG)	SPRING RATE TTC(IN-LBS/DEG)
0.0	0.19300E+05

TRSTF	TRAILER FRAME ROLL STIFFNESS(IN-LB/DEG)	1500000.00
PW	WEIGHT OF PAYLOAD (LBS)	49970.00
PJ1	POLL MOMENT OF INERTIA OF PAYLOAD (IN-LB-SEC**2)	87260.00
PJ2	PITCH MOMENT OF INERTIA OF PAYLOAD (IN-LB-SEC**2)	2458900.00
PJ3	YAW MOMENT OF INERTIA OF PAYLOAD (IN-LB-SEC**2)	2458900.00
PX	HORIZONTAL DISTANCE FROM MIDPOINT OF REAR SUSPENSION TO PAYLOAD MASS CENTER (IN)	211.40
PZ	VERTICAL DISTANCE FROM GROUND TO PAYLOAD MASS CENTER (IN)	68.00
RCH1	ROLL CENTER HEIGHT, TRACTOR FRONT SUSPENSION (IN)	24.00
RCH2	ROLL CENTER HEIGHT, TRACTOR REAR SUSPENSION (IN)	30.00
RCH3	ROLL CENTER HEIGHT, TRAILER SUSPENSION (IN	30.00
RS1	COMPLIANCE STEER (DEG/IN)	0.0
RSC1	ROLL STEER COEFFICIENT, TRACTOR FRONT SUSPENSION	0.0
RSC2	ROLL STEER COEFFICIENT, TRACTOR REAR SUSPENSION	0.10
RSC3	ROLL STEER COEFFICIENT, TRAILER SUSPENSION	0.10
SY1	HORIZONTAL DISTANCE FROM TRACTOR BODY X-AXIS TO TRACTOR FRONT SUSPENSION (IN)	17.00
SY2	HORIZONTAL DISTANCE FROM TRACTOR BODY X-AXIS TO TRACTOR REAR SUSPENSION (IN)	20.00
SY3	HORIZONTAL DISTANCE FROM TRAILER BODY X-AXIS TO TRAILER SUSPENSION (IN)	20.00
TIMF	MAXIMUM REAL TIME FOR SIMULATION (SEC)	4.00
TRA1	HALF TRACK, TRACTOR FRONT AXLE (IN)	40.25
TRA2	HALF TRACK, TRACTOR REAR AXLE(S) (IN)	36.00
TRA3	HALF TRACK, TRAILER AXLE(S) (IN)	36.00
VEL	INITIAL VELOCITY (FT/SEC)	73.33
W1	SPRUNG WEIGHT OF TRACTOR (LBS)	9150.00
W2	SPRUNG WEIGHT OF TRAILER (LBS)	12080.00
WS1	WEIGHT OF TRACTOR FRONT SUSPENSION (LBS)	1200.00
WS2	WEIGHT OF TRACTOR FRONT TANDEM SUSPENSION (LBS)	2300.00
WS3	WEIGHT OF TRACTOR REAR TANDEM SUSPENSION (LBS)	2300.00
WS4	WEIGHT OF TRAILER FRONT TANDEM SUSPENSION (LBS)	1500.00
WS5	WEIGHT OF TRAILER REAR TANDEM SUSPENSION (LBS)	1500.00

```
BRAKE PARAMETERS: TQ(1,1,1) = 0.050 TQ(1,1,2) = 0.270
                  TQ(1,2,1) = 0.050 TQ(1,2,2) = 0.270
                  TQ(2,1,1) = 0.075 TQ(2,1,2) = 0.245
                  TQ(2,2,1) = 0.075 TQ(2,2,2) = 0.245
                  TQ(3,1,1) = 0.075 TQ(3,1,2) = 0.245
                  TQ(3,2,1) = 0.075 TQ(3,2,2) = 0.245
                  TQ(4,1,1) = 0.175 TQ(4,1,2) = 0.303
                  TQ(4,2,1) = 0.175 TQ(4,2,2) = 0.303
                  TQ(5,1,1) = 0.175 TQ(5,1,2) = 0.303
                  TQ(5,2,1) = 0.175 TQ(5,2,2) = 0.303

    TABLE 1: TIME VS PRESSURE (PSI)
             NO. OF POINTS:  2
          0.0           0.0
          0.0500        0.0

    INPUT PARAMETER TABLE FOR BRAKE FORCE CALCULATION SUBROUTINE
    SYMBOL      DESCRIPTION                         INITIAL VALUE
                                AXLE 1, LEFT SIDE
    IBRT        BRAKE TYPE                                     NONE
                                AXLE 2, LEFT SIDE
    IBRT        BRAKE TYPE                                     NONE
                                AXLE 3, LEFT SIDE
    IBRT        BRAKE TYPE                                     NONE
                                AXLE 4, LEFT SIDE
    IBRT        BRAKE TYPE                                     NONE
                                AXLE 5, LEFT SIDE
    IBRT        BRAKE TYPE                                     NONE

    TABLE  2: TIME VS STEER ANGLE (DEG)
              LEFT SIDE
              NO. OF POINTS:  2
          0.0           0.0
          8.0000       08.0000


    TABLE  3: TIME VS STEER ANGLE (DEG)
              RIGHT SIDE
              NO. OF POINTS:  2
          0.0           0.0
          8.0000       08.0000


    PARAMETERS FOR INCLINE SURFACE:
          G1          GRAVITY X COMPONENT           0.0
          G2          GRAVITY Y COMPONENT           0.0
          G3          GRAVITY Z COMPONENT           1.000

    THERE WILL BE NO WIND THIS RUN

THE ANTILOCK SYSTEM WILL NOT BE USED THIS RUN

     *** END INPUT ***
```

	EMPTY	LOADED
DISTANCE FROM TRAILER SPRUNG MASS CENTER TO TRAILER REAR AXLE CENTERLINE (IN)	179.500	205.189
DISTANCE FROM TRAILER SPRUNG MASS CENTER TO GROUND (IN)	57.300	65.917
ROLL MOMENT OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	21099.996	111244.875
PITCH MOMENT OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	759480.000	3246906.000
YAW MOMENT OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	759480.000	3244020.000

THE STATIC LOADS ON THE TIRES ARE

AXLE NUMBER	LOAD
1	11997.266
2	17003.195
3	17003.195
4	16998.172
5	16998.172
TOTAL	80000.000

THE TRACTOR TOTAL SPRUNG MASS CENTER IS 67.689 INCHES BEHIND THE FRONT AXLE,
THE TOTAL YAW MOMENT OF INERTIA IS 224224.188 IN LB SEC**2.

THE TRAILER MASS CENTER IS 214.274 INCHES BEHIND THE FIFTH WHEEL,
THE TOTAL YAW MOMENT OF INERTIA IS 3569055.000 IN LB SEC**2

TIME INCREMENT TO BE PRINTED OUT IS 0.10

TRACTOR FRONT TIRES : FIRESTONE 10X20 RIB
TRACTOR LEADING TANDEM TIRES : FIRESTONE 10X20 RIB
TRACTOR TRAILING TANDEM TIRES : FIRESTONE 10X20 RIB

TRAILER LEADING TANDEM TIRES : FIRESTONE 10X20 RIB
TRAILER TRAILING TANDEM TIRES : FIRESTONE 10X20 RIB

*** BEGIN OUTPUT ***

165 INCH WHEEL BASE 3AXLE TRACTOR,VAN TRAILER RUN# 145

INPUT PARAMETER TABLE

SYMBOL	DESCRIPTION	INITIAL VALUE
KEY(1)	TRACTOR AXLE KEY: 0 FOR SINGLE AXLE 1 FOR WALKING BEAM 2 FOR 4 ELLIPTIC LEAF	2
KEY(2)	TRAILER AXLE KEY	2
AA1	HORIZONTAL DISTANCE FORM TRACTOR FRONT LEAF-FRAME CONTACT TO AXLE CENTER (IN)	24.00
AA2	HORIZONTAL DISTANCE FROM TRACTOR REAR LEAF-FRAME CONTACT TO AXLE CENTER (IN)	24.00
AA4	HORIZONTAL DISTANCE FROM TRACTOR FRONT LEAF-FRAME CONTACT TO LOAD LEVELER PIN (IN	1.00
AA5	HORIZONTAL DISTANCE FROM TRACTOR REAR LEAF-FRAME CONTACT TO LOAD LEVELER PIN (IN	1.00
AA6	VERTICAL DISTANCE FROM AXLE DOWN TO TRACTOR TORQUE ROD (IN)	0.0
AA7	ANGLE BETWEEN TRACTOR TORQUE ROD AND HORIZONTAL (DEG)	0.0
AA8	HORIZONTAL DISTANCE FROM AXLE CENTER FORWARD TO TRACTOR TORQUE ROD (IN)	0.0
AA9	HORIZONTAL DISTANCE FROM TRAILER FRONT LEAF-FRAME CONTACT TO AXLE CENTER (IN)	18.50
AA10	HORIZONTAL DISTANCE FROM TRAILER REAR LEAF-FRAME CONTACT TO AXLE CENTER (IN)	18.50
AA12	HORIZONTAL DISTANCE FROM TRAILER FRONT LEAF-FRAME CONTACT TO LOAD LEVELER PIN (IN	6.25
AA13	HORIZONTAL DISTANCE FROM TRAILER REAR LEAF-FRAME CONTACT TO LOAD LEVELER PIN (IN	6.25
AA14	VERTICAL DISTANCE FROM AXLE DOWN TO TRAILER TORQUE ROD (IN)	7.00
AA15	ANGLE BETWEEN TRAILER TORQUE ROD AND HORIZONTAL (DEG)	15.01
AA16	HORIZONTAL DISTANCE FROM AXLE CENTER FORWARD TO TRAILER TORQUE ROD (IN)	5.50
A1	HORIZONTAL DISTANCE FROM TRACTOR CG TO CENTER OF TRACTOR FRONT SUSPENSION (IN)	57.75
A2	HORIZONTAL DISTANCE FROM TRACTOR CG TO CENTER OF TRACTOR REAR SUSPENSION (IN)	107.25
A3	HORIZONTAL DISTANCE FROM TRAILER CG TO 5TH WHEEL (IN)	230.50
A4	HORIZONTAL DISTANCE FROM TRAILER CG TO CENTER OF TRAILER SUSPENSION (IN)	179.50
ALPHA1	STATIC DISTANCE, TRACTOR FRONT AXLE TO GROUND (IN)	19.50
ALPHA2	STATIC DISTANCE, TRACTOR REAR AXLE(S) TO GROUND (IN)	19.50
ALPHA3	STATIC DISTANCE, TRAILER AXLE(S) TO GROUND (IN)	19.50
AN1	TIRE PRESSURE DIST. FUNCTION FOR TRACTOR FRONT TIRES	0.250
AN2	TIRE PRESSURE DIST. FUNCTION FOR TRACTOR FRONT TANDEM TIRES	0.250
AN3	TIRE PRESSURE DIST. FUNCTION FOR TRACTOR REAR TANDEM TIRES	0.250
AN4	TIRE PRESSURE DIST. FUNCTION FOR TRAILOR FRONT TANDEM TIRES	0.250
AN5	TIRE PRESSURE DIST. FUNCTION FOR TRAILOR REAR TANDEM TIRES	0.250
BB	HORIZONTAL DISTANCE FROM 5TH WHEEL TO MIDPOINT OF TRACTOR REAR SUSPENSION (IN)	24.70
C1	VISCOUS DAMPING: JOUNCE ON TRACTOR FRONT SUSPENSION (LB-SEC/IN)	10.00
C2	VISCOUS DAMPING: REBOUND ON TRACTOR FRONT SUSPENSION (LB-SEC/IN)	20.00
C3	VISCOUS DAMPING: JOUNCE ON TRACTOR REAR SUSPENSION (LB-SEC/IN)	10.00
C4	VISCOUS DAMPING: REBOUND ON TRACTOR REAR SUSPENSION (LB-SEC/IN)	20.00
C5	VISCOUS DAMPING: JOUNCE ON TRAILER SUSPENSION (LB-SEC/IN)	10.00
C6	VISCOUS DAMPING: REBOUND ON TRAILER SUSPENSION (LB-SEC/IN)	20.00

CALF1	LATERAL STIFFNESS, TRACTOR FRONT TIRES (LBS/DEG)	-1.00
CF1	MAXIMUM COULOMB FRICTION, TRACTOR FRONT SUSPENSION (LB)	500.00
CF2	MAXIMUM COULOMB FRICTION, TRACTOR REAR SUSPENSION (LB)	1500.00
CF3	MAXIMUM COULOMB FRICTION, TRAILER SUSPENSION (LB)	1500.00
CS1	LONGITUDINAL STIFFNESS, TRACTOR FRONT TIRES (LBS)	28000.00
CS2	LONGITUDINAL STIFFNESS, TRACTOR FRONT TANDEM TIRES (LBS)	28000.00
CS3	LONGITUDINAL STIFFNESS, TRACTOR REAR TANDEM TIRES (LBS)	28000.00
CS4	LONGITUDINAL STIFFNESS, TRAILER FRONT TANDEM TIRES (LBS)	28000.00
CS5	LONGITUDINAL STIFFNESS, TRAILER REAR TANDEM TIRES (LBS)	28000.00
D	VERTICAL DISTANCE FROM 5TH WHEEL CONNECTION TO TRACTOR CG (IN)	4.50
DELTA1	STATIC VERTICAL DISTANCE, TRACTOR CG TO TRACTOR FRONT AXLE (IN)	24.50
DELTA3	STATIC VERTICAL DISTANCE, TRAILER CG TO TRAILER AXLE (IN)	37.80
DT2	DISTANCE BETWEEN DUAL TIRES, TRACTOR REAR SUSPENSION (IN)	13.00
DT3	DISTANCE BETWEEN DUAL TIRES, TRAILER SUSPENSION (IN)	13.00
FA1	FRICTION REDUCTION PARAMETER FOR TRACTOR FRONT TIRES	0.0
FA2	FRICTION REDUCTION PARAMETER FOR TRACTOR FRONT TANDEM TIRES	0.0
FA3	FRICTION REDUCTION PARAMETER FOR TRACTOR REAR TANDEM TIRES	0.0
FA4	FRICTION REDUCTION PARAMETER FOR TRAILER FRONT TANDEM TIRES	0.0
FA5	FRICTION REDUCTION PARAMETER FOR TRAILER REAR TANDEM TIRES	0.0
IXX	TRACTOR SPRUNG MASS ROLL MOMENT OF INERTIA (IN-LB-SEC**2)	14230.00
IYY	TRACTOR SPRUNG MASS PITCH MOMENT OF INERTIA (IN-LB-SEC**2)	102690.00
IZZ	TRACTOR YAW MOMENT OF INERTIA (IN-LB-SEC**2)	102690.00
IXZ	TRACTOR PITCH PLANE CROSS MOMENT (IN-LB-SEC**2)	0.0
ITXX	TRAILER SPRUNG MASS ROLL MOMENT OF INERTIA (IN-LB-SEC**2)	21100.00
ITYY	(IN-LB-SEC**2) MASS PITCH MOMENT OF INER	759480.00
ITZZ	TRAILER YAW MOMENT OF INERTIA (IN-LB-SEC**2)	759480.00
ITXZ	TRAILER PITCH PLANE CROSS MOMENT (IN-LB-SEC**2)	0.0
JA1	ROLL MOMENT OF TRACTOR FRONT AXLE (IN-LB-SEC**2)	3719.00
JA2	ROLL MOMENT OF TRACTOR FRONT TANDEM AXLE (IN-LB-SEC**2)	4458.00
JA3	ROLL MOMENT OF TRAILER FRONT TANDEM AXLE (IN-LB-SEC**2)	4100.00
JS1	POLAR MOMENT OF TRACTOR FRONT WHEELS (IN-LB-SEC**2)	103.00
JS2	POLAR MOMENT OF TRACTOR FRONT TANDEM WHEELS (IN-LB-SEC**2)	231.00
JS3	POLAR MOMENT OF TRACTOR REAR TANDEM WHEELS (IN-LB-SEC**2)	231.00
JS4	POLAR MOMENT OF TRAILER FRONT TANDEM WHEELS (IN-LB-SEC**2)	231.00
JS5	POLAR MOMENT OF TRAILER REAR TANDEM WHEELS (IN-LB-SEC**2)	231.00
K1	SPRING RATE, TRACTOR FRONT SUSPENSION (LB/IN)	1300.00
K2	SPRING RATE, TRACTOR REAR SUSPENSION (LB/IN)	10000.00
K3	SPRING RATE, TRAILER SUSPENSION (LB/IN)	16000.00

KRS1	FRONT AUXILIARY ROLL STIFFNESS(IN-LB/DEG	0.0
KRS2	REAR AUXILIARY ROLL STIFFNESS(IN-LB/DEG	0.0
KRS3	TRAILER AUXILIARY ROLL STIFFNESS(IN-LB/DEG	0.0
AKRS	TRACTOR TR TANDEM AUX ROLL STIFFNESS(IN-LB/DEG)	0.0
KT1	SPRING RATE, TRACTOR FRONT TIRES (LB/IN)	5700.00
KT2	SPRING RATE, TRACTOR FRONT TANDEM TIRES (LB/IN)	5700.00
KT3	SPRING RATE, TRACTOR REAR TANDEM TIRES (LB/IN)	5700.00
KT4	SPRING RATE, TRAILER FRONT TANDEM TIRES (LB/IN)	5300.00
KT5	SPRING RATE, TRAILER REAR TANDEM TIRES (LB/IN)	5300.00

FIFTH WHEEL SPRING RATE

ROTATION WH5DFL (DEG)	SPRING RATE MC5 (IN-LBS/DEG)
0.0	0.20000E+08

TRACTOR FRAME ROLL SPRING RATE

ROTATION TTDFL(DEG)	SPRING RATE TTC(IN-LBS/DEG)
0.0	0.17000E+05

TRSTF	TRAILER FRAME ROLL STIFFNESS(IN-LB/DEG)	1500000.00
PW	WEIGHT OF PAYLOAD (LBS)	49586.00
PJ1	POLL MOMENT OF INERTIA OF PAYLOAD (IN-LB-SEC**2)	86590.00
PJ2	PITCH MOMENT OF INERTIA OF PAYLOAD (IN-LB-SEC**2)	2472220.00
PJ3	YAW MOMENT OF INERTIA OF PAYLOAD (IN-LB-SEC**2)	2472220.00
PX	HORIZONTAL DISTANCE FROM MIDPOINT OF REAR SUSPENSION TO PAYLOAD MASS CENTER (IN)	209.80
PZ	VERTICAL DISTANCE FROM GROUND TO PAYLOAD MASS CENTER (IN)	68.00
RCH1	ROLL CENTER HEIGHT, TRACTOR FRONT SUSPENSION (IN)	24.00
RCH2	ROLL CENTER HEIGHT, TRACTOR REAR SUSPENSION (IN)	30.00
RCH3	ROLL CENTER HEIGHT, TRAILER SUSPENSION (IN	30.00
RS1	COMPLIANCE STEER (DEG/IN)	0.0
RSC1	ROLL STEER COEFFICIENT, TRACTOR FRONT SUSPENSION	0.0
RSC2	ROLL STEER COEFFICIENT, TRACTOR REAR SUSPENSION	0.10
RSC3	ROLL STEER COEFFICIENT, TRAILER SUSPENSION	0.10
SY1	HORIZONTAL DISTANCE FROM TRACTOR BODY X-AXIS TO TRACTOR FRONT SUSPENSION (IN)	17.00
SY2	HORIZONTAL DISTANCE FROM TRACTOR BODY X-AXIS TO TRACTOR REAR SUSPENSION (IN)	20.00
SY3	HORIZONTAL DISTANCE FROM TRAILER BODY X-AXIS TO TRAILER SUSPENSION (IN)	20.00
TIMF	MAXIMUM REAL TIME FOR SIMULATION (SEC)	0.10
TRA1	HALF TRACK, TRACTOR FRONT AXLE (IN)	40.25
TRA2	HALF TRACK, TRACTOR REAR AXLE(S) (IN)	36.00
TRA3	HALF TRACK, TRAILER AXLE(S) (IN)	36.00
VEL	INITIAL VELOCITY (FT/SEC)	73.33
W1	SPRUNG WEIGHT OF TRACTOR (LBS)	9550.00
W2	SPRUNG WEIGHT OF TRAILER (LBS)	12080.00
WS1	WEIGHT OF TRACTOR FRONT SUSPENSION (LBS)	1200.00
WS2	WEIGHT OF TRACTOR FRONT TANDEM SUSPENSION (LBS)	2300.00
WS3	WEIGHT OF TRACTOR REAR TANDEM SUSPENSION (LBS)	2300.00
WS4	WEIGHT OF TRAILER FRONT TANDEM SUSPENSION (LBS)	1500.00
WS5	WEIGHT OF TRAILER REAR TANDEM SUSPENSION (LBS)	1500.00

```
BRAKE PARAMETERS: TQ(1,1,1) = 0.050 TQ(1,1,2) = 0.270
                  TQ(1,2,1) = 0.050 TQ(1,2,2) = 0.270
                  TQ(2,1,1) = 0.075 TQ(2,1,2) = 0.245
                  TQ(2,2,1) = 0.075 TQ(2,2,2) = 0.245
                  TQ(3,1,1) = 0.075 TQ(3,1,2) = 0.245
                  TQ(3,2,1) = 0.075 TQ(3,2,2) = 0.245
                  TQ(4,1,1) = 0.175 TQ(4,1,2) = 0.303
                  TQ(4,2,1) = 0.175 TQ(4,2,2) = 0.303
                  TQ(5,1,1) = 0.175 TQ(5,1,2) = 0.303
                  TQ(5,2,1) = 0.175 TQ(5,2,2) = 0.303

    TABLE 1: TIME VS PRESSURE (PSI)
             NO. OF POINTS:  2
          0.0            0.0
          0.0500         0.0

    INPUT PARAMETER TABLE FOR BRAKE FORCE CALCULATION SUBROUTINE
    SYMBOL      DESCRIPTION                         INITIAL VALUE
                                AXLE 1, LEFT SIDE
    IBRT        BRAKE TYPE                                     NONE
                                AXLE 2, LEFT SIDE
    IBRT        BRAKE TYPE                                     NONE
                                AXLE 3, LEFT SIDE
    IBRT        BRAKE TYPE                                     NONE
                                AXLE 4, LEFT SIDE
    IBRT        BRAKE TYPE                                     NONE
                                AXLE 5, LEFT SIDE
    IBRT        BRAKE TYPE                                     NONE

    TABLE  2: TIME VS STEER ANGLE (DEG)
              LEFT SIDE
              NO. OF POINTS:  2
          0.0            0.0
          8.0000        08.0000


    TABLE  3: TIME VS STEER ANGLE (DEG)
              RIGHT SIDE
              NO. OF POINTS:  2
          0.0            0.0
          8.0000        08.0000


    PARAMETERS FOR INCLINE SURFACE:
          G1          GRAVITY X COMPONENT            0.0
          G2          GRAVITY Y COMPONENT            0.0
          G3          GRAVITY Z COMPONENT            1.000

    THERE WILL BE NO WIND THIS RUN

THE ANTILOCK SYSTEM WILL NOT BE USED THIS RUN

     *** END INPUT ***
```

	EMPTY	LOADED
DISTANCE FROM TRAILER SPRUNG MASS CENTER TO TRAILER REAR AXLE CENTERLINE (IN)	179.500	203.86
DISTANCE FROM TRAILER SPRUNG MASS CENTER TO GROUND (IN)	57.300	65.904
ROLL MOMENT OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	21099.996	110570.500
PITCH MOMENT OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	759480.000	3257679.00
YAW MOMENT OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	759480.000	3254798.00

THE STATIC LOADS ON THE TIRES ARE

AXLE NUMBER	LOAD
1	11997.523
2	17007.320
3	17007.320
4	17001.918
5	17001.918
TOTAL	80016.000

THE TRACTOR TOTAL SPRUNG MASS CENTER IS 85.375 INCHES BEHIND THE FRONT AXLE,
THE TOTAL YAW MOMENT OF INERTIA IS 239847.063 IN LB SEC**2.

THE TRAILER MASS CENTER IS 215.594 INCHES BEHIND THE FIFTH WHEEL,
THE TOTAL YAW MOMENT OF INERTIA IS 3575726.000 IN LB SEC**2

TIME INCREMENT TO BE PRINTED OUT IS 0.10

TRACTOR FRONT TIRES : FIRESTONE 10X20 RIB
TRACTOR LEADING TANDEM TIRES : FIRESTONE 10X20 RIB
TRACTOR TRAILING TANDEM TIRES : FIRESTONE 10X20 RIB

TRAILER LEADING TANDEM TIRES : FIRESTONE 10X20 RIB
TRAILER TRAILING TANDEM TIRES : FIRESTONE 10X20 RIB

*** BEGIN OUTPUT ***
#

200 INCH WHEEL BASE 3AXLE TRACTOR,VAN TRAILER RUN # 193

INPUT PARAMETER TABLE

SYMBOL	DESCRIPTION	INITIAL VALUE
KEY(1)	TRACTOR AXLE KEY: 0 FOR SINGLE AXLE 1 FOR WALKING BEAM 2 FOR 4 ELLIPTIC LEAF	2
KEY(2)	TRAILER AXLE KEY	2
AA1	HORIZONTAL DISTANCE FORM TRACTOR FRONT LEAF-FRAME CONTACT TO AXLE CENTER (IN)	24.00
AA2	HORIZONTAL DISTANCE FROM TRACTOR REAR LEAF-FRAME CONTACT TO AXLE CENTER (IN)	24.00
AA4	HORIZONTAL DISTANCE FROM TRACTOR FRONT LEAF-FRAME CONTACT TO LOAD LEVELER PIN (IN	1.00
AA5	HORIZONTAL DISTANCE FROM TRACTOR REAR LEAF-FRAME CONTACT TO LOAD LEVELER PIN (IN	1.00
AA6	VERTICAL DISTANCE FROM AXLE DOWN TO TRACTOR TORQUE ROD (IN)	0.0
AA7	ANGLE BETWEEN TRACTOR TORQUE ROD AND HORIZONTAL (DEG)	0.0
AA8	HORIZONTAL DISTANCE FROM AXLE CENTER FORWARD TO TRACTOR TORQUE ROD (IN)	0.0
AA9	HORIZONTAL DISTANCE FROM TRAILER FRONT LEAF-FRAME CONTACT TO AXLE CENTER (IN)	18.50
AA10	HORIZONTAL DISTANCE FROM TRAILER REAR LEAF-FRAME CONTACT TO AXLE CENTER (IN)	18.50
AA12	HORIZONTAL DISTANCE FROM TRAILER FRONT LEAF-FRAME CONTACT TO LOAD LEVELER PIN (IN	6.25
AA13	HORIZONTAL DISTANCE FROM TRAILER REAR LEAF-FRAME CONTACT TO LOAD LEVELER PIN (IN	6.25
AA14	VERTICAL DISTANCE FROM AXLE DOWN TO TRAILER TORQUE ROD (IN)	7.00
AA15	ANGLE BETWEEN TRAILER TORQUE ROD AND HORIZONTAL (DEG)	15.01
AA16	HORIZONTAL DISTANCE FROM AXLE CENTER FORWARD TO TRAILER TORQUE ROD (IN)	5.50
A1	HORIZONTAL DISTANCE FROM TRACTOR CG TO CENTER OF TRACTOR FRONT SUSPENSION (IN)	60.00
A2	HORIZONTAL DISTANCE FROM TRACTOR CG TO CENTER OF TRACTOR REAR SUSPENSION (IN)	140.00
A3	HORIZONTAL DISTANCE FROM TRAILER CG TO 5TH WHEEL (IN)	230.50
A4	HORIZONTAL DISTANCE FROM TRAILER CG TO CENTER OF TRAILER SUSPENSION (IN)	179.50
ALPHA1	STATIC DISTANCE, TRACTOR FRONT AXLE TO GROUND (IN)	19.50
ALPHA2	STATIC DISTANCE, TRACTOR REAR AXLE(S) TO GROUND (IN)	19.50
ALPHA3	STATIC DISTANCE, TRAILER AXLE(S) TO GROUND (IN)	19.50
AN1	TIRE PRESSURE DIST. FUNCTION FOR TRACTOR FRONT TIRES	0.250
AN2	TIRE PRESSURE DIST. FUNCTION FOR TRACTOR FRONT TANDEM TIRES	0.250
AN3	TIRE PRESSURE DIST. FUNCTION FOR TRACTOR REAR TANDEM TIRES	0.250
AN4	TIRE PRESSURE DIST. FUNCTION FOR TRAILOR FRONT TANDEM TIRES	0.250
AN5	TIRE PRESSURE DIST. FUNCTION FOR TRAILOR REAR TANDEM TIRES	0.250
BB	HORIZONTAL DISTANCE FROM 5TH WHEEL TO MIDPOINT OF TRACTOR REAR SUSPENSION (IN)	24.40
C1	VISCOUS DAMPING: JOUNCE ON TRACTOR FRONT SUSPENSION (LB-SEC/IN)	10.00
C2	VISCOUS DAMPING: REBOUND ON TRACTOR FRONT SUSPENSION (LB-SEC/IN)	20.00
C3	VISCOUS DAMPING: JOUNCE ON TRACTOR REAR SUSPENSION (LB-SEC/IN)	10.00
C4	VISCOUS DAMPING: REBOUND ON TRACTOR REAR SUSPENSION (LB-SEC/IN)	20.00
C5	VISCOUS DAMPING: JOUNCE ON TRAILER SUSPENSION (LB-SEC/IN)	10.00
C6	VISCOUS DAMPING: REBOUND ON TRAILER SUSPENSION (LB-SEC/IN)	20.00

CALF1	LATERAL STIFFNESS, TRACTOR FRONT TIRES (LBS/DEG)	-1.00
CF1	MAXIMUM COULOMB FRICTION, TRACTOR FRONT SUSPENSION (LB)	500.00
CF2	MAXIMUM COULOMB FRICTION, TRACTOR REAR SUSPENSION (LB)	1500.00
CF3	MAXIMUM COULOMB FRICTION, TRAILER SUSPENSION (LB)	1500.00
CS1	LONGITUDINAL STIFFNESS, TRACTOR FRONT TIRES (LBS)	28000.00
CS2	LONGITUDINAL STIFFNESS, TRACTOR FRONT TANDEM TIRES (LBS)	28000.00
CS3	LONGITUDINAL STIFFNESS, TRACTOR REAR TANDEM TIRES (LBS)	28000.00
CS4	LONGITUDINAL STIFFNESS, TRAILER FRONT TANDEM TIRES (LBS)	28000.00
CS5	LONGITUDINAL STIFFNESS, TRAILER REAR TANDEM TIRES (LBS)	28000.00
D	VERTICAL DISTANCE FROM 5TH WHEEL CONNECTION TO TRACTOR CG (IN)	4.50
DELTA1	STATIC VERTICAL DISTANCE, TRACTOR CG TO TRACTOR FRONT AXLE (IN)	24.50
DELTA3	STATIC VERTICAL DISTANCE, TRAILER CG TO TRAILER AXLE (IN)	37.80
DT2	DISTANCE BETWEEN DUAL TIRES, TRACTOR REAR SUSPENSION (IN)	13.00
DT3	DISTANCE BETWEEN DUAL TIRES, TRAILER SUSPENSION (IN)	13.00
FA1	FRICTION REDUCTION PARAMETER FOR TRACTOR FRONT TIRES	0.0
FA2	FRICTION REDUCTION PARAMETER FOR TRACTOR FRONT TANDEM TIRES	0.0
FA3	FRICTION REDUCTION PARAMETER FOR TRACTOR REAR TANDEM TIRES	0.0
FA4	FRICTION REDUCTION PARAMETER FOR TRAILER FRONT TANDEM TIRES	0.0
FA5	FRICTION REDUCTION PARAMETER FOR TRAILER REAR TANDEM TIRES	0.0
IXX	TRACTOR SPRUNG MASS ROLL MOMENT OF INERTIA (IN-LB-SEC**2)	15200.00
IYY	TRACTOR SPRUNG MASS PITCH MOMENT OF INERTIA (IN-LB-SEC**2)	153270.00
IZZ	TRACTOR YAW MOMENT OF INERTIA (IN-LB-SEC**2)	153270.00
IXZ	TRACTOR PITCH PLANE CROSS MOMENT (IN-LB-SEC**2)	0.0
ITXX	TRAILER SPRUNG MASS ROLL MOMENT OF INERTIA (IN-LB-SEC**2)	21100.00
ITYY	(IN-LB-SEC**2) MASS PITCH MOMENT OF INER	759480.00
ITZZ	TRAILER YAW MOMENT OF INERTIA (IN-LB-SEC**2)	759480.00
ITXZ	TRAILER PITCH PLANE CROSS MOMENT (IN-LB-SEC**2)	0.0
JA1	ROLL MOMENT OF TRACTOR FRONT AXLE (IN-LB-SEC**2)	3719.00
JA2	ROLL MOMENT OF TRACTOR FRONT TANDEM AXLE (IN-LB-SEC**2)	4458.00
JA3	ROLL MOMENT OF TRAILER FRONT TANDEM AXLE (IN-LB-SEC**2)	4100.00
JS1	POLAR MOMENT OF TRACTOR FRONT WHEELS (IN-LB-SEC**2)	103.00
JS2	POLAR MOMENT OF TRACTOR FRONT TANDEM WHEELS (IN-LB-SEC**2)	231.00
JS3	POLAR MOMENT OF TRACTOR REAR TANDEM WHEELS (IN-LB-SEC**2)	231.00
JS4	POLAR MOMENT OF TRAILER FRONT TANDEM WHEELS (IN-LB-SEC**2)	231.00
JS5	POLAR MOMENT OF TRAILER REAR TANDEM WHEELS (IN-LB-SEC**2)	231.00
K1	SPRING RATE, TRACTOR FRONT SUSPENSION (LB/IN)	1300.00
K2	SPRING RATE, TRACTOR REAR SUSPENSION (LB/IN)	10000.00
K3	SPRING RATE, TRAILER SUSPENSION (LB/IN)	16000.00

KRS1	FRONT AUXILIARY ROLL STIFFNESS(IN-LB/DEG	0.0
KRS2	REAR AUXILIARY ROLL STIFFNESS(IN-LB/DEG	0.0
KRS3	TRAILER AUXILIARY ROLL STIFFNESS(IN-LB/DEG	0.0
AKRS	TRACTOR TR TANDEM AUX ROLL STIFFNESS(IN-LB/DEG)	0.0
KT1	SPRING RATE, TRACTOR FRONT TIRES (LB/IN)	5700.00
KT2	SPRING RATE, TRACTOR FRONT TANDEM TIRES (LB/IN)	5700.00
KT3	SPRING RATE, TRACTOR REAR TANDEM TIRES (LB/IN)	5700.00
KT4	SPRING RATE, TRAILER FRONT TANDEM TIRES (LB/IN)	5300.00
KT5	SPRING RATE, TRAILER REAR TANDEM TIRES (LB/IN)	5300.00

FIFTH WHEEL SPRING RATE

ROTATION WH5DFL (DEG)	SPRING RATE MC5 (IN-LBS/DEG)
0.0	0.20000E+08

TRACTOR FRAME ROLL SPRING RATE

ROTATION TTDFL(DEG)	SPRING RATE TTC(IN-LBS/DEG)
0.0	0.14000E+05

TRSTF	TRAILER FRAME ROLL STIFFNESS(IN-LB/DEG)	1500000.00
PW	WEIGHT OF PAYLOAD (LBS)	48920.00
PJ1	POLL MOMENT OF INERTIA OF PAYLOAD (IN-LB-SEC**2)	85427.00
PJ2	PITCH MOMENT OF INERTIA OF PAYLOAD (IN-LB-SEC**2)	2493130.00
PJ3	YAW MOMENT OF INERTIA OF PAYLOAD (IN-LB-SEC**2)	2493130.00
PX	HORIZONTAL DISTANCE FROM MIDPOINT OF REAR SUSPENSION TO PAYLOAD MASS CENTER (IN)	207.10
PZ	VERTICAL DISTANCE FROM GROUND TO PAYLOAD MASS CENTER (IN)	68.00
RCH1	ROLL CENTER HEIGHT, TRACTOR FRONT SUSPENSION (IN)	24.00
RCH2	ROLL CENTER HEIGHT, TRACTOR REAR SUSPENSION (IN)	30.00
RCH3	ROLL CENTER HEIGHT, TRAILER SUSPENSION (IN	30.00
RS1	COMPLIANCE STEER (DEG/IN)	0.0
RSC1	ROLL STEER COEFFICIENT, TRACTOR FRONT SUSPENSION	0.0
RSC2	ROLL STEER COEFFICIENT, TRACTOR REAR SUSPENSION	0.10
RSC3	ROLL STEER COEFFICIENT, TRAILER SUSPENSION	0.10
SY1	HORIZONTAL DISTANCE FROM TRACTOR BODY X-AXIS TO TRACTOR FRONT SUSPENSION (IN)	17.00
SY2	HORIZONTAL DISTANCE FROM TRACTOR BODY X-AXIS TO TRACTOR REAR SUSPENSION (IN)	20.00
SY3	HORIZONTAL DISTANCE FROM TRAILER BODY X-AXIS TO TRAILER SUSPENSION (IN)	20.00
TIMF	MAXIMUM REAL TIME FOR SIMULATION (SEC)	4.00
TRA1	HALF TRACK, TRACTOR FRONT AXLE (IN)	40.25
TRA2	HALF TRACK, TRACTOR REAR AXLE(S) (IN)	36.00
TRA3	HALF TRACK, TRAILER AXLE(S) (IN)	36.00
VEL	INITIAL VELOCITY (FT/SEC)	73.33
W1	SPRUNG WEIGHT OF TRACTOR (LBS)	10200.00
W2	SPRUNG WEIGHT OF TRAILER (LBS)	12080.00
WS1	WEIGHT OF TRACTOR FRONT SUSPENSION (LBS)	1200.00
WS2	WEIGHT OF TRACTOR FRONT TANDEM SUSPENSION (LBS)	2300.00
WS3	WEIGHT OF TRACTOR REAR TANDEM SUSPENSION (LBS)	2300.00
WS4	WEIGHT OF TRAILER FRONT TANDEM SUSPENSION (LBS)	1500.00
WS5	WEIGHT OF TRAILER REAR TANDEM SUSPENSION (LBS)	1500.00

```
BRAKE PARAMETERS: TQ(1,1,1) = 0.050 TQ(1,1,2) = 0.270
                  TQ(1,2,1) = 0.050 TQ(1,2,2) = 0.270
                  TQ(2,1,1) = 0.075 TQ(2,1,2) = 0.245
                  TQ(2,2,1) = 0.075 TQ(2,2,2) = 0.245
                  TQ(3,1,1) = 0.075 TQ(3,1,2) = 0.245
                  TQ(3,2,1) = 0.075 TQ(3,2,2) = 0.245
                  TQ(4,1,1) = 0.175 TQ(4,1,2) = 0.303
                  TQ(4,2,1) = 0.175 TQ(4,2,2) = 0.303
                  TQ(5,1,1) = 0.175 TQ(5,1,2) = 0.303
                  TQ(5,2,1) = 0.175 TQ(5,2,2) = 0.303

    TABLE 1: TIME VS PRESSURE (PSI)
             NO. OF POINTS:  2
          0.0           0.0
          0.0500        0.0

    INPUT PARAMETER TABLE FOR BRAKE FORCE CALCULATION SUBROUTINE
    SYMBOL      DESCRIPTION                           INITIAL VALUE
                                AXLE 1, LEFT SIDE
    IBRT        BRAKE TYPE                                      NONE
                                AXLE 2, LEFT SIDE
    IBRT        BRAKE TYPE                                      NONE
                                AXLE 3, LEFT SIDE
    IBRT        BRAKE TYPE                                      NONE
                                AXLE 4, LEFT SIDE
    IBRT        BRAKE TYPE                                      NONE
                                AXLE 5, LEFT SIDE
    IBRT        BRAKE TYPE                                      NONE

    TABLE  2: TIME VS STEER ANGLE (DEG)
              LEFT SIDE
              NO. OF POINTS:  2
          0.0           0.0
          8.0000       08.0000


    TABLE  3: TIME VS STEER ANGLE (DEG)
              RIGHT SIDE
              NO. OF POINTS:  2
          0.0           0.0
          8.0000       08.0000


    PARAMETERS FOR INCLINE SURFACE:
          G1          GRAVITY X COMPONENT           0.0
          G2          GRAVITY Y COMPONENT           0.0
          G3          GRAVITY Z COMPONENT           1.000

    THERE WILL BE NO WIND THIS RUN

THE ANTILOCK SYSTEM WILL NOT BE USED THIS RUN

     *** END INPUT ***
```

	EMPTY	LOADED
DISTANCE FROM TRAILER SPRUNG MASS CENTER TO TRAILER REAR AXLE CENTERLINE (IN)	179.500	201.634
DISTANCE FROM TRAILER SPRUNG MASS CENTER TO GROUND (IN)	57.300	65.881
ROLL MOMENT OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	21099.996	109399.813
PITCH MOMENT OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	759480.000	3274597.000
YAW MOMENT OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	759480.000	3271724.000

THE STATIC LOADS ON THE TIRES ARE

AXLE NUMBER	LOAD
1	11999.914
2	16999.664
3	16999.664
4	17000.379
5	17000.379
TOTAL	80000.000

THE TRACTOR TOTAL SPRUNG MASS CENTER IS 95.750 INCHES BEHIND THE FRONT AXLE,
THE TOTAL YAW MOMENT OF INERTIA IS 365106.750 IN LB SEC**2.

THE TRAILER MASS CENTER IS 217.818 INCHES BEHIND THE FIFTH WHEEL,
THE TOTAL YAW MOMENT OF INERTIA IS 3585798.000 IN LB SEC**2

TIME INCREMENT TO BE PRINTED OUT IS 0.10

TRACTOR FRONT TIRES : FIRESTONE 10X20 RIB
TRACTOR LEADING TANDEM TIRES : FIRESTONE 10X20 RIB
TRACTOR TRAILING TANDEM TIRES : FIRESTONE 10X20 RIB

TRAILER LEADING TANDEM TIRES : FIRESTONE 10X20 RIB
TRAILER TRAILING TANDEM TIRES : FIRESTONE 10X20 RIB

*** BEGIN OUTPUT ***

TIRE DATA

(TRANSPORT 1)

FIRESTONE 10.00X20 RIB
********* ******** ***

```
0.25               AN PRESSURE DISTRIBUTION FUNCTION
0.000              FA FRICTION REDUCTION PARAMETER
05                    ALIGNING TORQUE TABLE
2000.0    05
0.0       0.0
1.0       31.0
3.0       43.54
7.0       61.00
10.0      39.0
4000.0    05
0.0       0.0
1.0       80.0
3.0       143.0
7.0       194.0
10.0      158.0
6000.0    05
0.0       0.0
1.0       130.0
3.0       261.0
7.0       373.0
10.0      329.0
8000.0    05
0.0       0.0
1.0       179.0
3.0       387.0
7.0       562.0
10.0      473.0
9000.0    05
0.0       0.0
1.0       200.0
3.0       452.0
7.0       650.0
10.0      565.0
06                          CORNERING STIFFNESS TABLE
0.0            0.0              1.0              10.0
2000.0         390.0            1.0              10.0
4000.0         605.0            1.0              10.0
6000.0         740.0            1.0              10.0
8000.0         800.0            1.0              10.0
9000.0         825.0            1.0              10.0
06                         MUZERO TABLE
0.0       1.0
2000.0    0.94
4000.0    0.94
6000.0    0.88
8000.0    0.85
9000.0    0.81
```

(TRANSPORT 1)

FIRESTONE 10.00X22 RIB
********* ******** ***

0.25		AN PRESSURE DISTRIBUTION FUNCTION		
0.002		FA FRICTION REDUCTION PARAMETER		
05		ALIGNING TORQUE TABLE		
1375.0	05			
0.00	0.0			
2.0	26.70			
4.0	31.80			
8.0	21.00			
16.0	5.50			
2890.0	05			
0.0	0.0			
2.0	90.20			
4.0	114.0			
8.0	85.5			
16.0	37.0			
5780.0	05			
0.0	0.0			
2.0	209.6			
4.0	301.8			
8.0	260.0			
16.0	110.0			
7500.0	05			
0.0	0.0			
2.0	282.50			
4.0	419.5			
8.0	414.0			
16.0	270.0			
9000.0	05			
0.0	0.0			
2.0	345.4			
4.0	533.1			
8.0	488.0			
16.0	380.0			
06		CORNERING STIFFNESS TABLE		
0.0		0.0	0.0	8.0
3000.0		550.0	0.0	8.0
4500.0		655.0	0.0	8.0
6000.0		705.0	0.0	8.0
7500.0		730.0	0.0	8.0
9000.0		780.0	0.0	8.0
06		MUZERO TABLE		
0.0	1.00			
3000.0	0.93			
4500.0	0.90			
6000.0	0.83			
7500.0	0.79			
9000.0	0.74			

(FLEETMASTER SUPERLUG)

UNIROYAL 10.00X20 LUG
******** ******** ***

```
0.25                 AN PRESSURE DISTRIBUTION FINCTION
0.000                FA FRICTION RED PARAMETER
04                   ALIGNING TORQUE TABLE
2000.0     05
0.00       0.0
2.0        40.0
4.0        49.0
8.0        50.0
16.0       16.0
4000.0     05
0.0        0.0
2.0        102.0
4.0        143.0
8.0        162.0
16.0       66.0
6000.0     05
0.0        0.0
2.0        165.0
4.0        248.0
8.0        306.0
16.0       147.0
8000.0     05
0.0        0.0
2.0        231.0
4.0        361.0
8.0        466.0
16.0       257.0
05             CORNERING STIFFNESS TABLE
0.0             0.0            0.5            10.0
2000.0          268.0          0.5            10.0
4000.0          430.0          0.5            10.0
6000.0          530.0          0.5            10.0
8000.0          590.0          0.5            10.0
05             MUZERO TABLE
0.0        0.95
2000.0     0.95
4000.0     0.88
6000.0     0.85
8000.0     0.82
```

APPENDIX III

DETAILED DATA FROM FULL-SCALE TESTS

This appendix contains test data obtained from trapezoidal steer experiments conducted on tractor-semitrailer vehicles. The tests were done at a forward speed of approximately 43 mph, in the fully loaded condition. The three tractor-semitrailer combinations for which test data are presented are listed below:

1) International Harvester tractor/Fruehauf van trailer,

2) International Harvester tractor/Trailmobile flat-bed trailer, and

3) Ford tractor/Trailmobile flat-bed trailer.

Each of the vehicles was tested under the following four test configurations:

1) baseline

2) frame stiffener attached to tractor frame

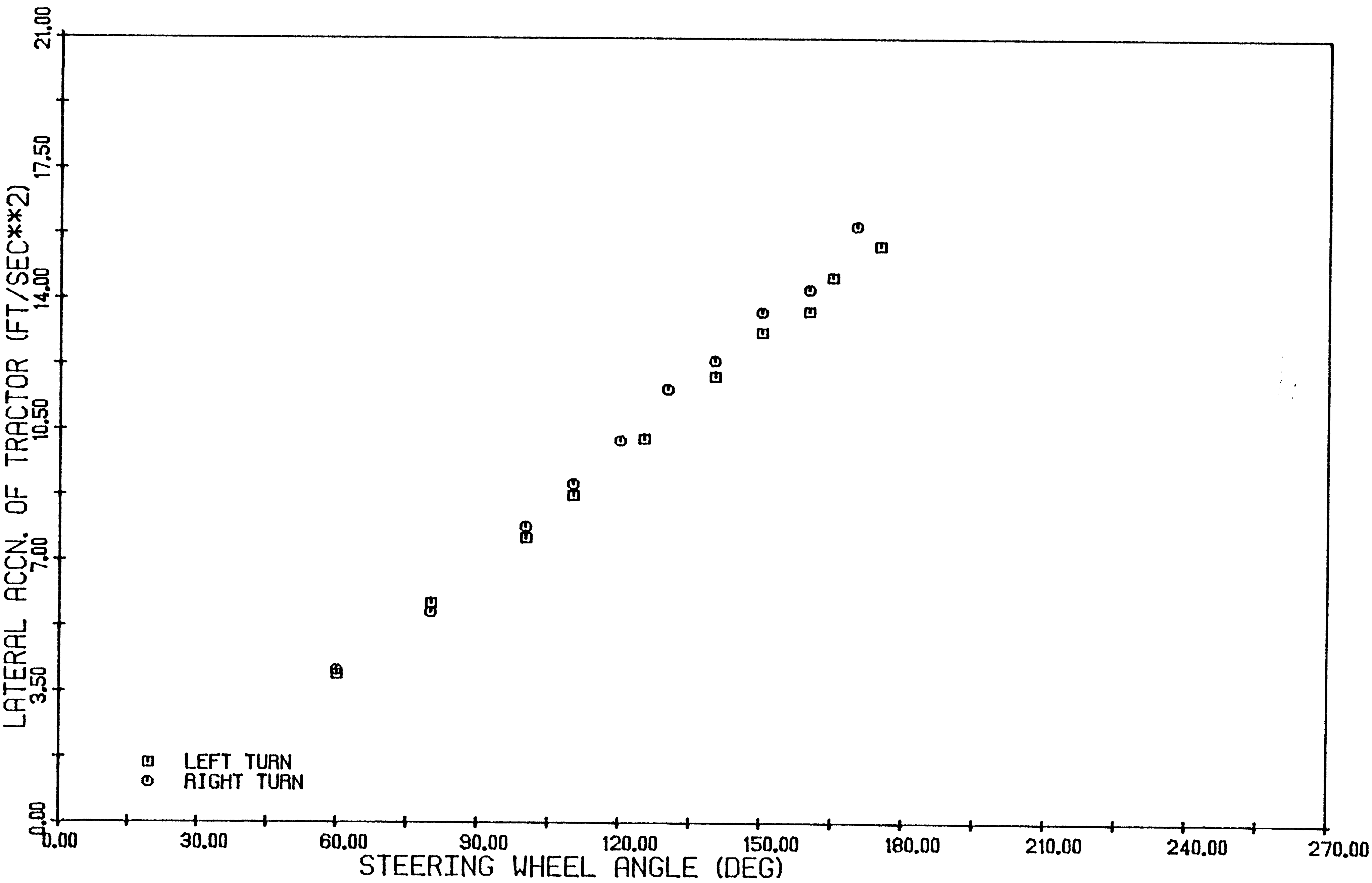
3) auxiliary front roll stiffener (sway bar) attached to tractor front axle, and

4) the condition in which both tractor frame stiffener and sway bar were used (also called the "modified" condition).

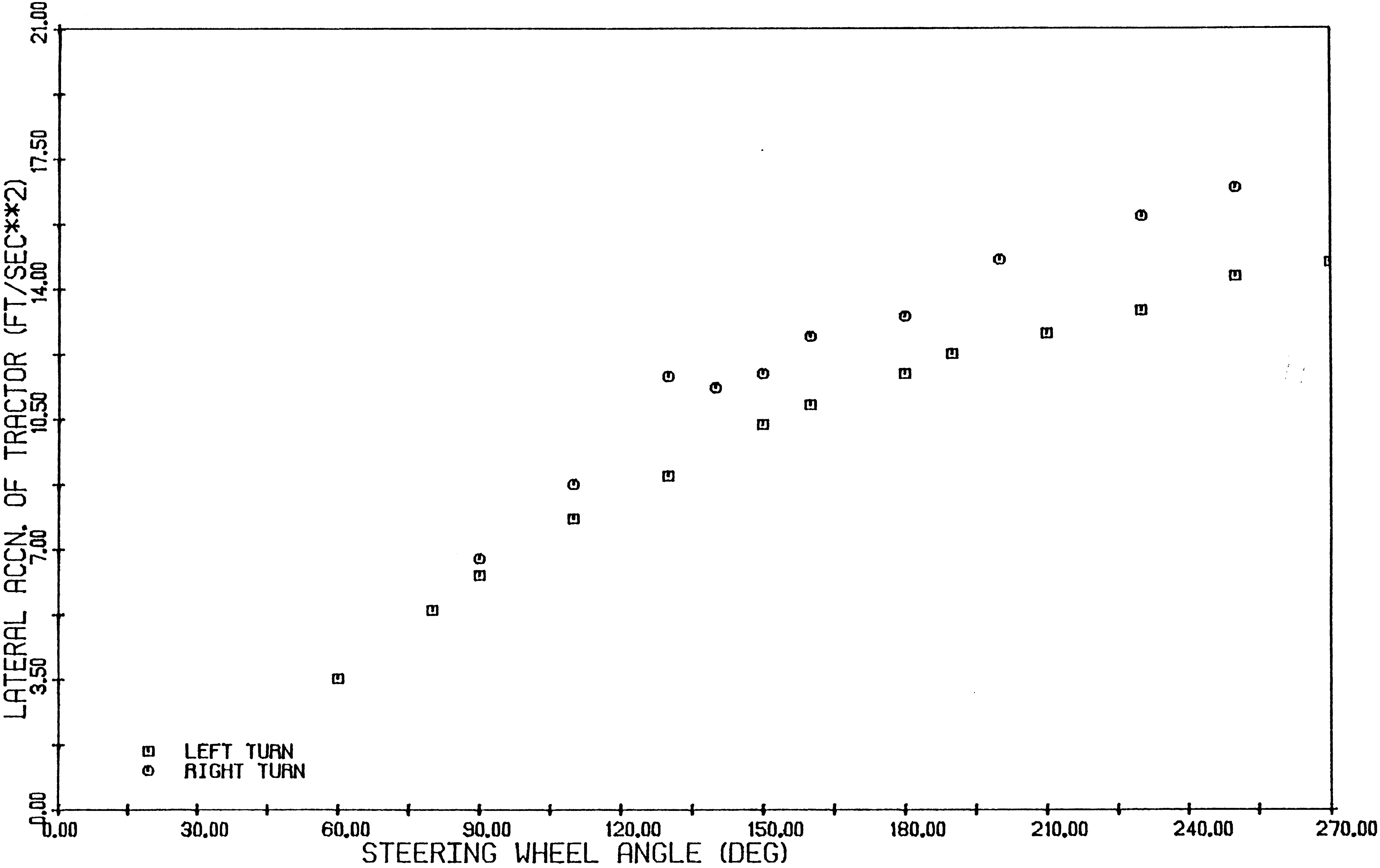
First, plots of steady-state lateral acceleration of the tractor as a function of steering-wheel angle are presented. These plots are followed by another set of plots which display the tractor steady-state yaw rate response as a function of the steering-wheel angle.

Next, the data are presented in the handling diagram format by using the $[(Lr/V - \delta_{FW}), a_y]$ coordinate system. The front-wheel angle, δ_{FW}, were estimated by using an "apparent" or "effective" steering ratio of 73 for the International Harvester tractor and 100 for the Ford tractor.

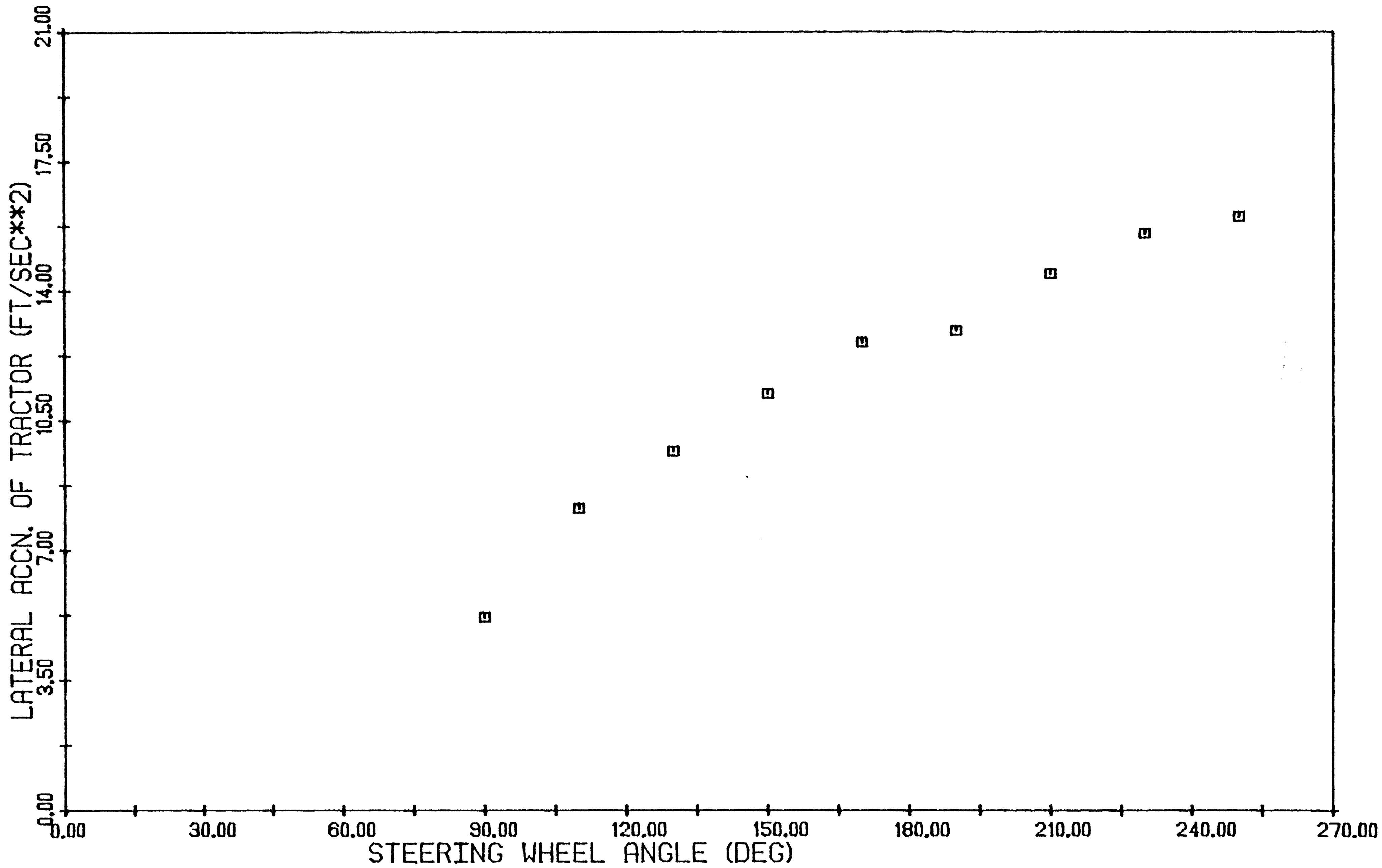
Lateral Acceleration vs. Steering-Wheel Angle



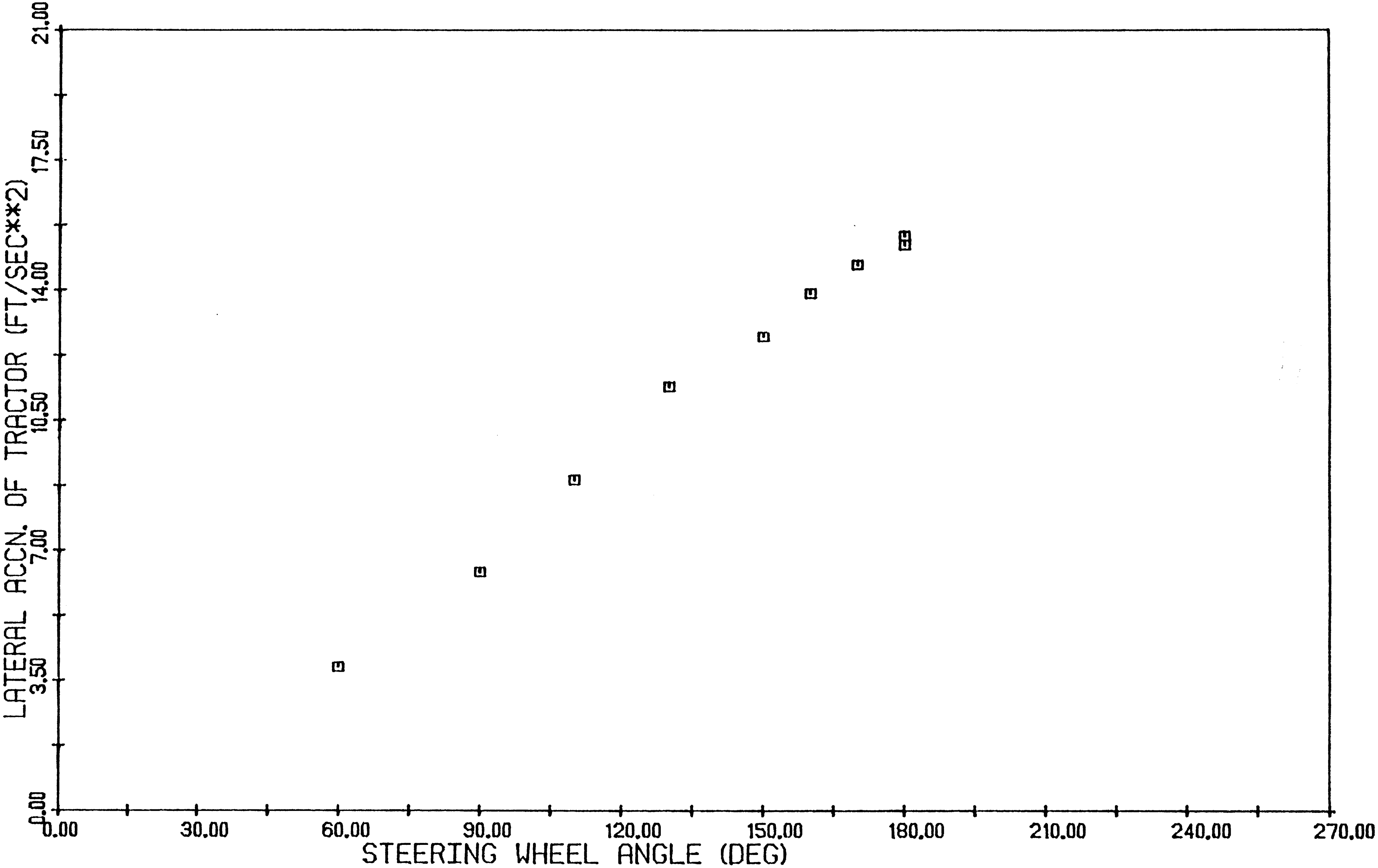
IHC-VAN TRAILER BASELINE



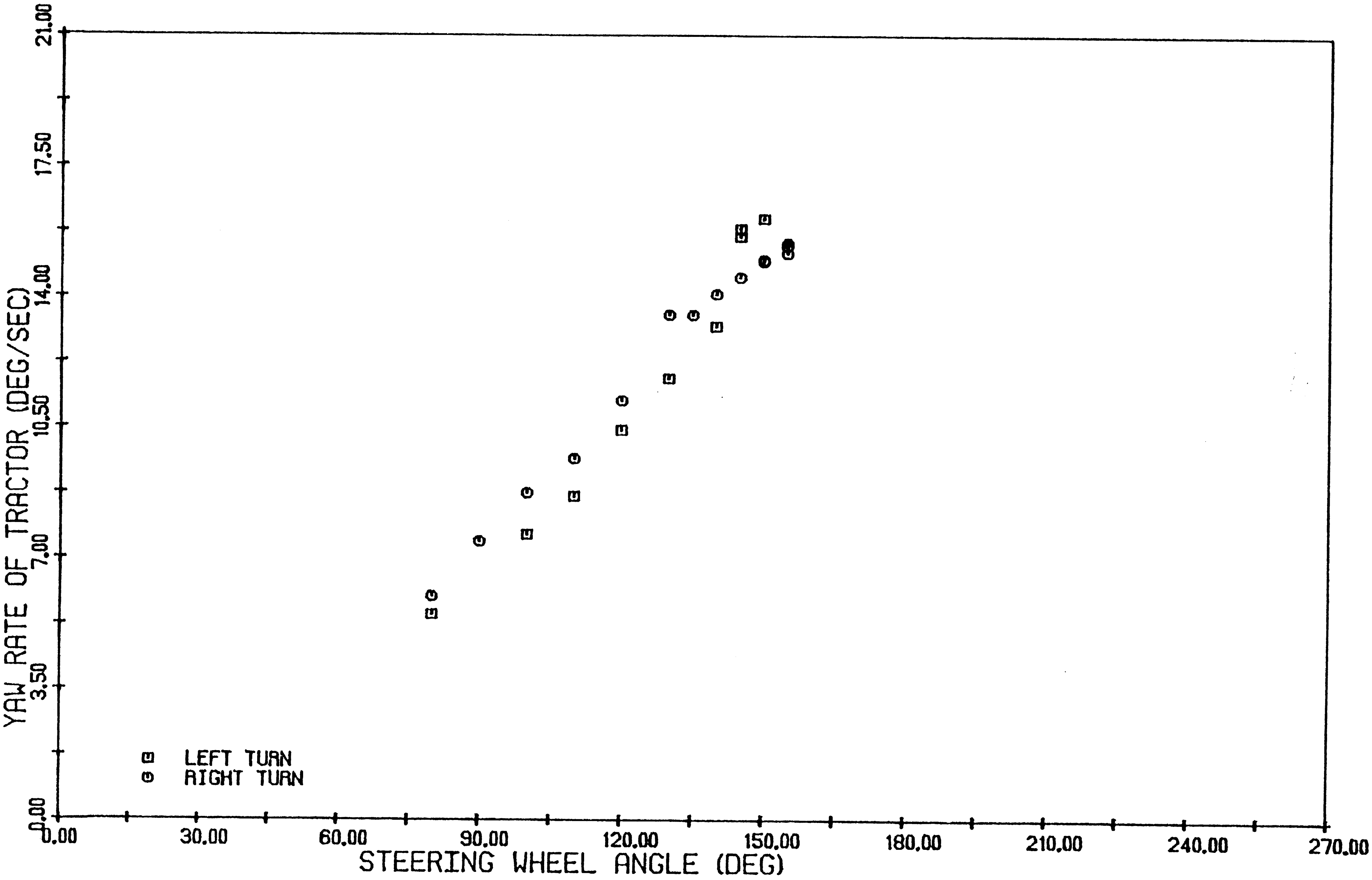
IHC-VAN TRAILER MODIFIED



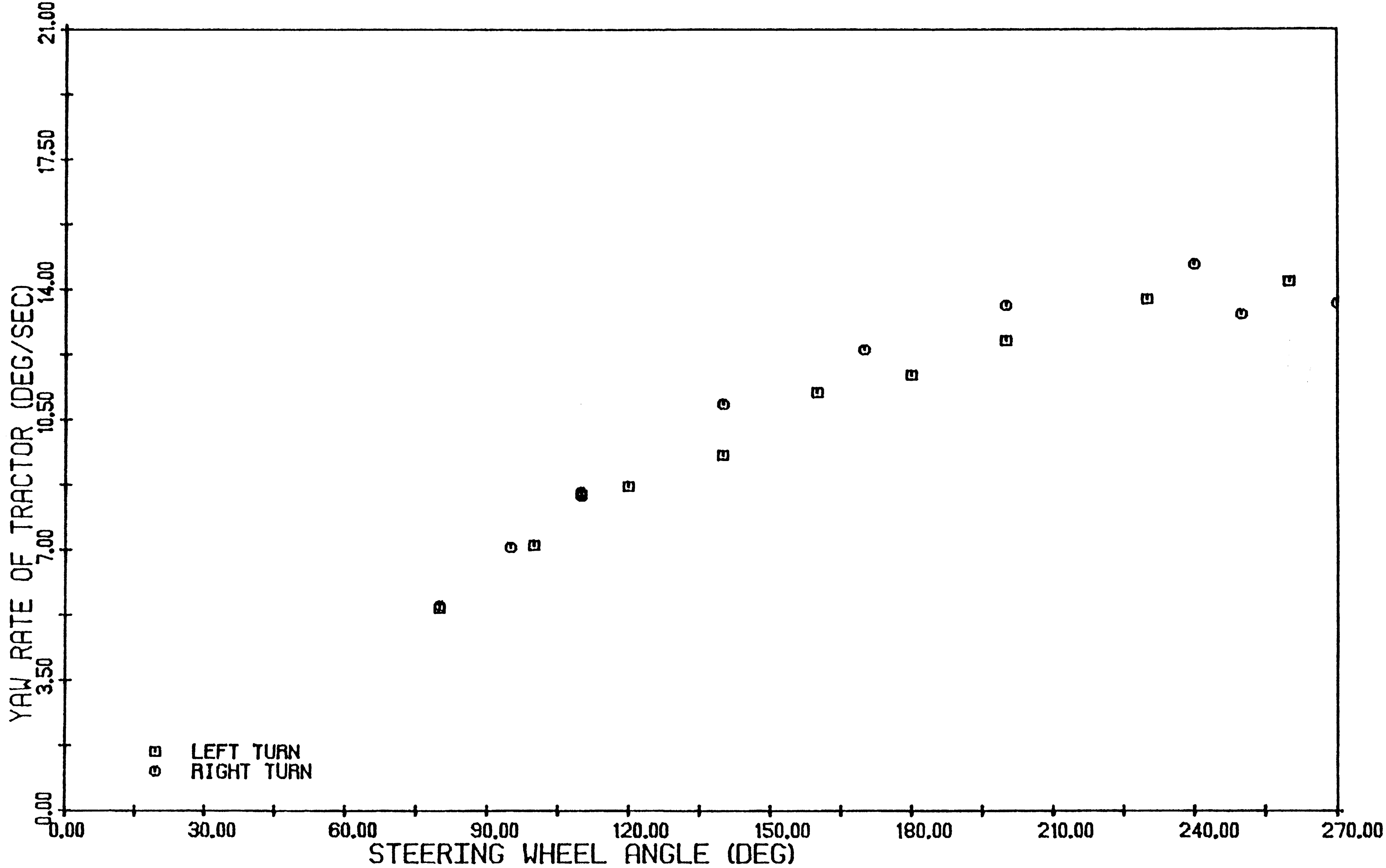
IHC-VAN TRAILER SWAY BAR ALONE



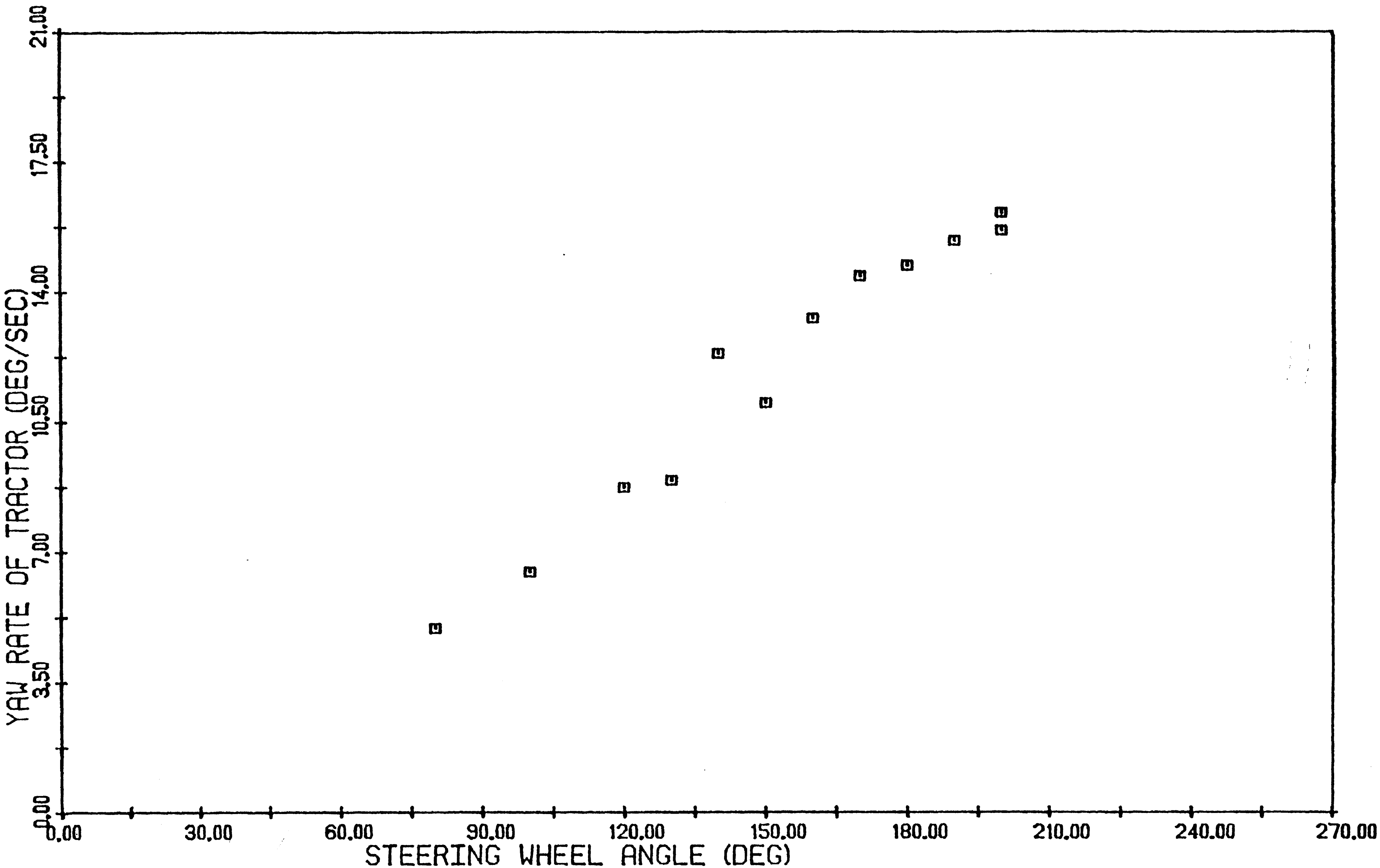
IHC-VAN TRAILER FRAME ALONE



IHC-FLAT BED TRAILER BASELINE



IHC-FLAT BED TRAILER MODIFIED



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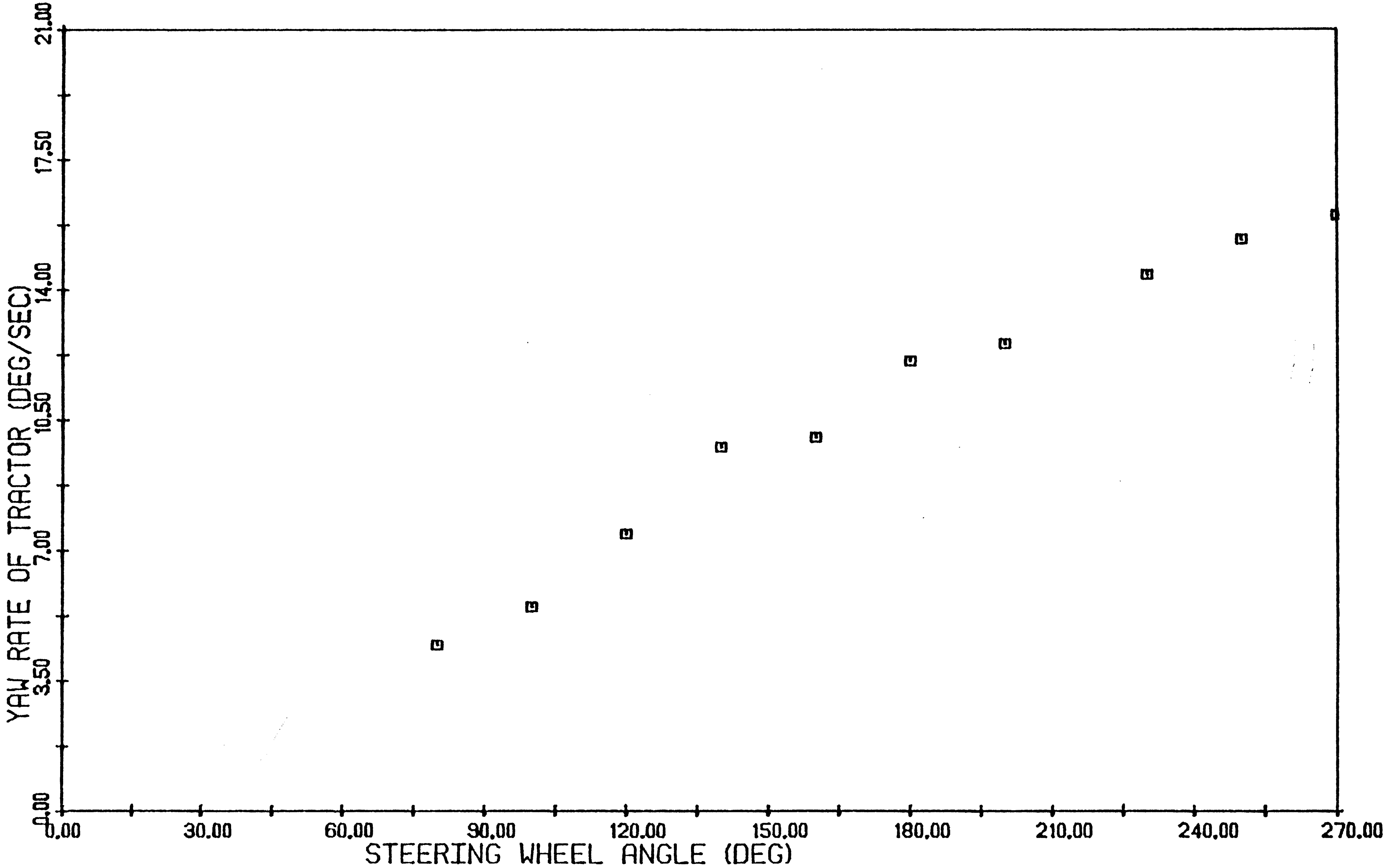
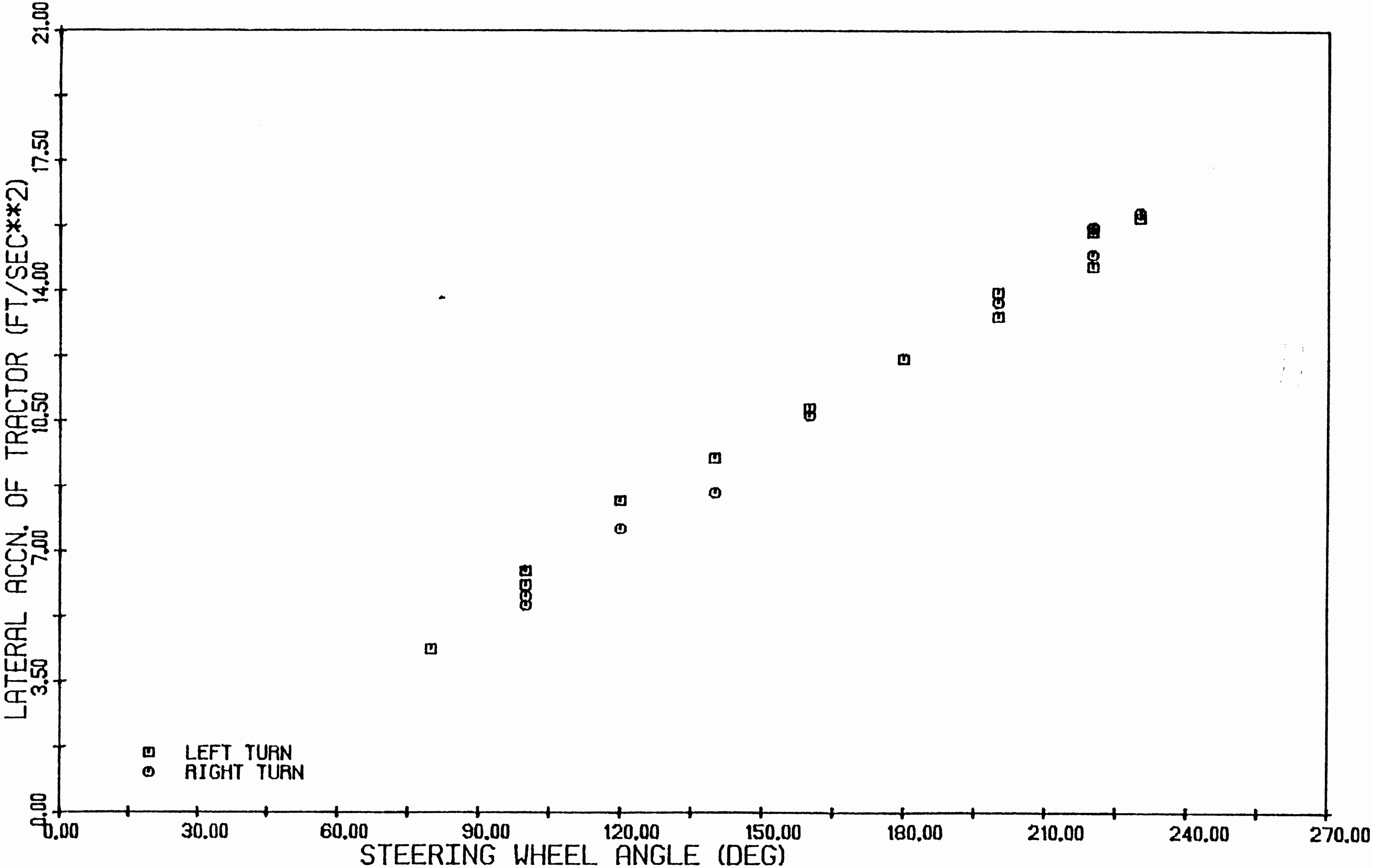
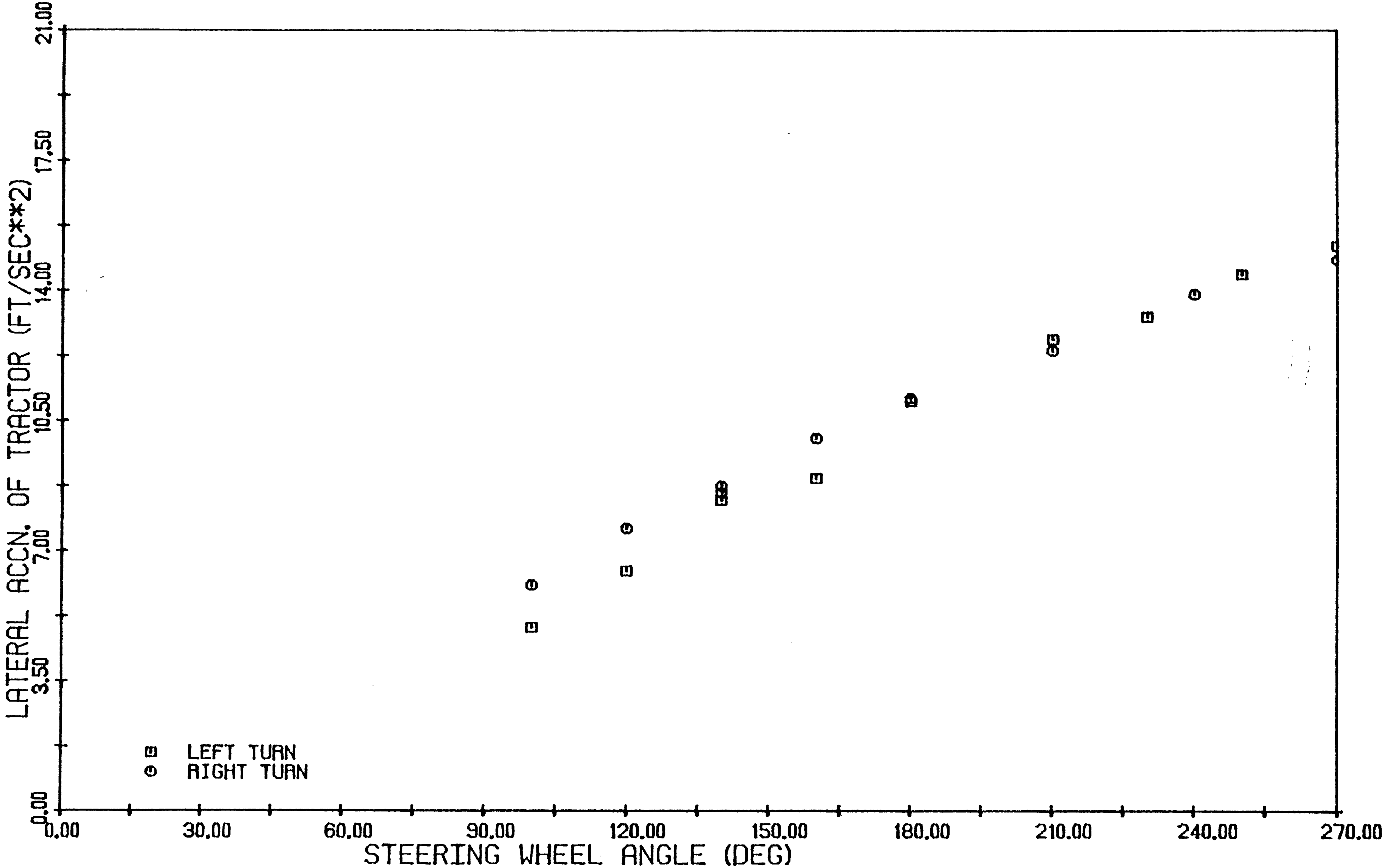


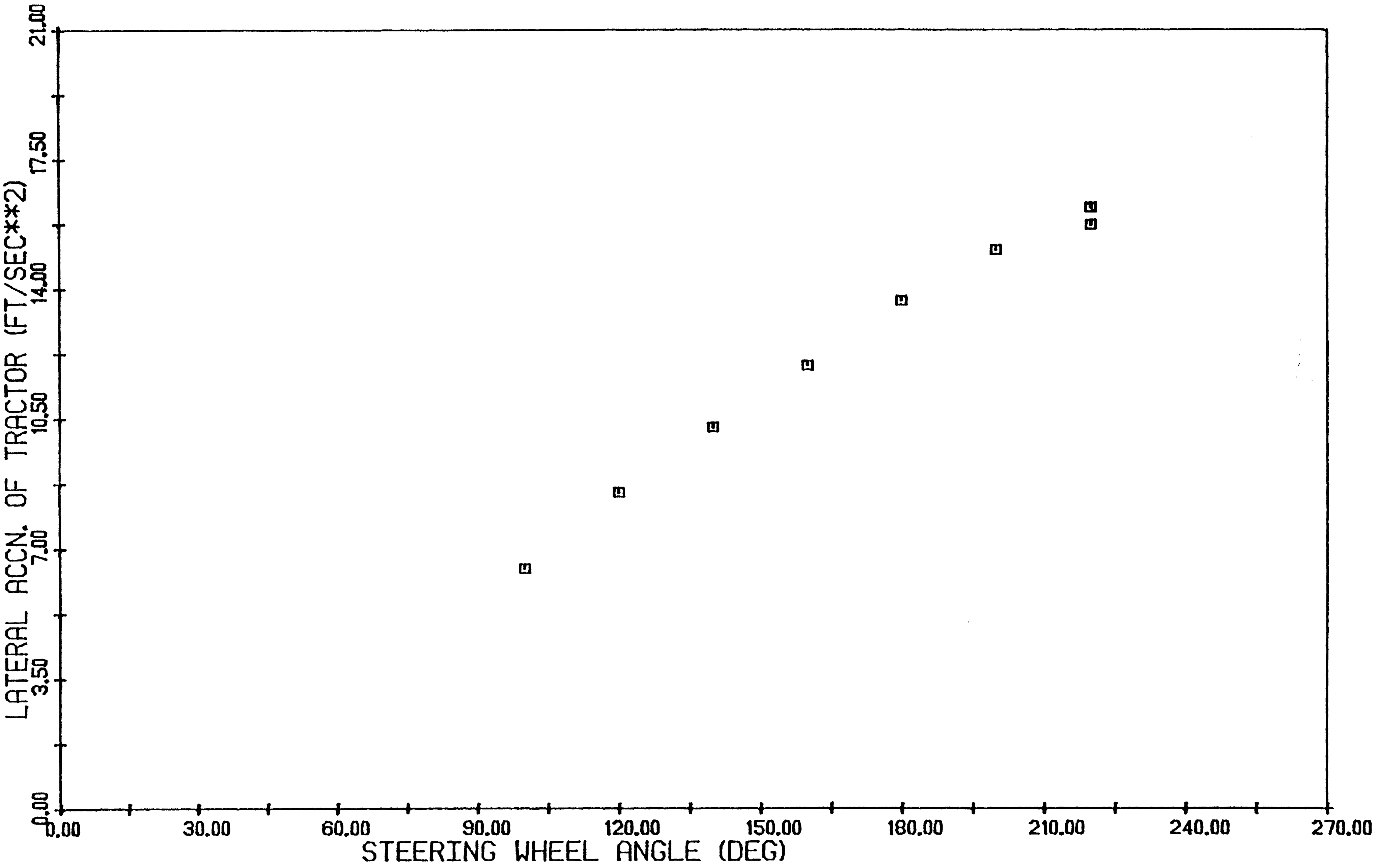
IHC-FLAT BED TRAILER SWAY BAR ALONE



FORD-FLAT BED TRAILER BASELINE



FORD-FLAT BED TRAILER MODIFIED



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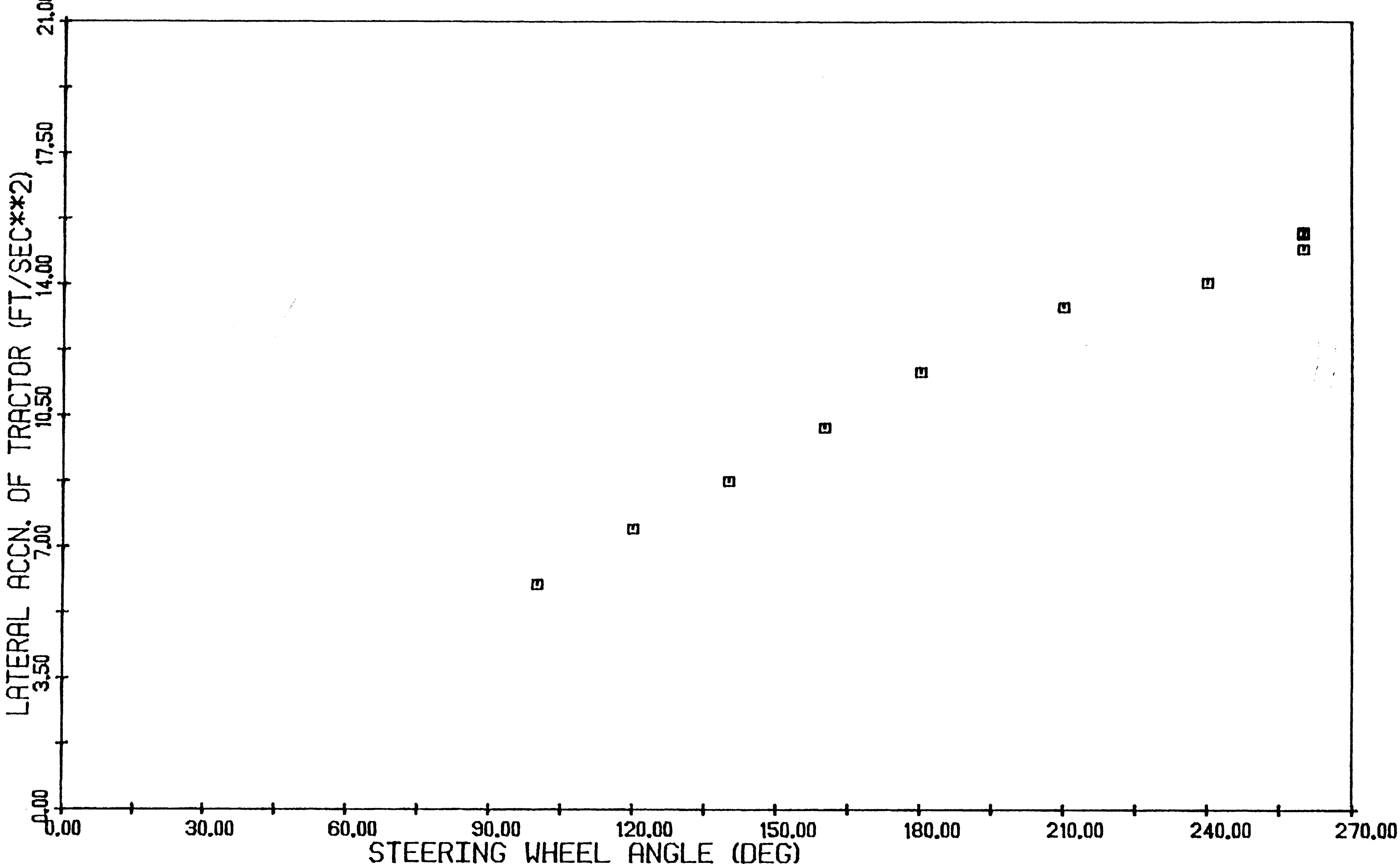
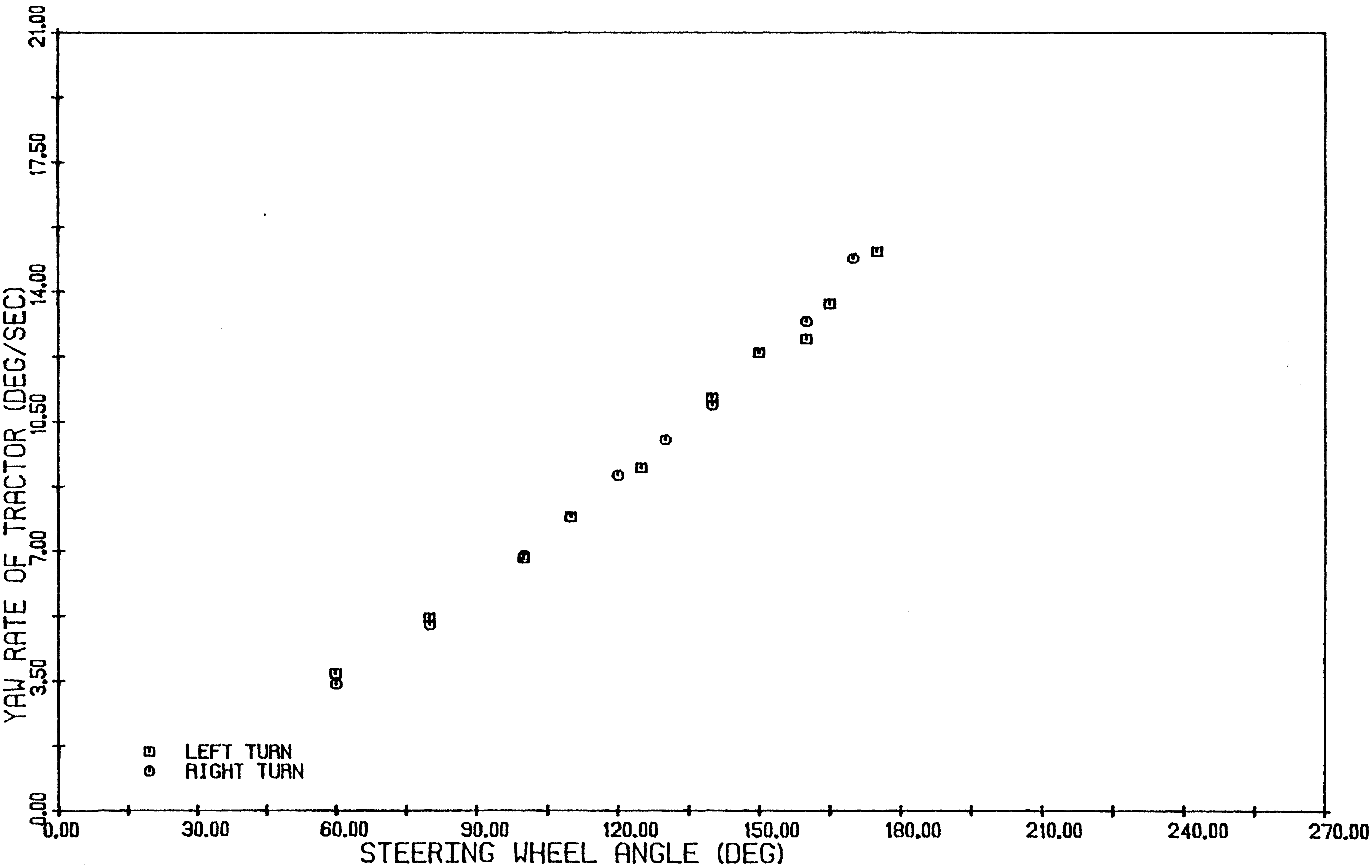
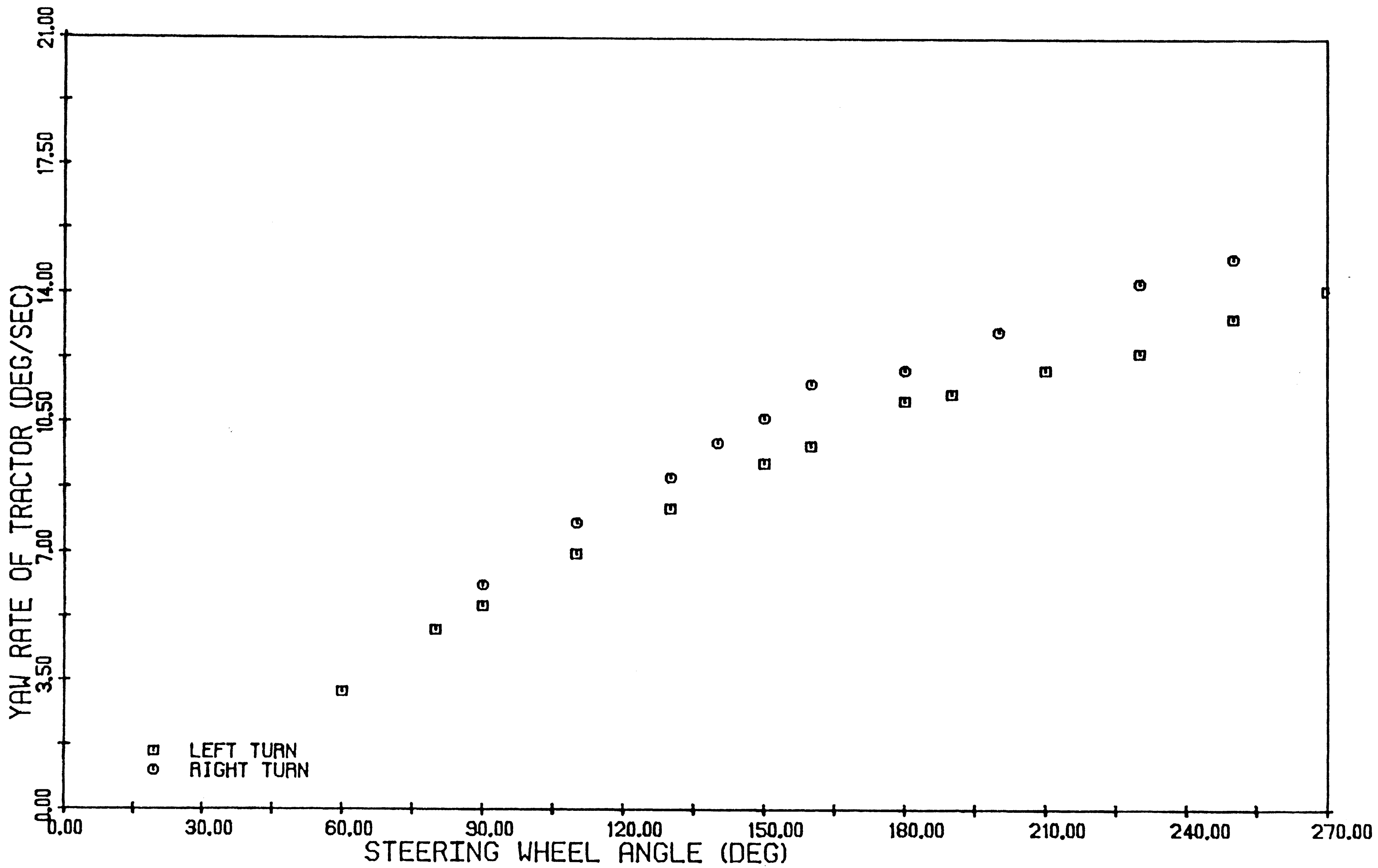


FORD-FLAT BED TRAILER SWAY BAR ALONE

Yaw Rate vs. Steering-Wheel Angle



IHC-VAN TRAILER BASELINE



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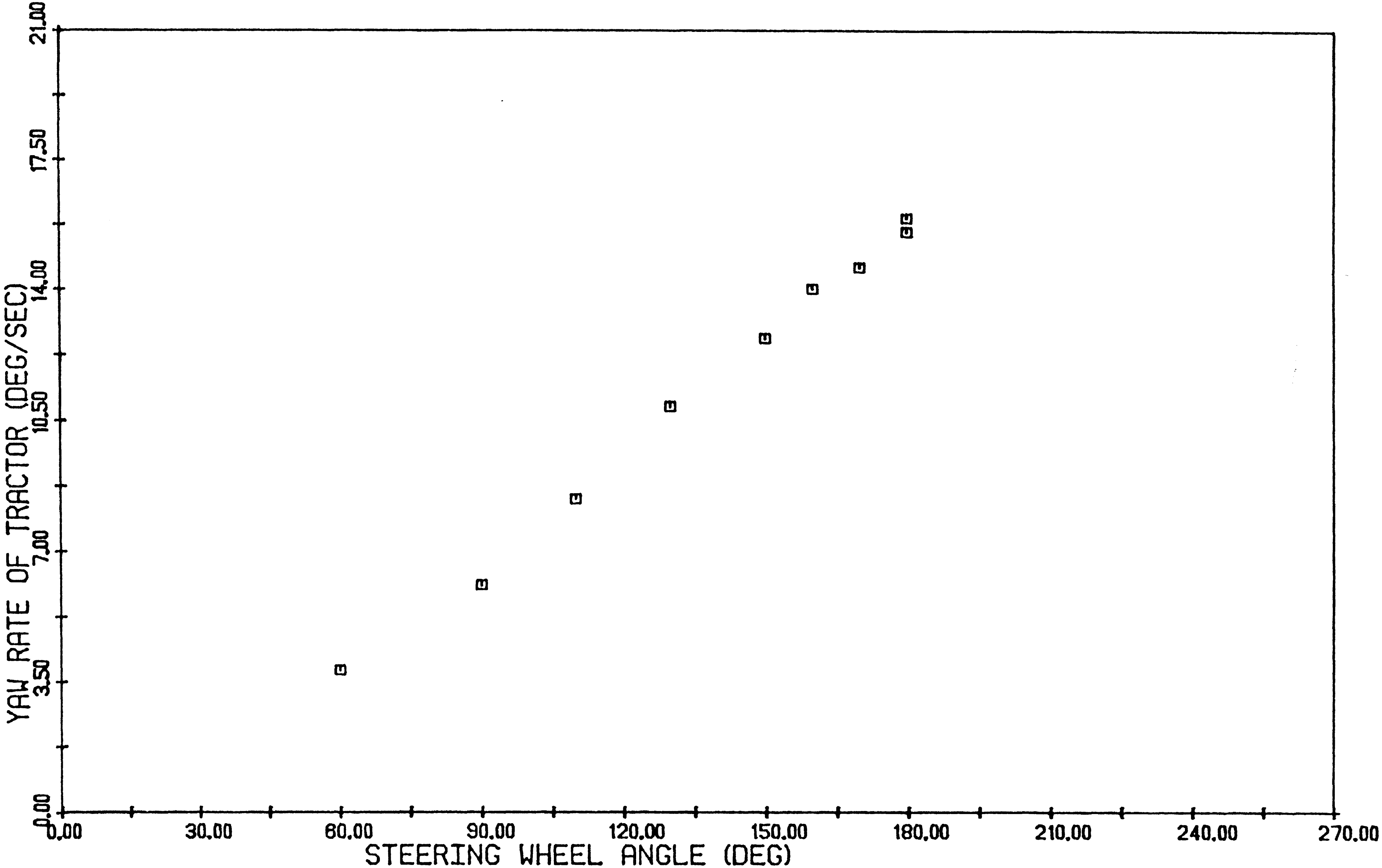

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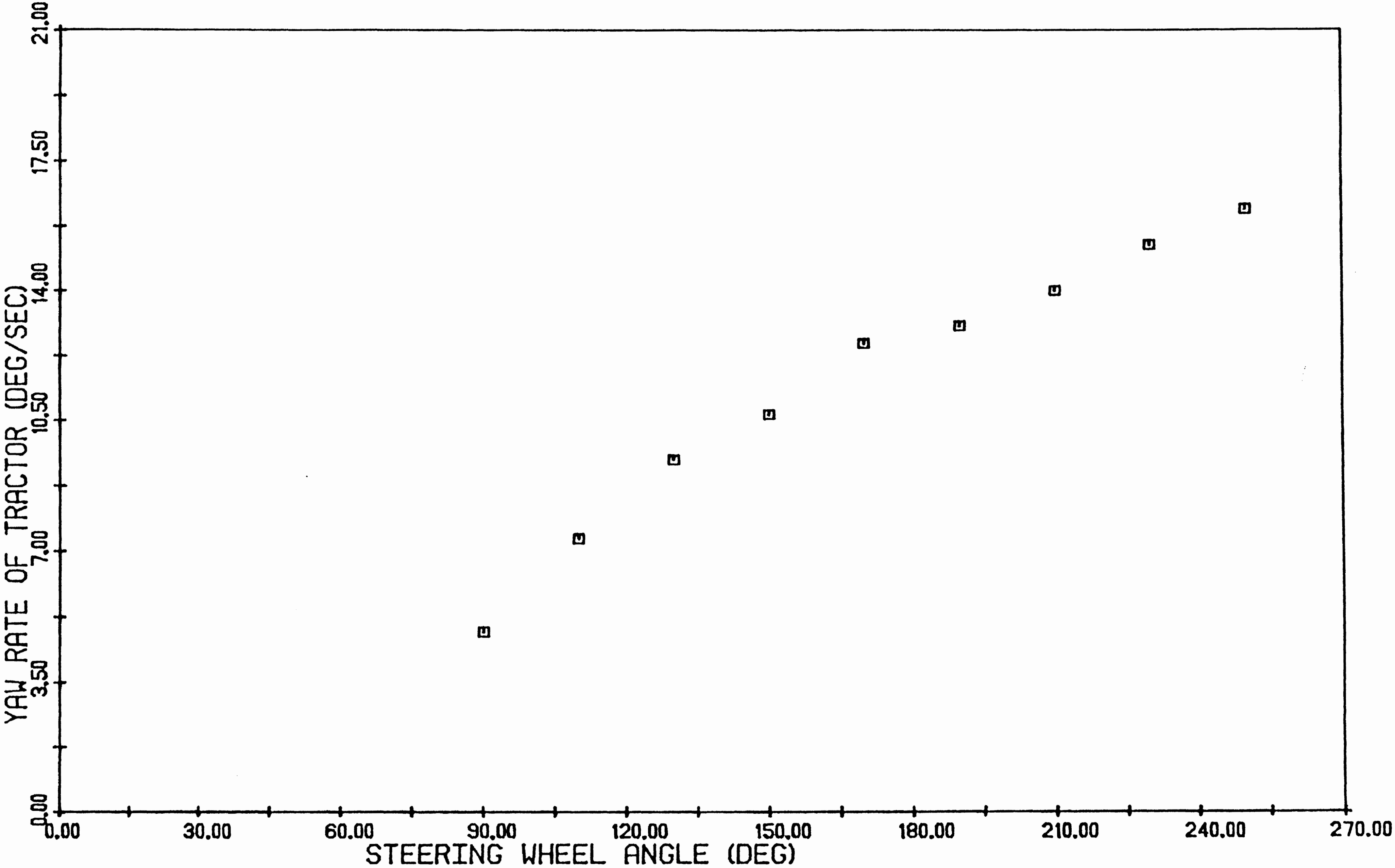

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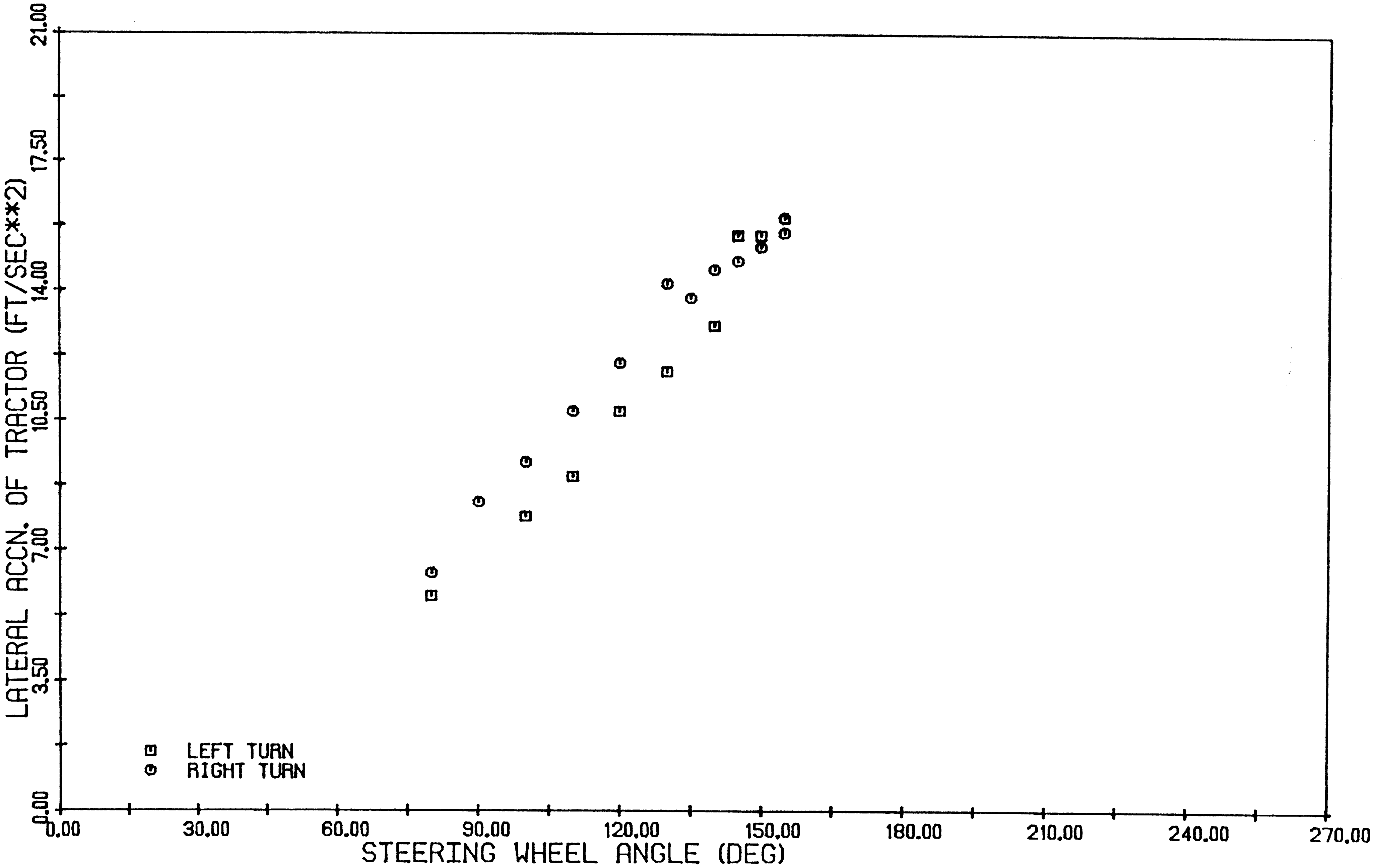

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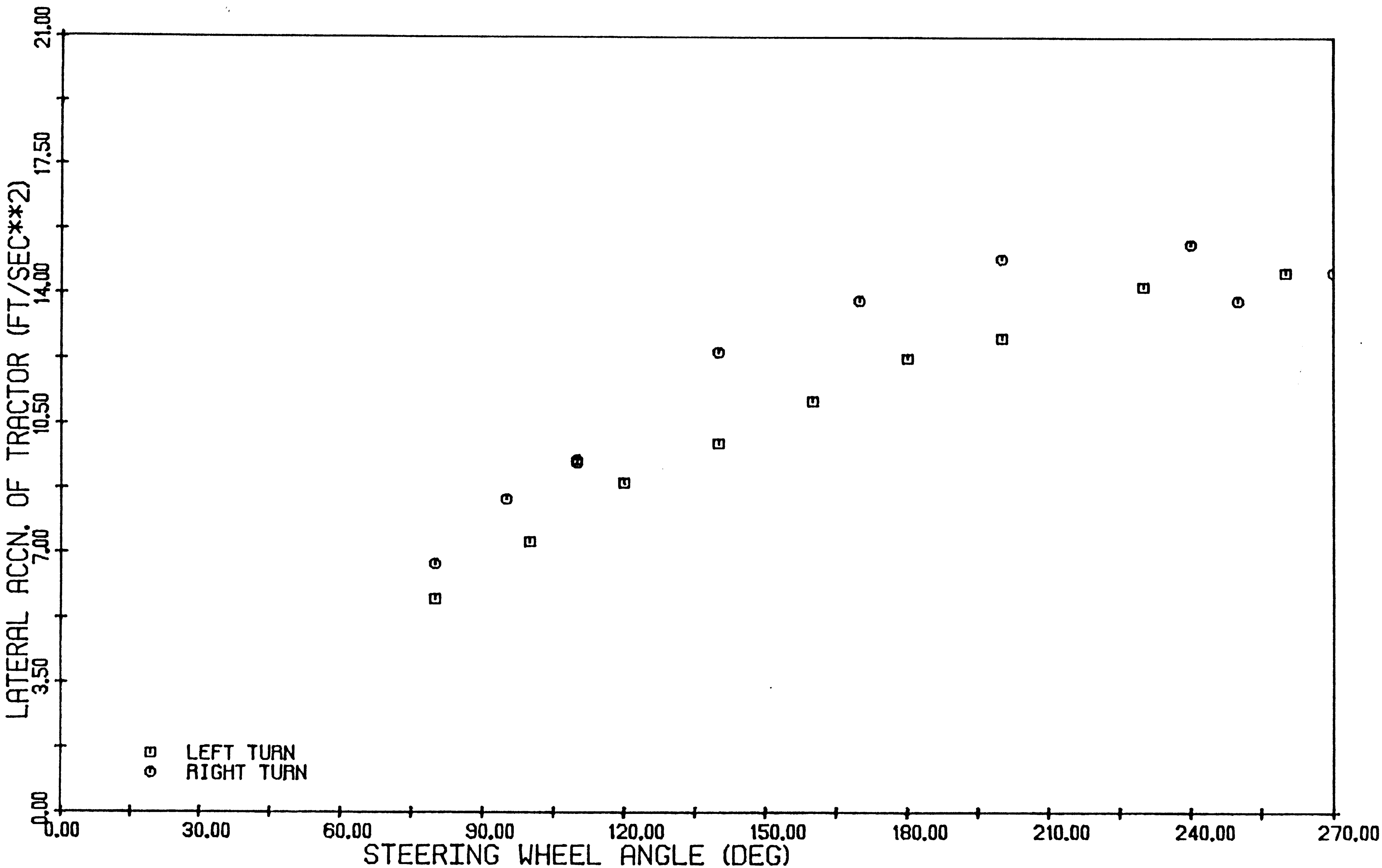

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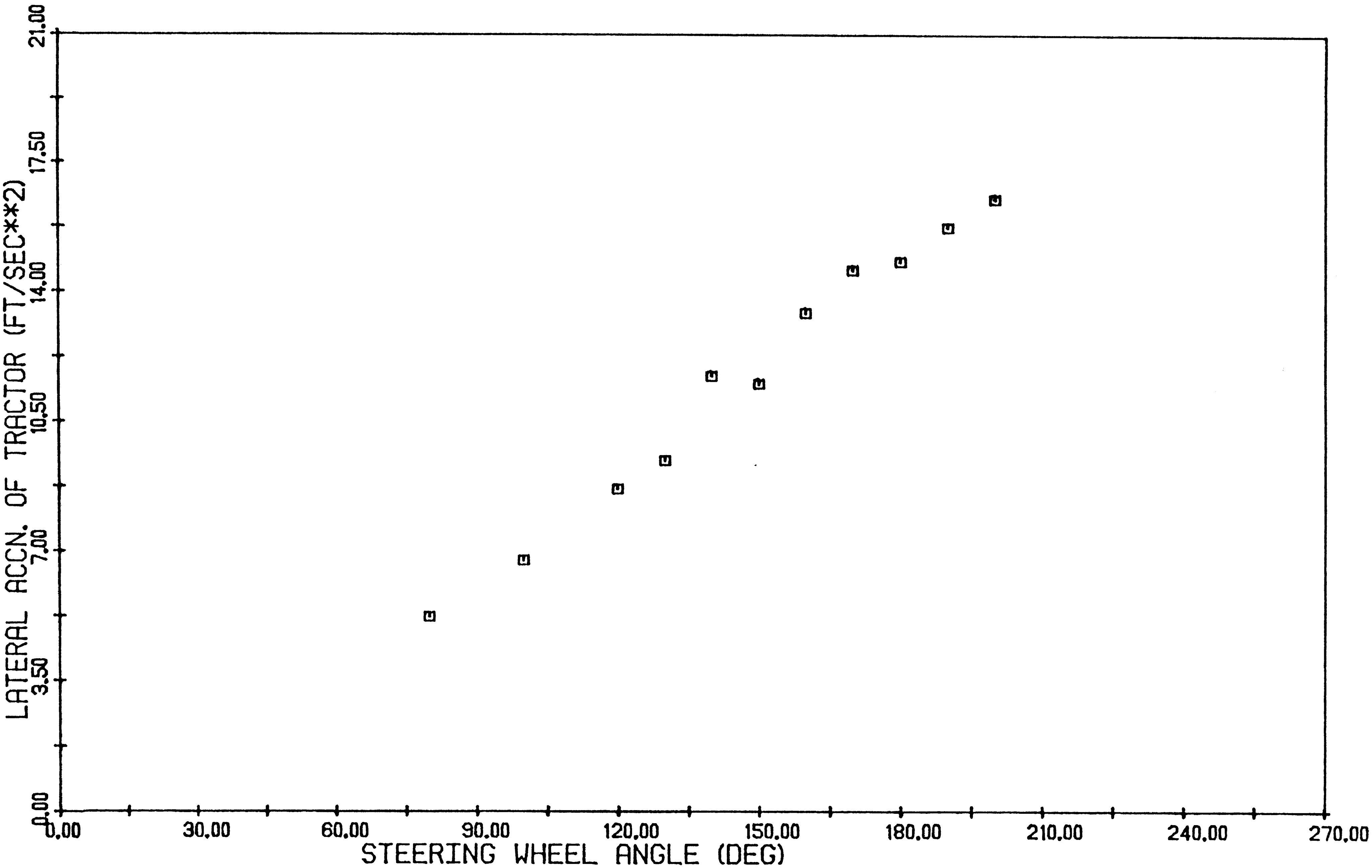

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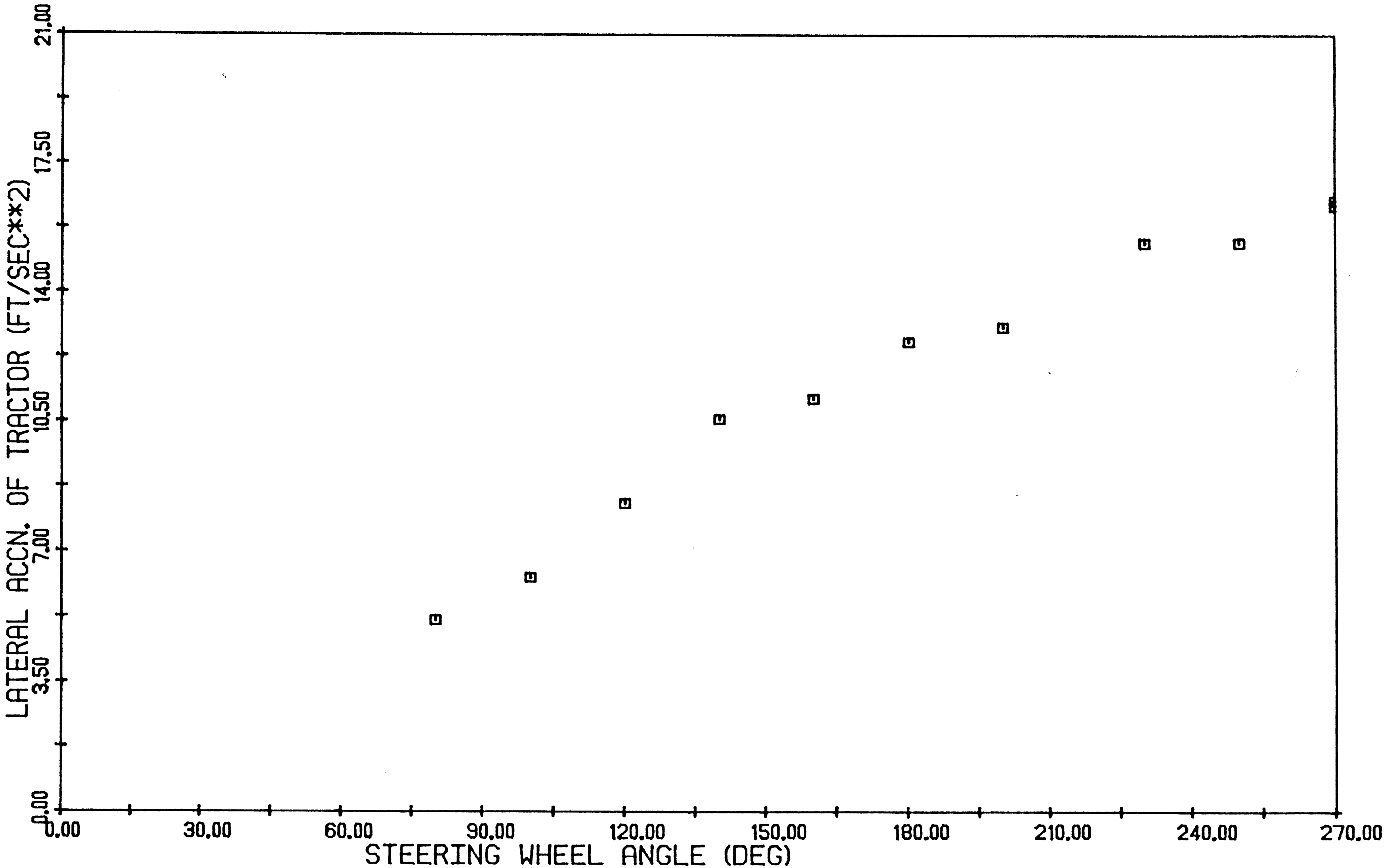

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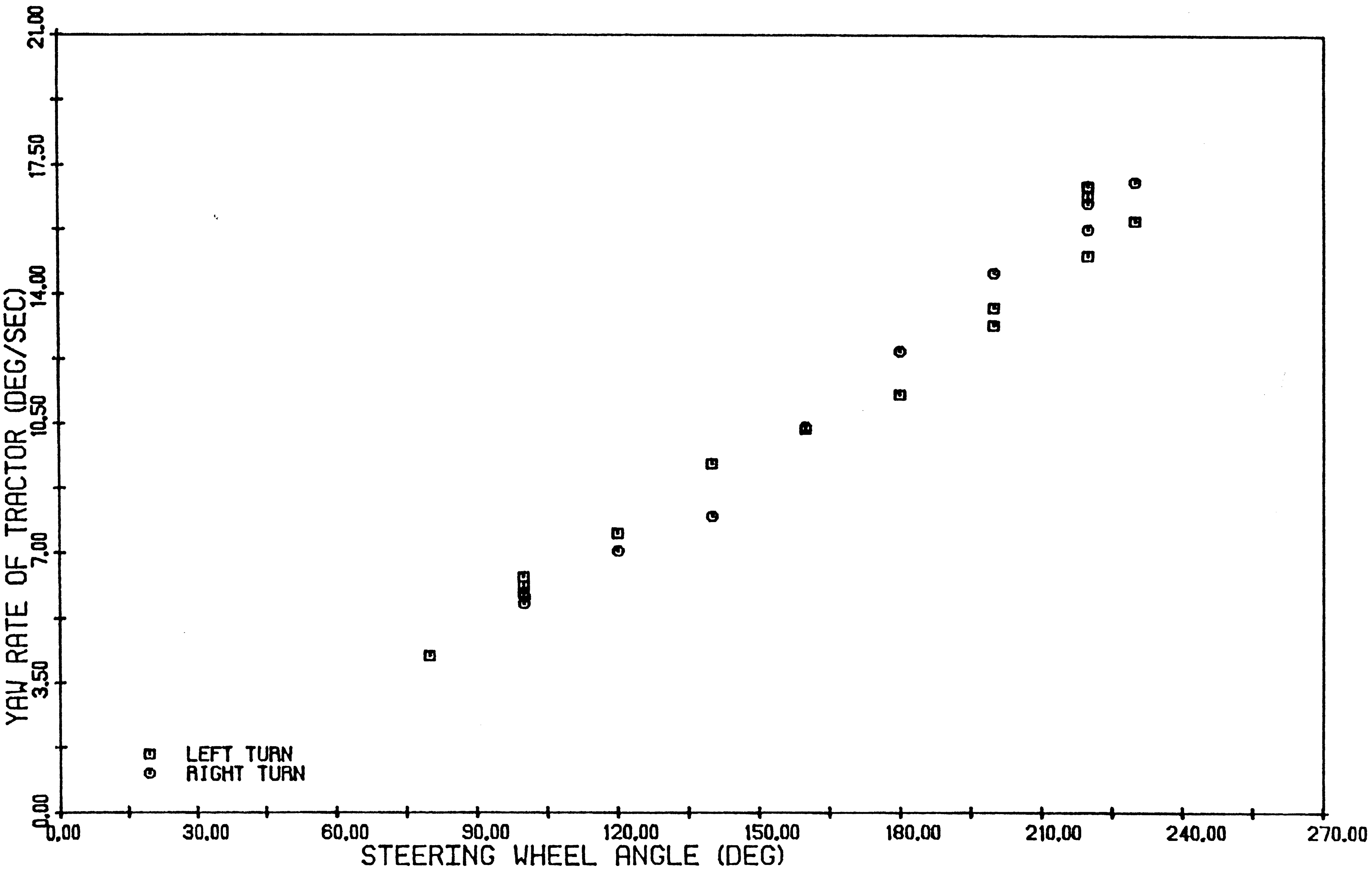
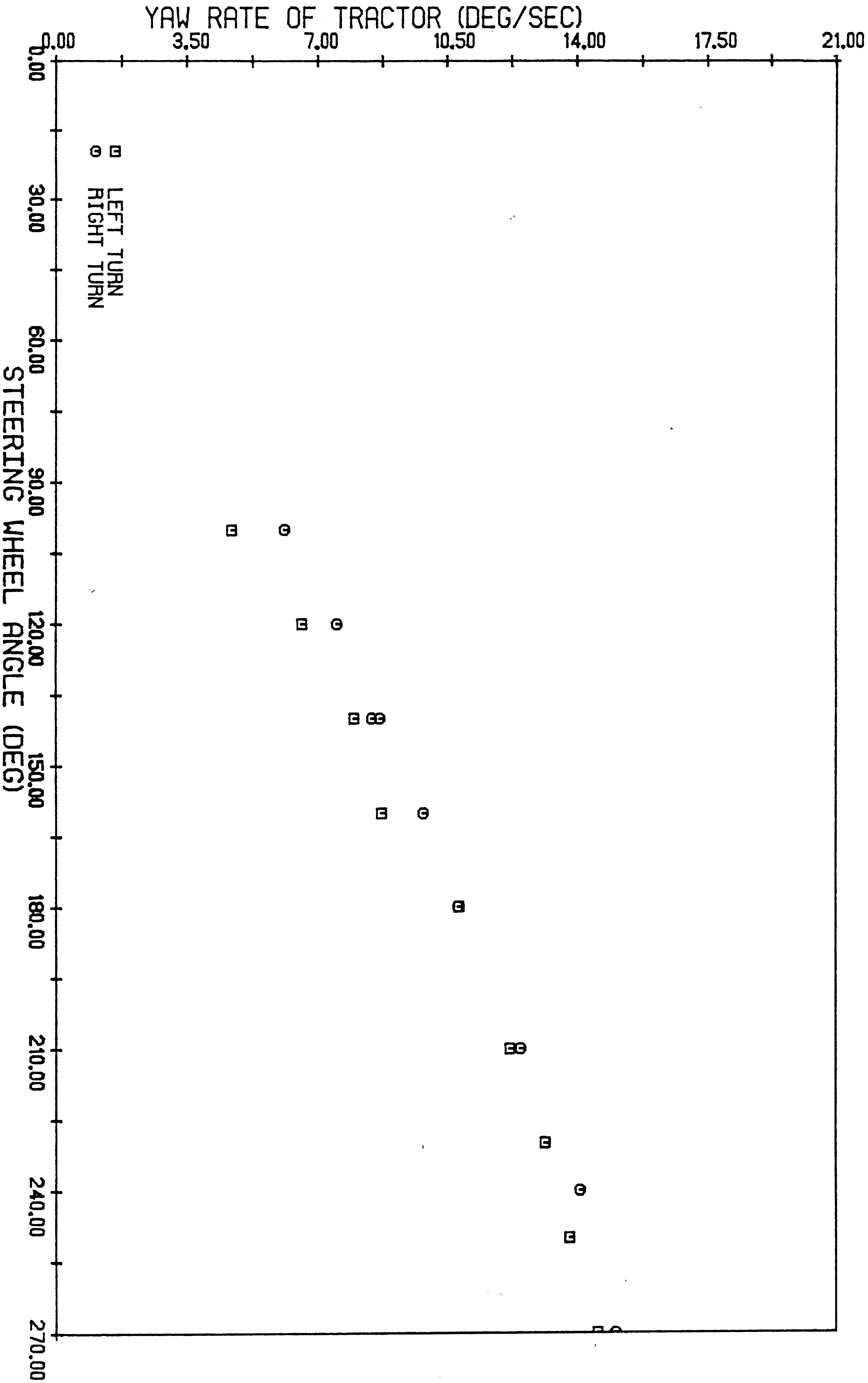


FORD-FLAT BED TRAILER BASELINE



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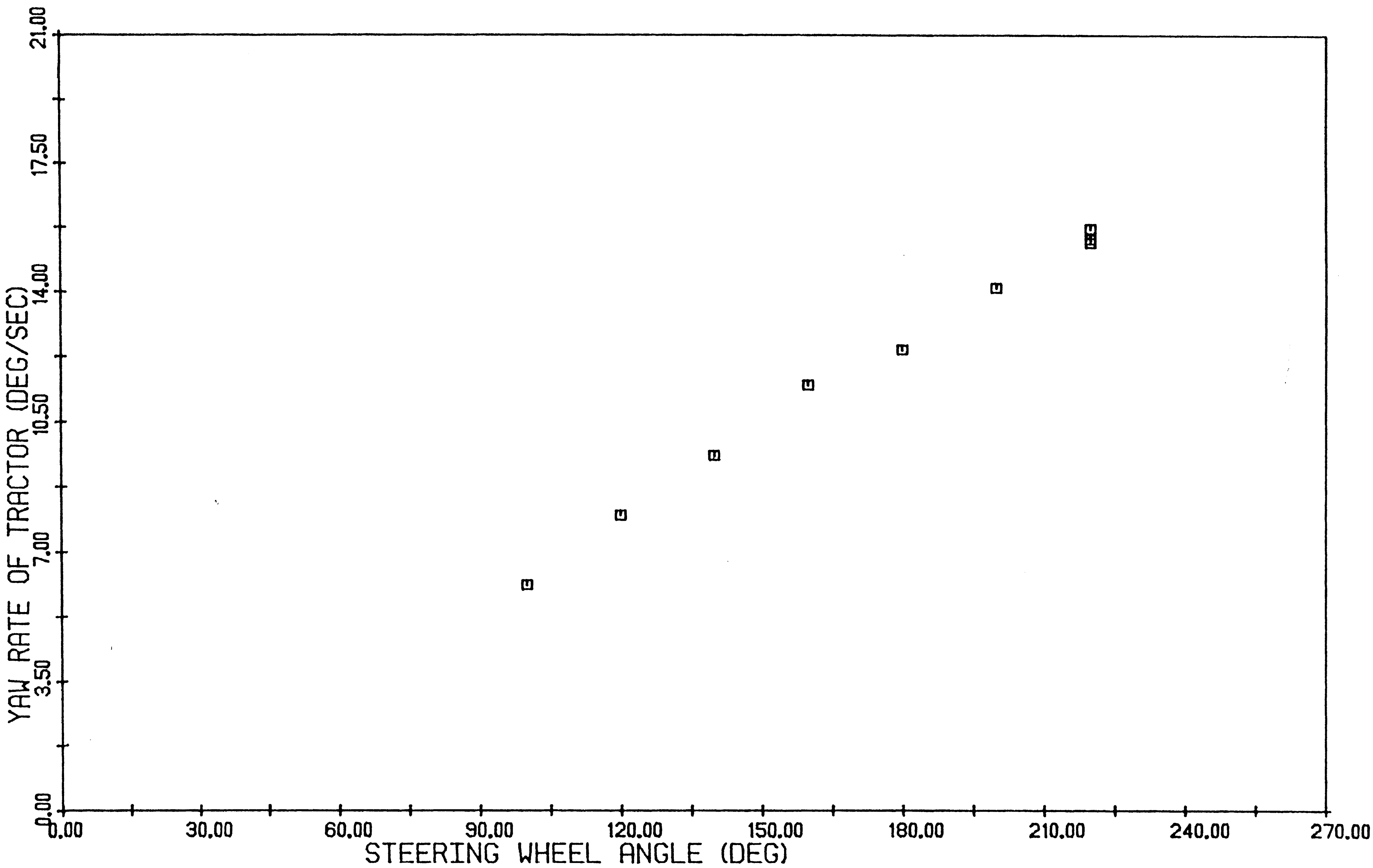

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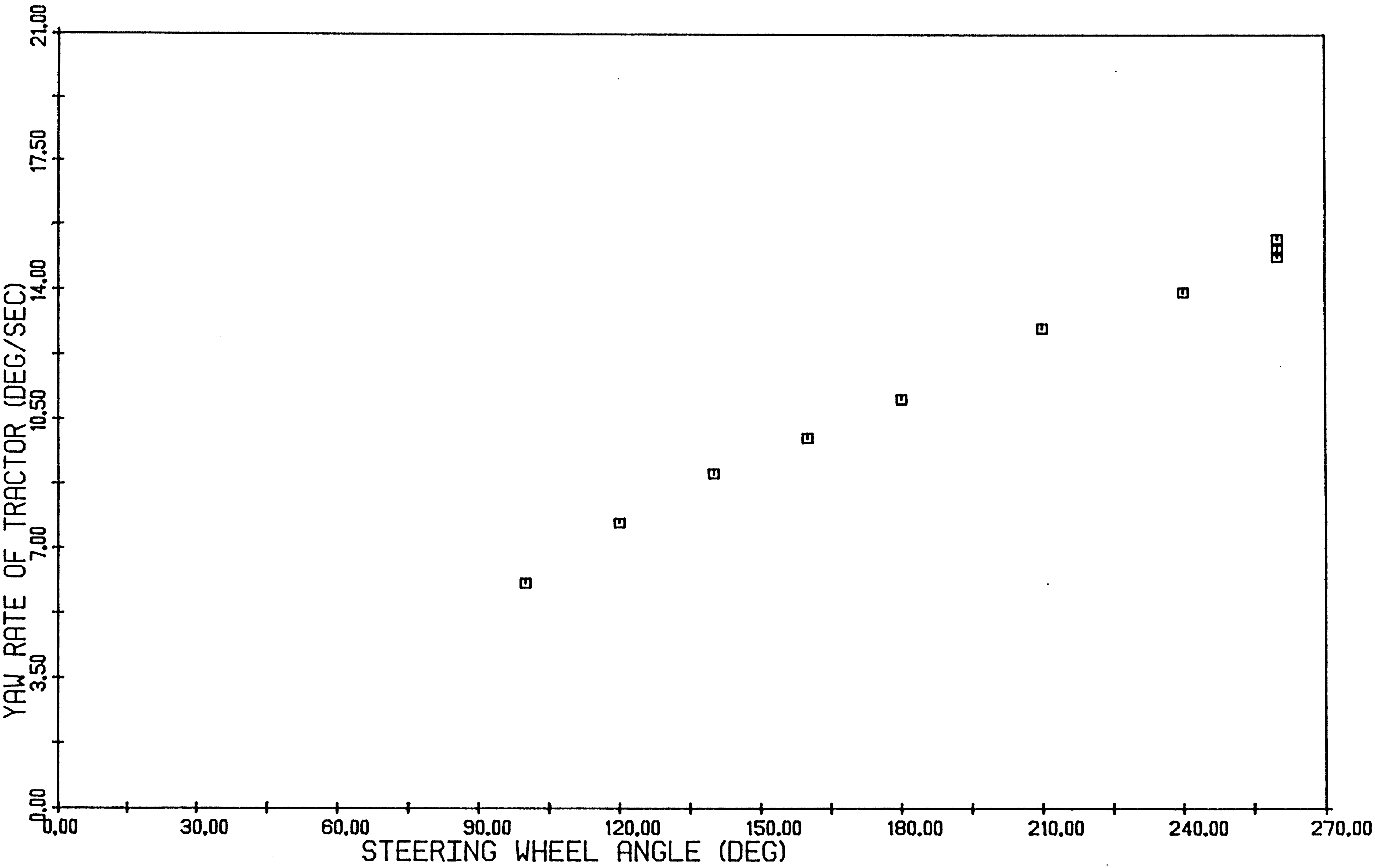
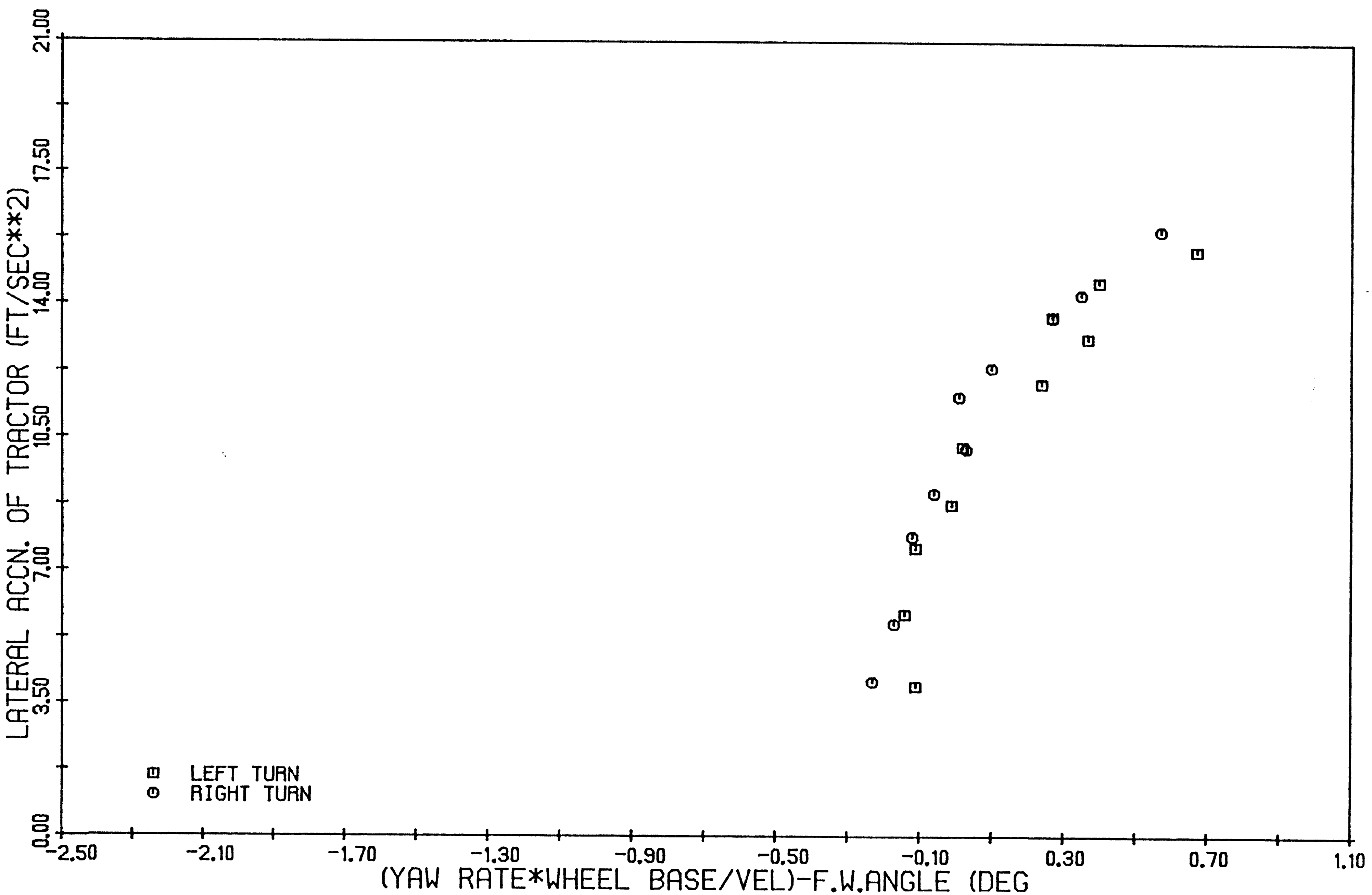


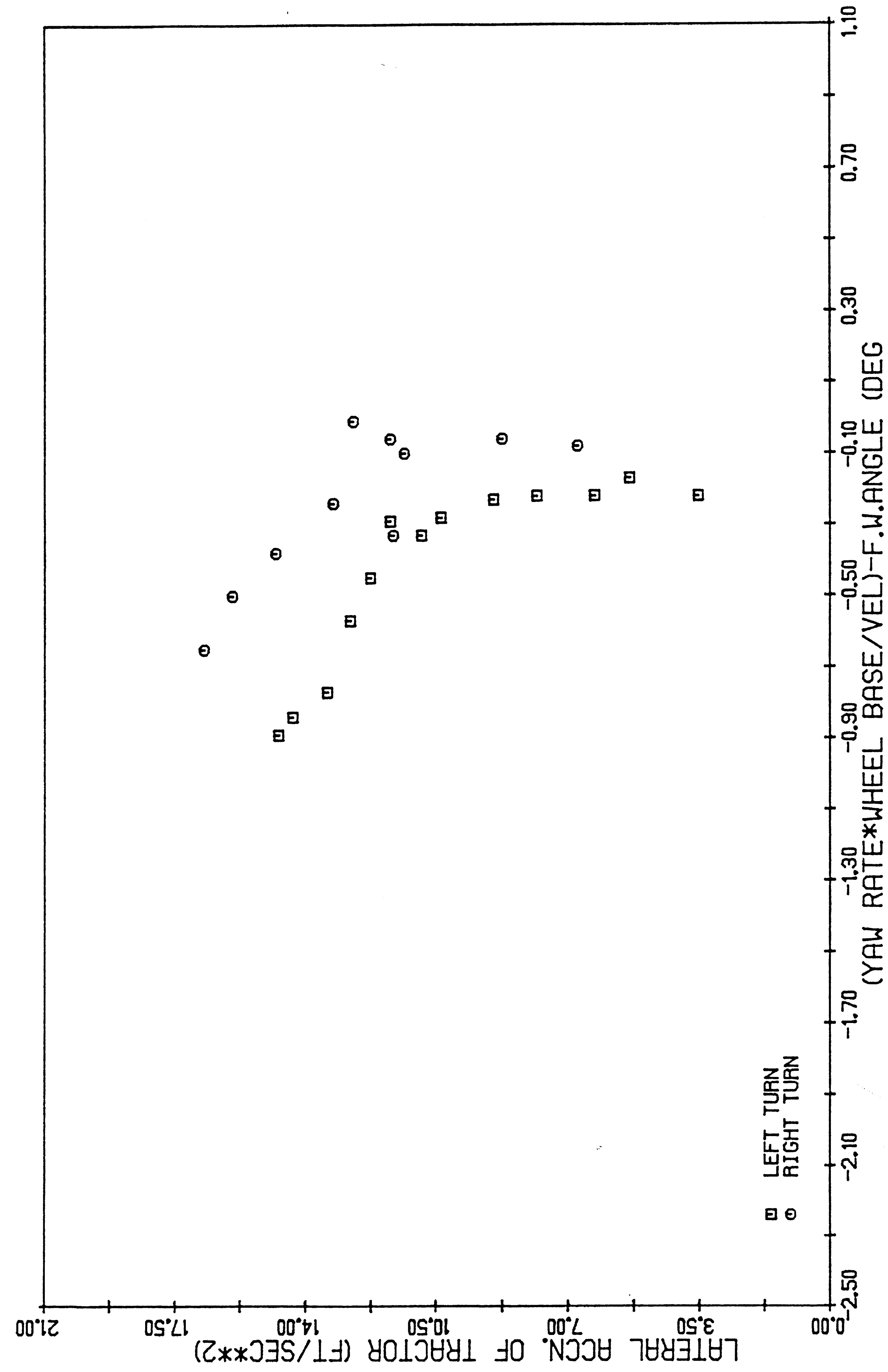
FORD-FLAT BED TRAILER SWAY BAR ALONE

Handling Diagrams

($Lr/V - \delta$) vs. Tractor Lateral Acceleration, a_y



IHC-VAN TRAILER BASELINE , SRATIO=73



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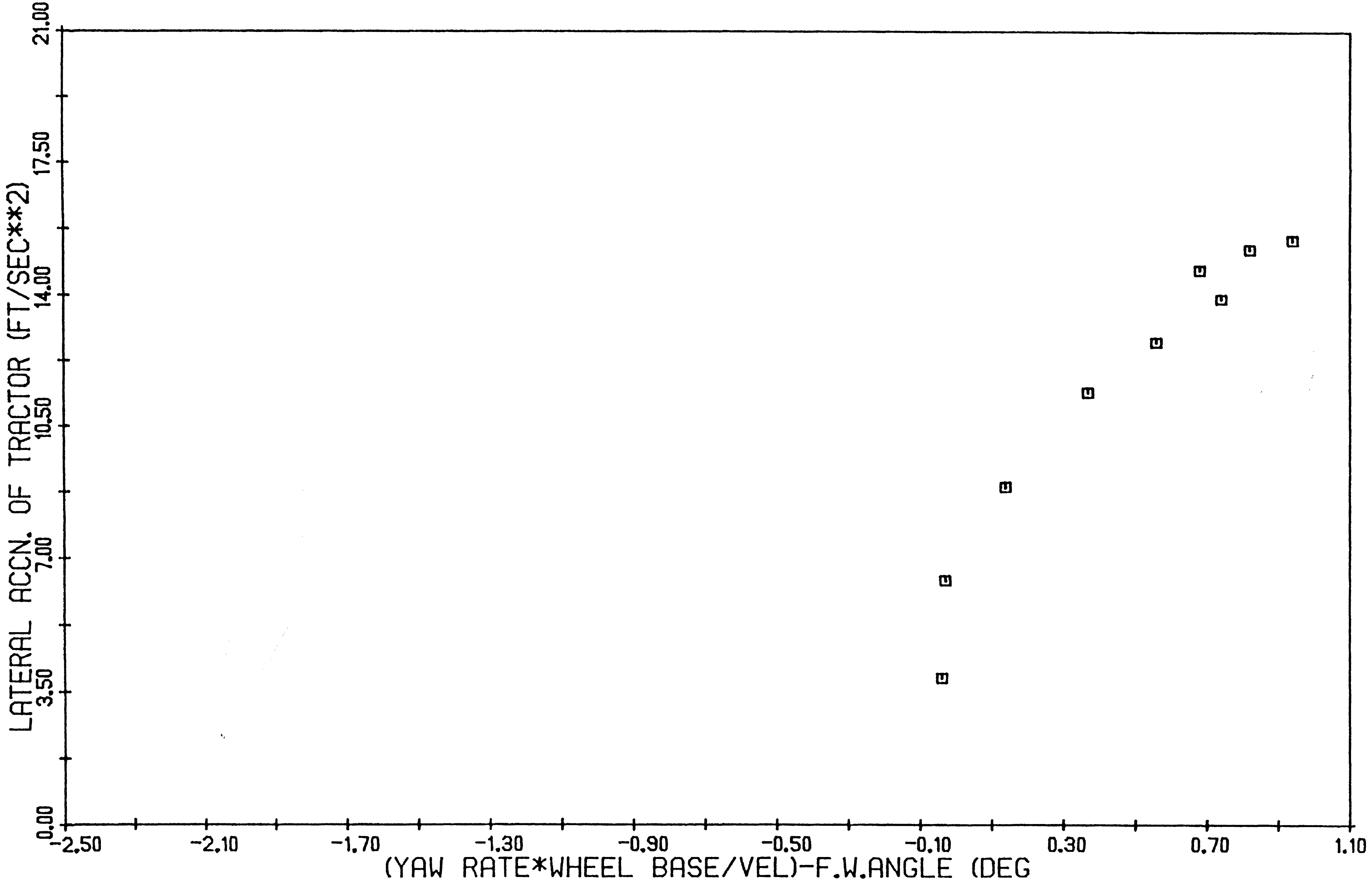
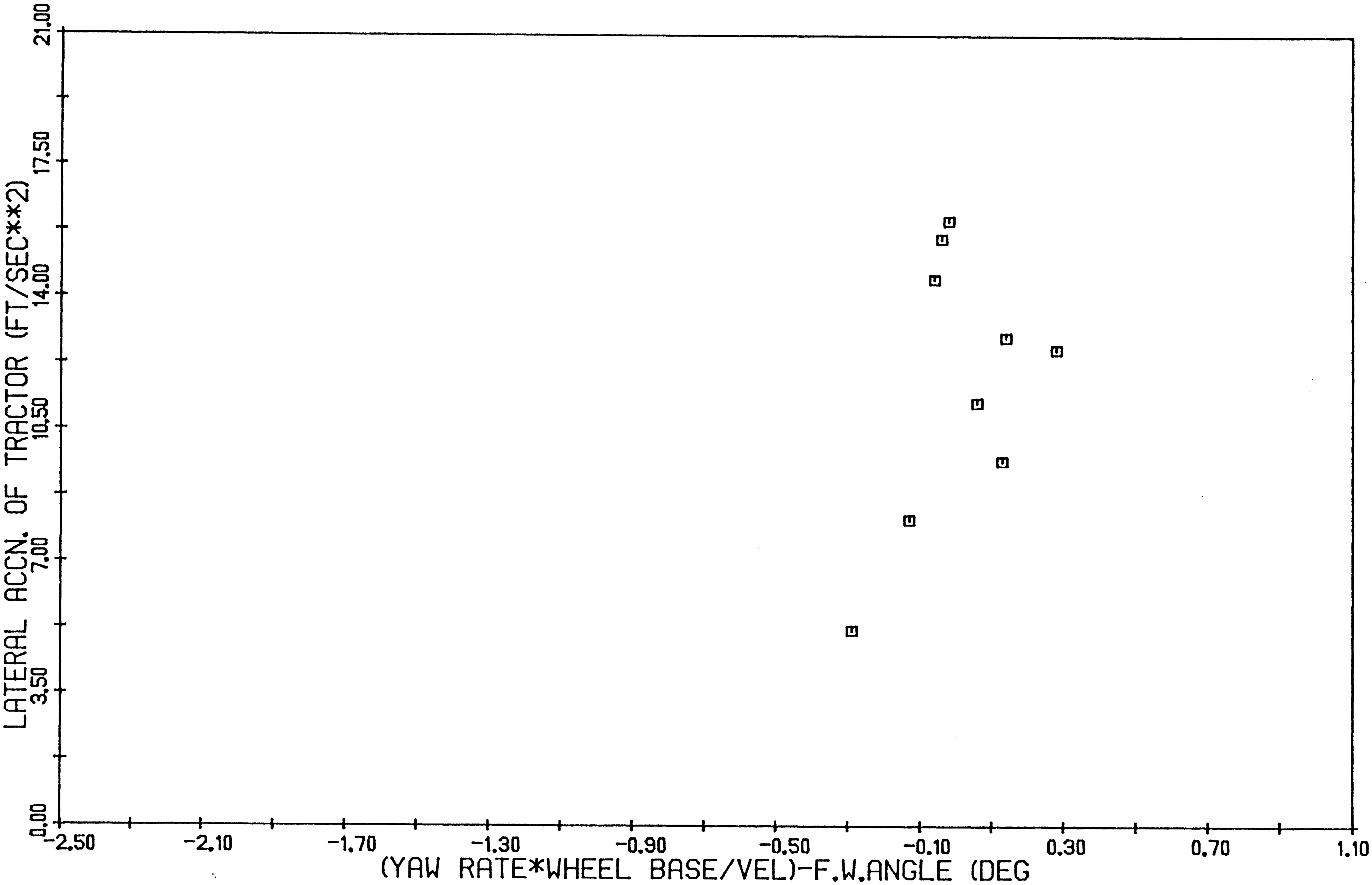


IHC-VAN TRAILER FRAME ALONE , SRATIO = 73



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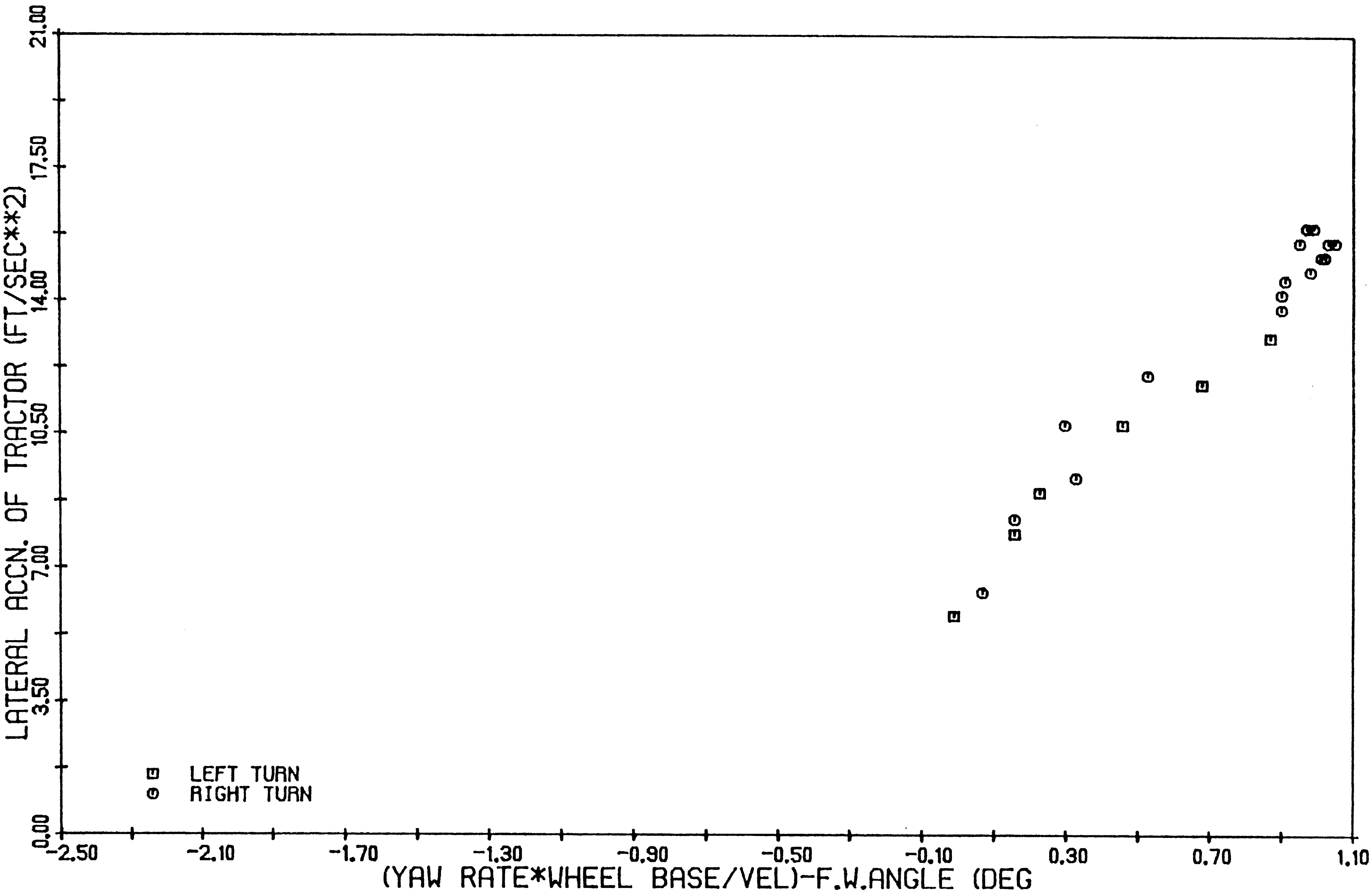
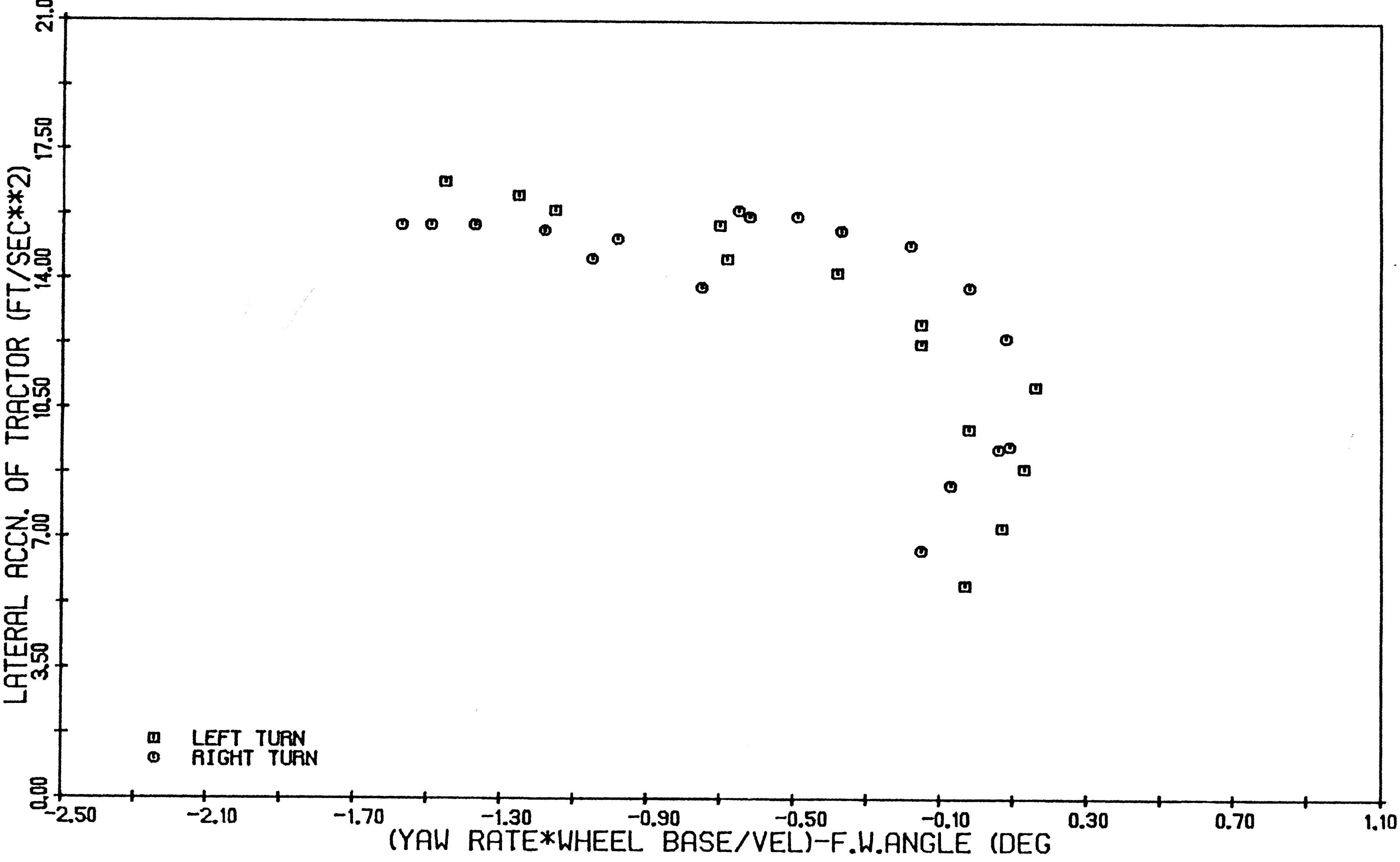


IHC-FLAT BED TRAILER BASELINE , SRATIO=73



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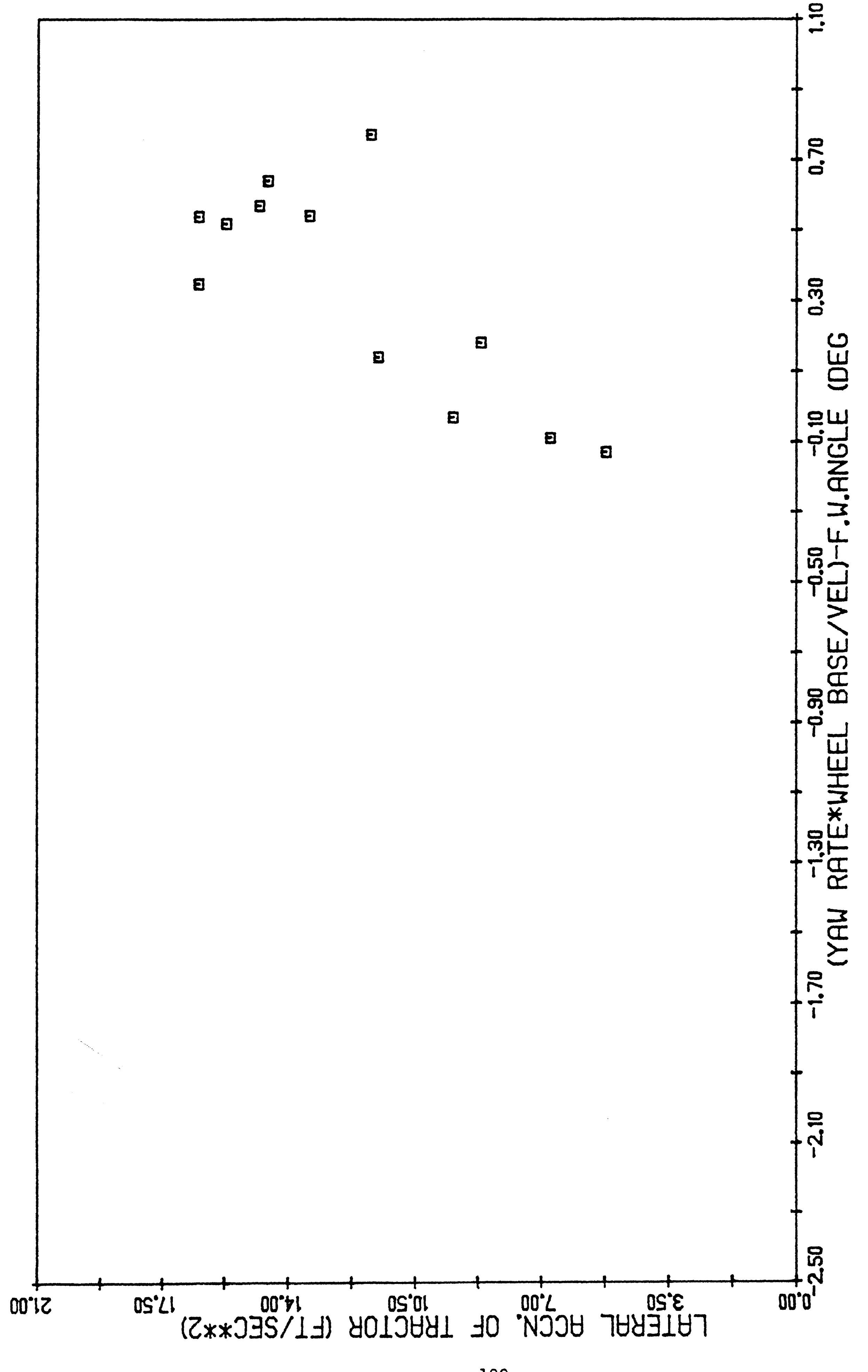

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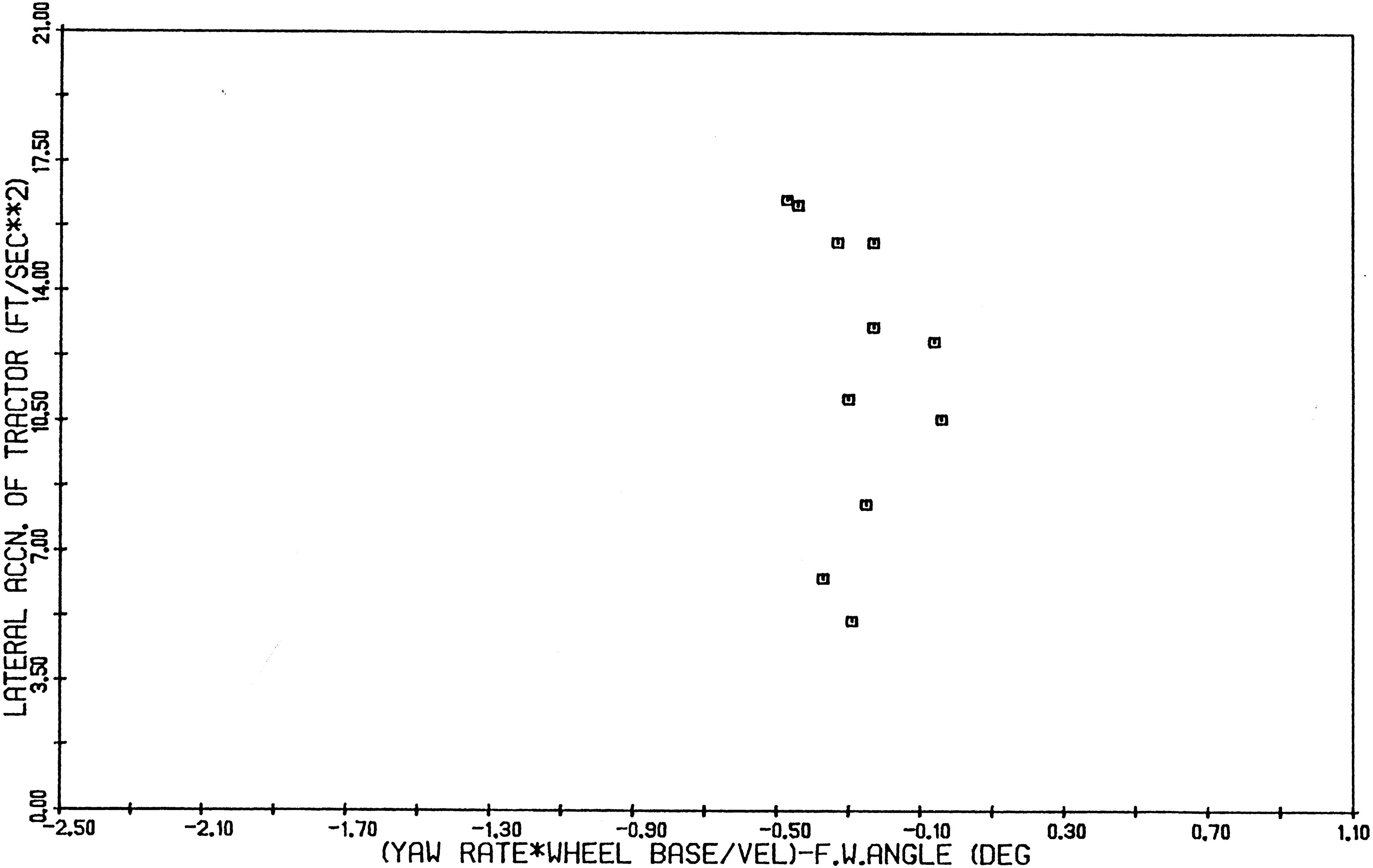
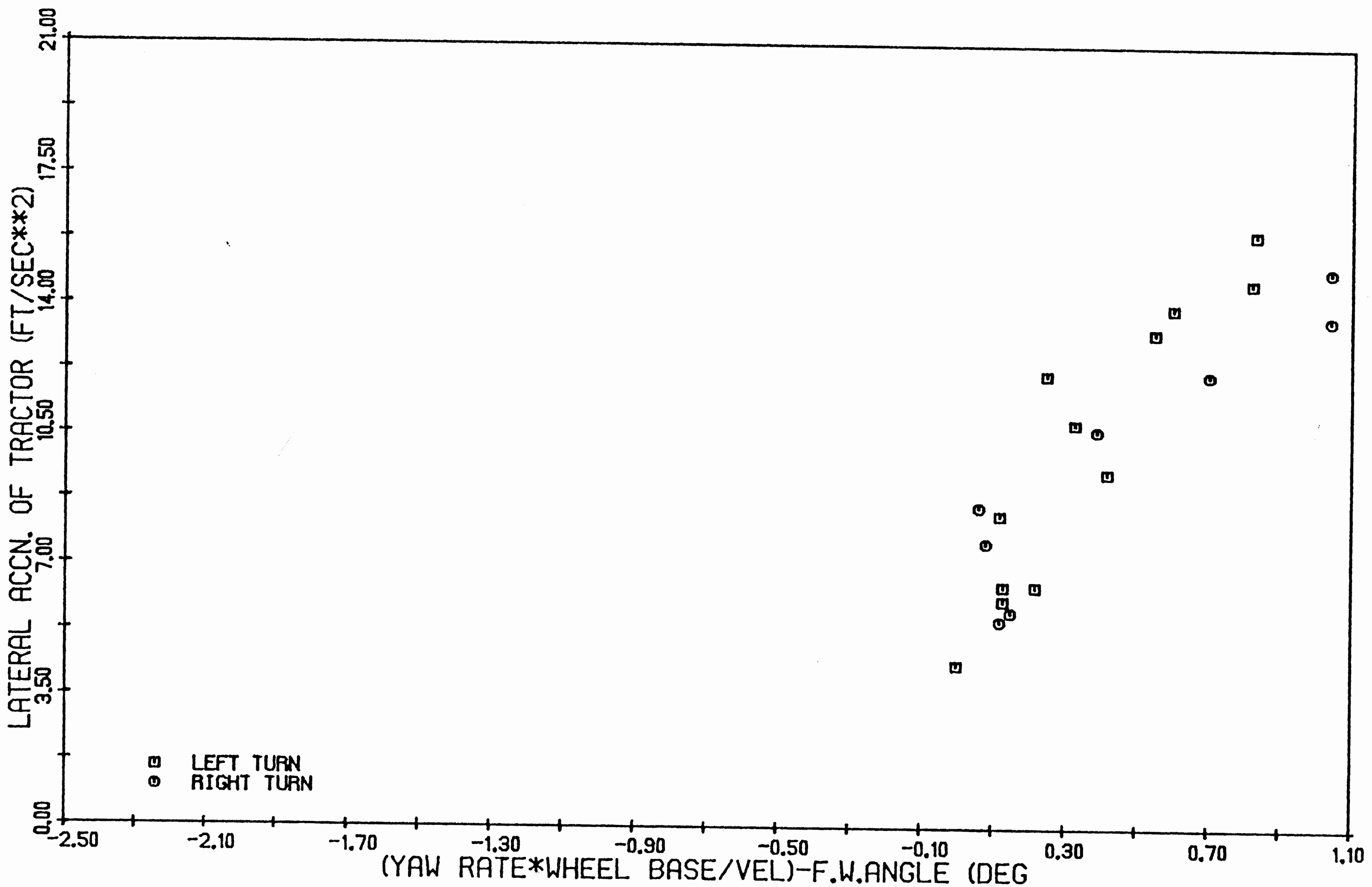
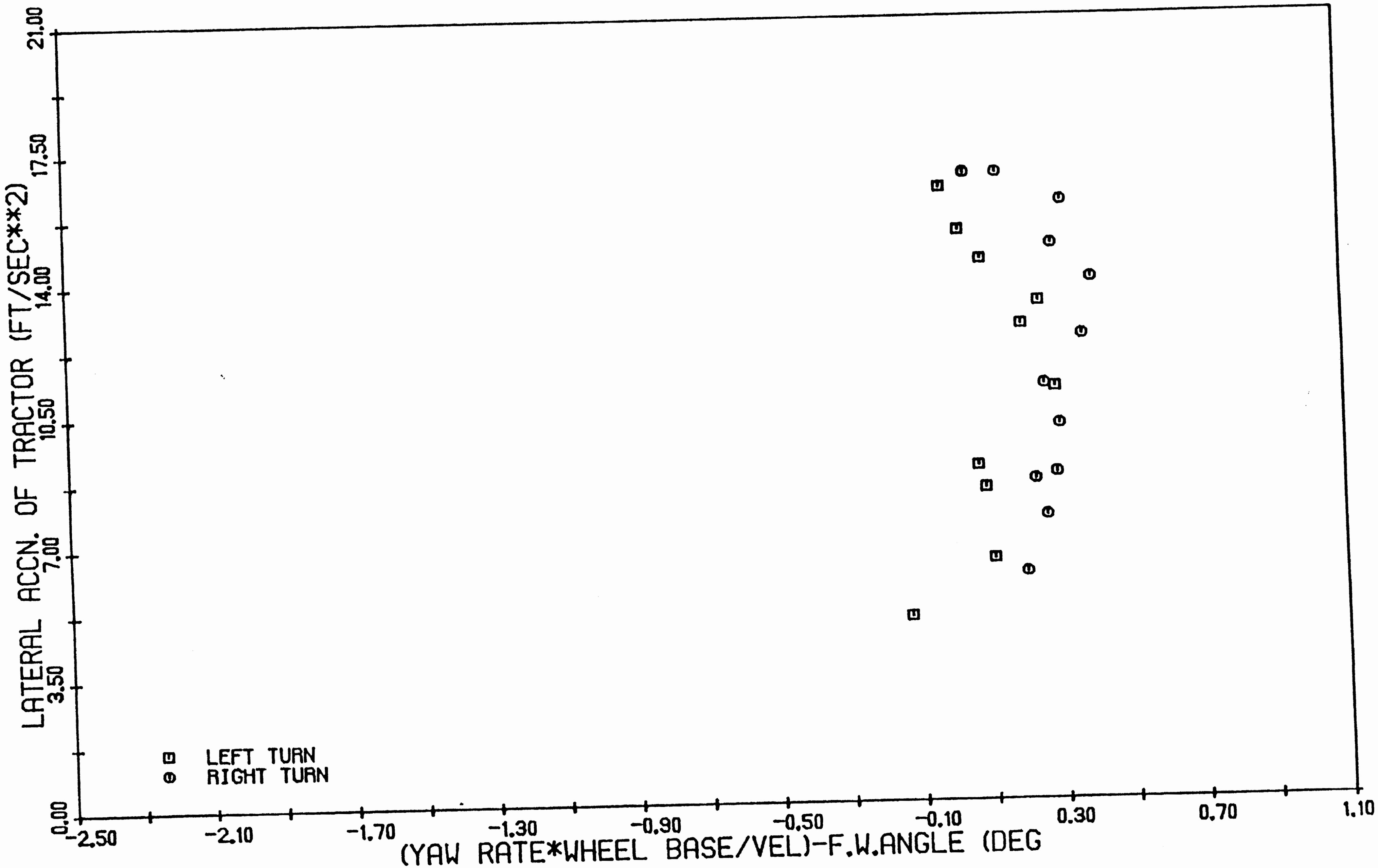


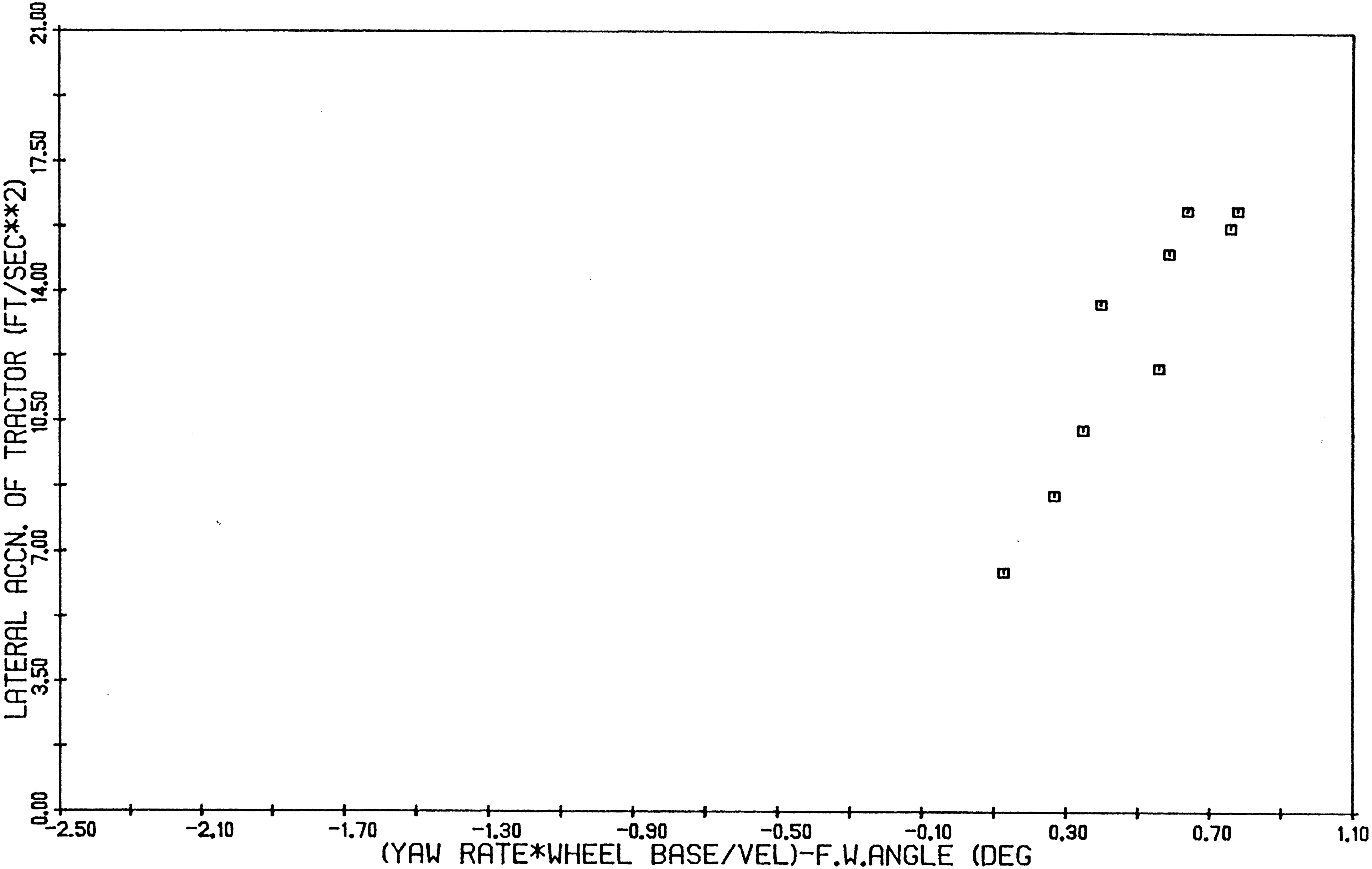
IHC-FLAT BED TRAILER SWAY BAR ALONE , SRATIO=73



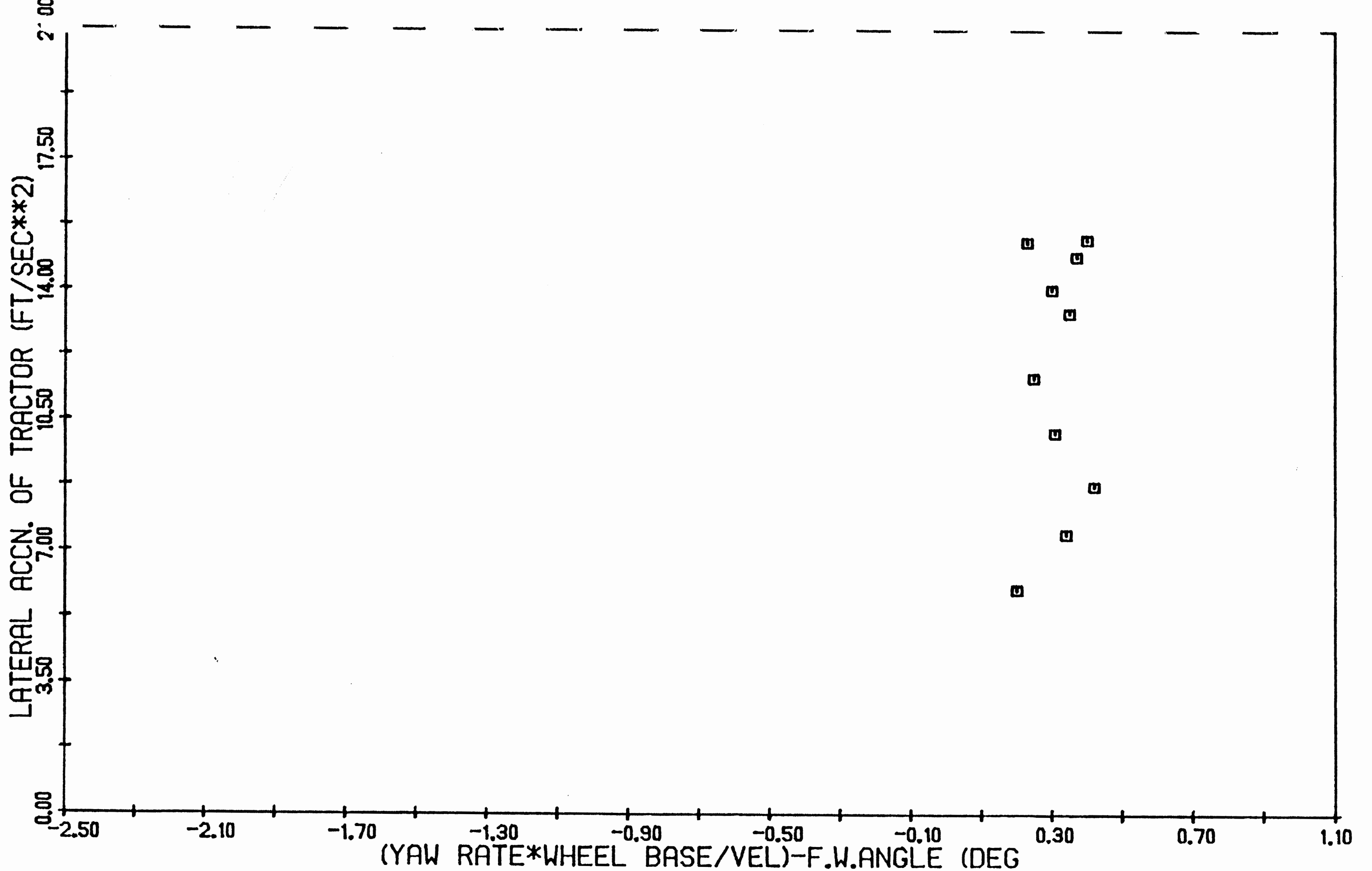
FORD-FLAT BED TRAILER BASELINE , SRATIO=100



FORD-FLAT BED TRAILER MODIFIED , SRATIO=100



FORD-FLAT BED TRAILER FRAME ALONE , SRATIO = 100



FORD-FLAT BED TRAILER SWAY BAR ALONE , SRATIO=100

APPENDIX IV

ANALYSIS OF TRACTOR-SEMITRAILER YAW RESPONSE

Linear analysis techniques have been used for the purpose of studying the steady turning behavior of passenger cars and articulated vehicles at low levels of lateral acceleration. Such maneuvers result in small levels of slip angle and side-to-side load transfer such that the assumption of linear tire characteristics (particularly, the cornering force versus slip angle relationship) is warranted.

Because of their relatively high ratio of c.g. height to track width, commercial vehicles possess a low rollover threshold (usually in the range of 0.45 to 0.65 g of lateral acceleration) and they experience large amounts of side-to-side load transfer, even at moderate levels of lateral acceleration. Since the cornering force produced at an axle is influenced by the amount of load transfer that takes place at that axle, as well as the magnitude of the slip angle, the steady turning behavior of commercial vehicles is very sensitive to the severity of the maneuver and to the roll moment distribution among the axles.

In this appendix, a simplified analysis of the steady turning behavior of tractor-trailer vehicles based on a quasi-linear yaw model (a model in which all geometric nonlinearities are neglected, but tire nonlinearities are retained) is used as an aid in understanding the phenomenon of yaw divergence of tractor-trailer combinations.

This analysis is developed in a number of steps which, together, form the basis for an understanding of the tractor-trailer yaw response characteristics within which tractor yaw stability is singled out as the primary issue. The discussion begins with a simplified analysis of the linear tractor-semitrailer. This analysis concludes with expressions describing the tractor's steady-state yaw response to front-wheel steer angle as well as the trailer's response to articulation angle.

Two basic types of tractor-semitrailer yaw divergency are identified. From this review, we see that all truly unstable yaw behaviors of tractor-semitrailers require that the tractor itself be operating in a yaw-unstable mode. Thus, all subsequent presentations of system stability are confined to displays of the tractor's operating state.

A generally useful diagram for presenting steady-state yaw response characteristics is then introduced. Called the "handling diagram," this presentation scheme is expanded to permit inclusion of the rollover threshold and to describe a yaw stability boundary for broad application of the diagram to the stability investigations of this study.

In successive steps, then, the treatment of the vehicle system with a nonlinear representation of the tire permits the definition of three basic forms of tractor yaw behavior vis-a-vis the handling diagram. Next, the addition of tandem axles as another mechanism influencing yaw response is covered, revealing a specific treatment of the handling diagram needed for representing the tandem-axle tractor. The last two sections develop the basis for evaluating the yaw behavior of the tandem-axle tractor with (a) a linear tire representation (for which a single curve on the handling diagram constitutes a complete description of the vehicle's steady-turning response) and (b) a nonlinear tire representation (for which a family of curves, one for each operating velocity, is needed to describe vehicle response).

IV.1 Simplified Analysis of the Steady-Turning Behavior of a Two-Axle Tractor/Single-Axle Trailer Combination

A plan view of the tractor-trailer combination, whose steady-turning behavior is to be analyzed, is shown in Figure IV.1. Simplifying assumptions made in the analysis are as follows:

1) All motions of the vehicle take place in the horizontal plane
2) The steer angle, δ, and the articulation angle, Γ, are small so that $\sin\delta \approx \delta$, $\cos\delta \approx 1.0$ and $\sin\Gamma \approx \Gamma$, $\cos\Gamma \approx 1.0$
3) The slip angles, α_i (i=1,2,3) at the tire-road interface are small, so that $\sin\alpha_i \approx \alpha_i$ and $\cos\alpha_i \approx 1.0$, although the lateral force can be made a nonlinear function of the slip angle

Table IV.1. List of Symbols Used in the Analysis

NOTE: A double subscript notation has been used when referring to the axles of the articulated vehicle. The first subscript stands for the unit number (1 = tractor, 2 = semitrailer) and the second subscript stands for the axle number of that unit. For example, axle "21" refers to the first axle on the semitrailer.

V	forward velocity of the tractor (in/sec)
v_i	lateral velocity at the mass center of the i^{th} unit (in/sec)
r_i	yaw rate of the i^{th} unit (rad/sec)
Γ	articulation angle of the tractor with respect to the trailer (rad)
δ	steer angle at the front wheels of the tractor (rad)
m_i	mass of the i^{th} unit ($lb \cdot sec^2/in$)
I_i	yaw moment of inertia of the i^{th} unit ($lb \cdot in \cdot sec^2$)
C_{ij}	sum of the cornering stiffnesses of all tires mounted on axle ij (lb/rad)
F_{ij}	lateral force at axle ij (lb)
α_{ij}	sideslip angle at axle ij (rad)
X_{ij}	longitudinal distance of axle ij from the mass center of the i^{th} unit (in)
X_{1A}	distance of tractor fifth wheel from mass center of tractor (in)
X_{2A}	distance of tractor fifth wheel from mass center of semitrailer (in)
a_y	lateral acceleration of the vehicle during a steady turn (in/sec^2)

4) Forward velocity of the vehicle is a constant

5) The radius of turn is large in comparison to the wheelbases of the tractor and trailer

6) The drive thrust needed to maintain a constant velocity is small and hence its influence on the cornering force characteristics at the drive axle is negligible

7) The influence of aligning torques and dual tire effects are negligible.

From Figure IV.1 we see that, under steady turning conditions, the slip angles α_{11}, α_{12}, and α_{21} can be expressed as:

$$\alpha_{11} = \frac{(v_1 + x_{11}r)}{V} - \delta \tag{1}$$

$$\alpha_{12} = \frac{(v_1 - x_{12}r)}{V} \tag{2}$$

$$\alpha_{21} = \frac{(v_1 - (x_{1A}+X_{2A}+x_{21})r)}{U} + \Gamma \tag{3}$$

$$\alpha_{12} - \alpha_{11} = \delta - L/R \tag{4}$$

$$\alpha_{21} - \alpha_{12} = \Gamma - L_T/R \tag{5}$$

where $L = (x_{11} + x_{12})$ wheelbase of tractor

and $L_T = (x_{1A}+x_{2A}+x_{21}-x_{12})$ wheelbase of trailer

Free-body diagrams of the tractor and trailer are shown in Figure IV.2. Upon applying Newton's laws and eliminating the constraint force at the fifth wheel, we obtain the set of governing nonlinear differential equations of motion.

$$-m_2(x_{1A}+x_{2A})\dot{r}_1 + (m_1+m_2)(Vr_1+\dot{v}_1) - m_2x_{2A}\ddot{\Gamma} = F_{y11}+F_{y12}+F_{y21} \tag{6}$$

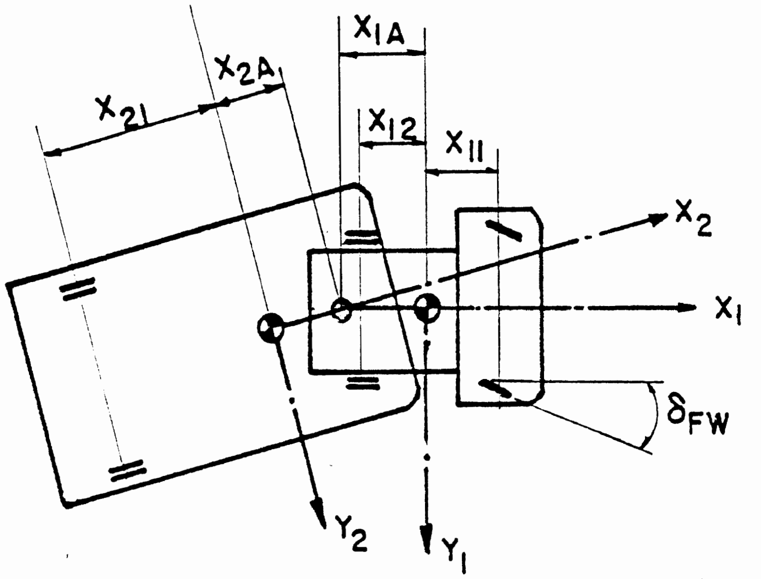
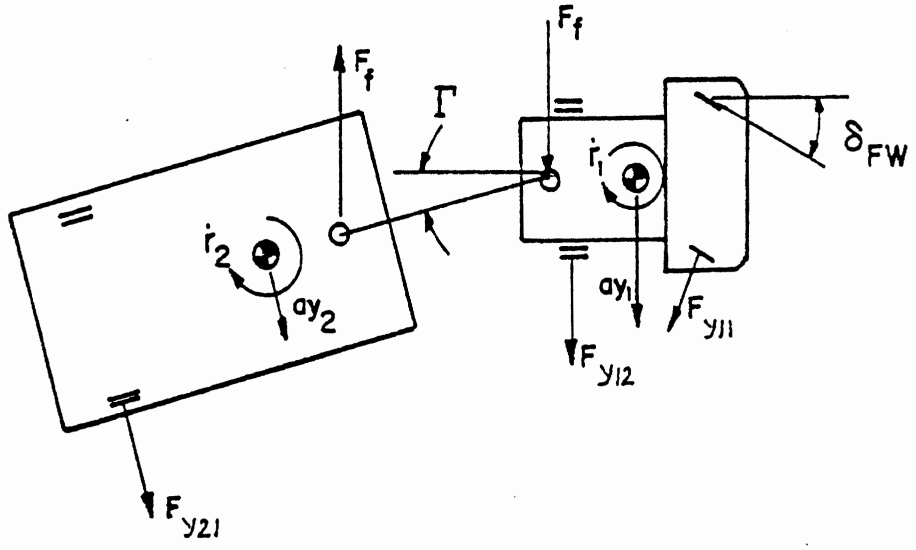


Figure IV.1



NOTE:

$$a_{y_1} = \dot{v}_1 + u r_1$$

$$a_{y_2} = \dot{v}_1 + u r_1 - X_{1A}\dot{r}_1 - X_{2A}\dot{r}_2$$

$$\dot{r}_2 = \dot{r}_1 + \ddot{\Gamma}$$

Figure IV.2

$$[I_1+I_2+m_2(x_{1A}+x_{2A})^2]\dot{r}_1 - m_2(x_{1A}+x_{2A})(Vr_1 + \dot{v}_1) + [I_2+m_2(x_{2A}+x_{1A})x_{2A}]\ddot{\Gamma}$$

$$= x_{11}F_{y11} - x_{12}F_{y12} - (x_{1A}+x_{2A}+x_{21})F_{y21} \qquad (7)$$

$$[I_2+m_2x_{2A}(x_{1A}+x_{2A})]\dot{r}_1 - m_2x_{2A}(\dot{v}_1 + Vr_1) + (I_2+m_2x_{2A}^2)\ddot{\Gamma} = -(x_{2A}+x_{21})F_{y21}$$

$$(8)$$

In the steady state $\dot{v}_1$, $\dot{r}_1$, $\dot{\Gamma}$, and $\ddot{\Gamma}$ are zero and (6), (7), and (8) reduce to equations of equilibrium, which can be solved for the steady-state cornering forces $\overline{F}_{y11}$, F_{y12}, and $\overline{F}_{y21}$:

$$\overline{F}_{y11} = \left[\frac{m_1x_{11}}{(x_{11}+x_{12})} + \frac{m_2x_{21}(x_{11}+x_{1A})}{(x_{11}+x_{12})(x_{2A}+x_{21})}\right]Vr \qquad (9)$$

$$\overline{F}_{y12} = \left[\frac{m_2x_{12}}{(x_{11}+x_{12})} + \frac{m_2x_{21}(x_{12}-x_{1A})}{(x_{11}+x_{12})(x_{2A}+x_{21})}\right]Vr \qquad (10)$$

$$\overline{F}_{y21} = \frac{m_2x_{2A}}{x_{2A}+x_{21}} \cdot Vr \qquad (11)$$

Since the connection at the fifth wheel is a pin joint, permitting the trailer to pitch with respect to the tractor, the vertical loads carried by each axle can be expressed as:

$$\overline{F}_{z11} = \frac{m_1g\ x_{11}}{(x_{11}+x_{12})} + \frac{m_2g\ x_{21}(x_{11}+x_{1A})}{(x_{11}+x_{12})(x_{2A}+x_{21})} \qquad (12)$$

$$\overline{F}_{z12} = \frac{m_2g\ x_{12}}{(x_{11}+x_{12})} + \frac{m_2g\ x_{21}(x_{12}-x_{1A})}{(x_{11}+x_{12})(x_{2A}+x_{21})} \qquad (13)$$

$$\overline{F}_{z21} = \frac{m_2g\ x_{2A}}{(x_{2A}+x_{21})} \qquad (14)$$

Substituting (12), (13), and (14) in (9), (10), and (11), respectively, we find

$$\frac{\overline{F}_{y11}}{\overline{F}_{z11}} = \frac{\overline{F}_{y12}}{\overline{F}_{z12}} = \frac{\overline{F}_{y21}}{\overline{F}_{z21}} = \frac{Vr}{g} \tag{15}$$

IV.1.1 Linear Tire Characteristics. For the case where the tire characteristics can be assumed to be linear, the cornering forces can be expressed as:

$$\begin{aligned} F_{y11} &= -C_{\alpha 11}\alpha_{11} = -C_{\alpha 11}\left(\frac{(v_1+x_{11}r)}{V} - \delta\right) \\ F_{y12} &= -C_{\alpha 12}\alpha_{12} = -C_{\alpha 12}\ \frac{(v_1-x_{12}r)}{V} \\ F_{y21} &= -C_{\alpha 21}\alpha_{21} = -C_{\alpha 21}\left[\frac{(v_1-(x_{1A}+x_{2A}+x_{21})r)}{V} + \Gamma\right] \end{aligned} \tag{16}$$

Substituting the expressions for F_{y11}, F_{y12}, F_{y21} in (9), (10), and (11), respectively, we get:

$$\frac{(v_1+x_{11}r)}{V} - \delta = \frac{-\overline{F}_{z11}}{C_{\alpha 11}}\ \frac{Vr}{g} \tag{17}$$

$$\frac{(v_1-x_{12}r)}{V} = \frac{-\overline{F}_{z12}}{C_{\alpha 12}}\ \frac{Vr}{g} \tag{18}$$

$$\frac{v_1 + (x_{1A}+x_{2A}+x_{21})r}{V} + \quad = \frac{-\overline{F}_{z21}}{C_{\alpha 21}}\ \frac{Vr}{g} \tag{19}$$

Equations (17) and (18) imply that:

$$\delta - \frac{(x_{11}+x_{12})r}{V} = \left(\frac{\overline{F}_{z11}}{C_{\alpha 11}} - \frac{\overline{F}_{z12}}{C_{\alpha 12}}\right)\frac{Vr}{g} \tag{20}$$

Equations (18) and (19) imply that:

$$\Gamma - \frac{(x_{1A}+x_{2A}+x_{21}-x_{12})r}{V} = \left(\frac{\overline{F}_{z12}}{C_{\alpha 12}} - \frac{\overline{F}_{z21}}{C_{\alpha 21}}\right)\frac{Vr}{g} \tag{21}$$

Equations (20) and (21) can be written in the form,

$$\delta = \frac{L}{R} + U \cdot \frac{Vr}{g} \tag{22}$$

$$\Gamma = \frac{L_T}{R} + U_T \cdot \frac{Vr}{g} \tag{23}$$

where

U is the under- or oversteer gradient for the tractor, rad/g

U_T is the under- or oversteer gradient for the trailer, rad/g

IV.2 Basic Modes of Tractor-Semitrailer Limit Yaw Response [1]

Since the articulation angle is a measure of the difference in the yaw orientation of the tractor and trailer units, it is influenced by the directional behavior of the tractor as well as the trailer and serves as a good indicator of the steady turning behavior of the system as a whole. We can therefore examine the steady-state articulation angle gain, $\Gamma/\delta)_{ss}$, to inventory the limiting yaw response modes of behavior.

Dividing Equation (23) by (22) we get

$$\left.\frac{\Gamma}{\delta}\right)_{ss} = \frac{L_T/R + U_T \cdot V^2/Rg}{L/R + U \cdot V^2/Rg} = \frac{L_T + U_T \cdot V^2/g}{L + U \cdot V^2/g} \tag{24}$$

On examining (24) we find that, depending on the signs and magnitudes of U and U_T, five types of directional behavior are possible. Each of the cases is discussed below.

(1) $U > 0$ and $U_T > 0$

In this case the tractor and the trailer are both understeer. The articulation angle gain is finite and positive for all values of forward velocity, V, and the vehicle therefore does not exhibit any directional instability. A plot of the articulation angle gain, as a function of the forward velocity, V, is shown in Figure IV.3.

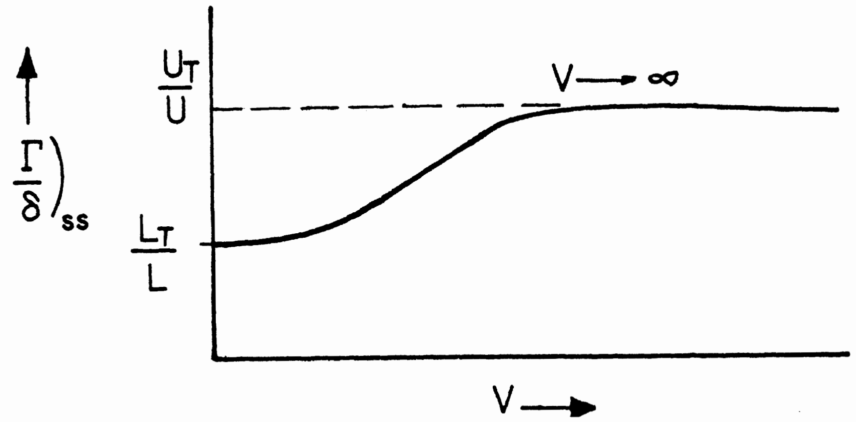


Figure IV.3

(2) $U > 0$, $U_T < 0$

In this case, the tractor is understeer, but the trailer is oversteer. We find that the articulation angle gain remains finite for all values of forward velocity, V, as shown in Figure IV.4.

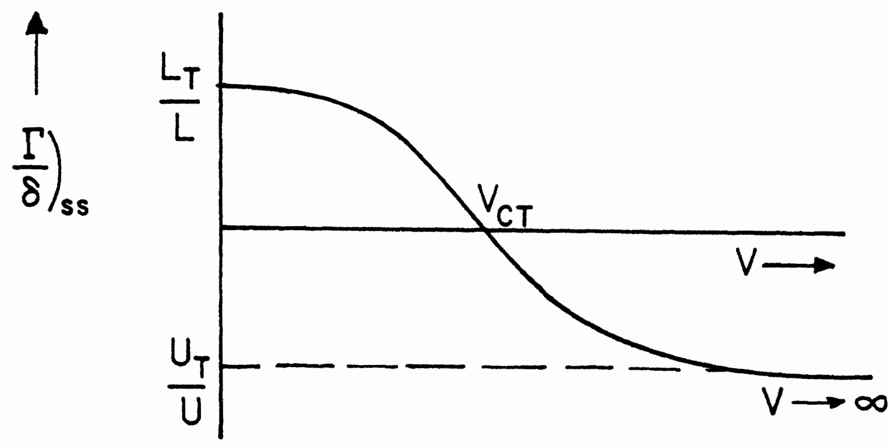


Figure IV.4

(3) $U < 0$, $U_T > 0$

In this case the tractor is oversteer while the trailer is understeer. When the tractor is oversteer, we find that the denominator in Equation (24) approaches zero as the velocity reaches the critical velocity, V_c, such that the articulation angle gain approaches infinity as shown in Figure IV.5. A divergent increase in the articulation angle causes the vehicle to fold up on the inside of the turn, creating a "tractor jackknife" type of instability.

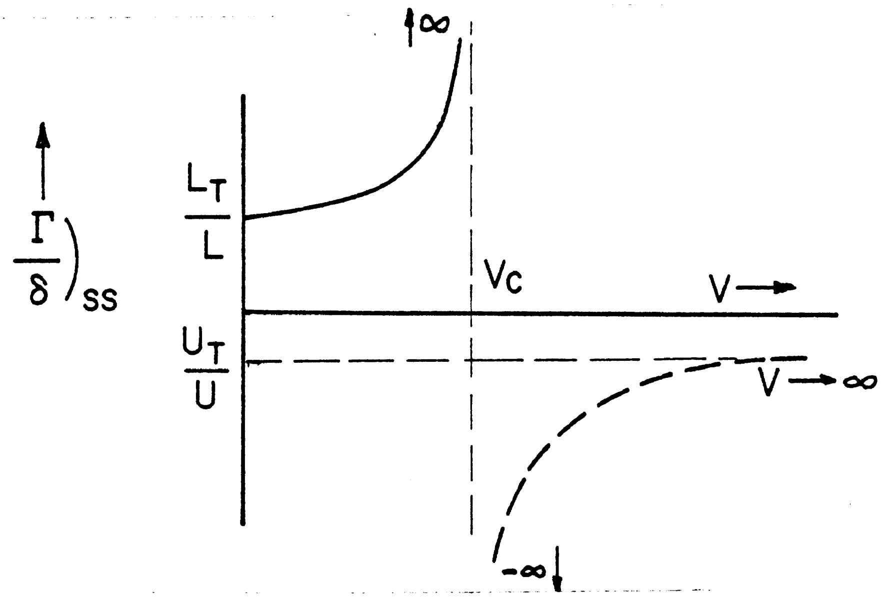


Figure IV.5

(4) $U < 0$, $U_T < 0$ and

$$\frac{|U_T|}{L_T} < \frac{|U|}{L} \qquad (25)$$

When the tractor and the trailer are both oversteer and the inequality (25) is satisfied, a steady turning behavior similar to that of Case (3) will be exhibited by the vehicle, and as shown in Figure IV.6, for velocities $V \geq V_c$ "tractor jackknifing" occurs.

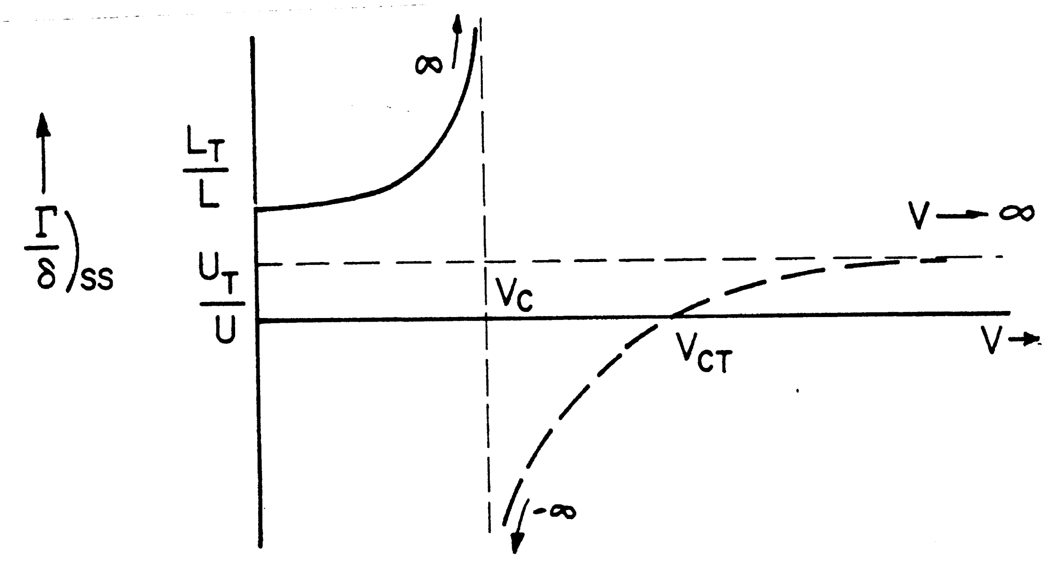


Figure IV.6

(5) $U < 0$, $U_T < 0$ and

$$\frac{|U_T|}{L_T} > \frac{|U|}{L} \qquad (26)$$

The tractor and trailer are oversteer in this case as well, but since the inequality (26) is satisfied, the articulation angle gain changes sign at V_{cT}. As the forward velocity approaches the critical velocity, V_c, the articulation angle gain approaches $-\infty$ and the vehicle is said to exhibit "trailer swing" type of directional instability, although, in practical terms, both vehicle elements are slewing in yaw, with the trailer's slew rate exceeding that of the tractor.

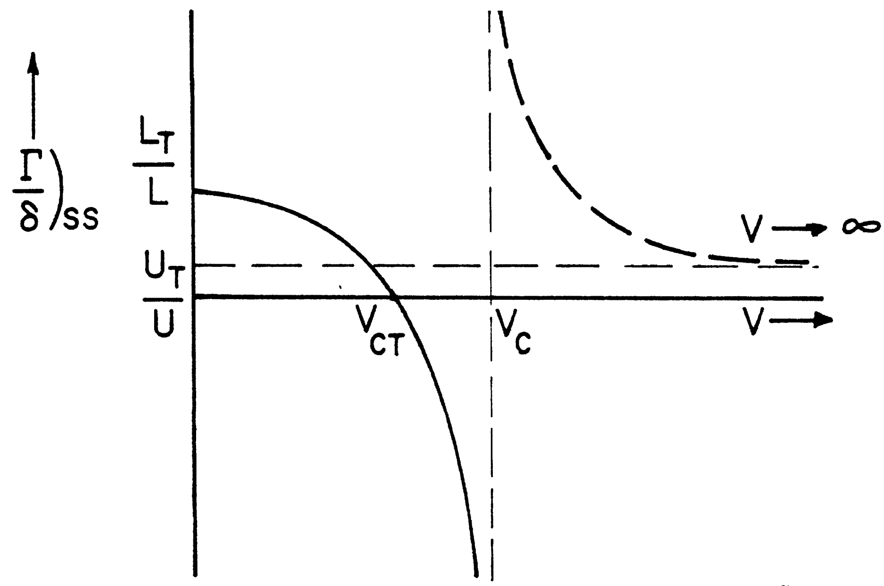


Figure IV.7

In summary, upon examining the five cases, we find that the steady turning behavior of the tractor ultimately determines the stability of the vehicle; i.e., the tractor must be operating with an oversteer response and the forward velocity must be in excess of the critical velocity, V_c, if a divergent type instability is to occur. The steady turning behavior of the trailer is of secondary importance in that it only determines the nature of the instability (i.e., whether the instability finally produces an articulation angle which is of the sort of "trailer swing" or "tractor jackknife).

Since an examination of the steady turning behavior of the tractor provides us with all the information needed to determine the static stability of a tractor-trailer combination, all further discussion will be limited to the steady turning performance of the tractor.

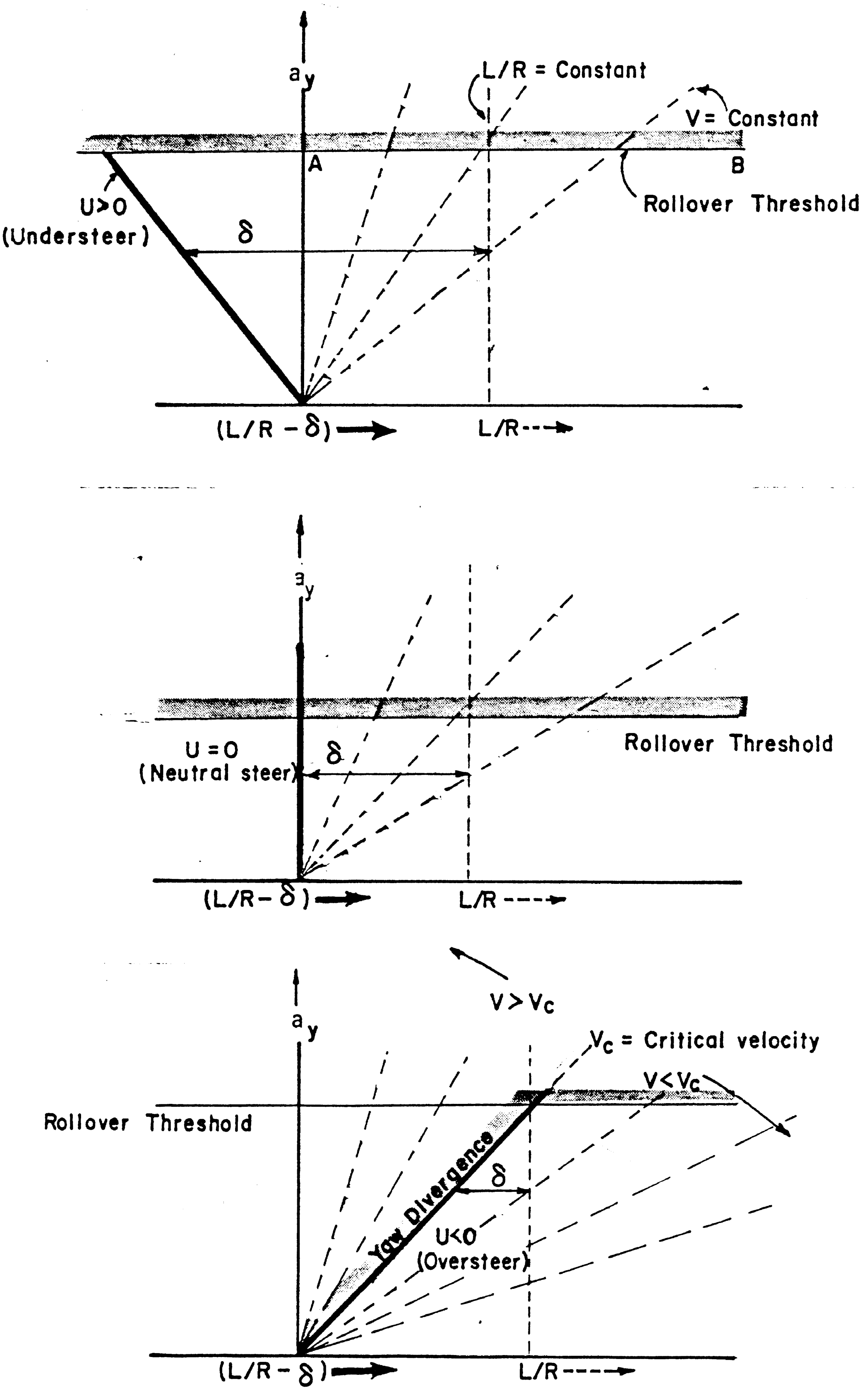
IV.3 The Handling Diagram

Given Equations (22) and (23), there is need for a generally useful means of presenting the basic features of vehicle yaw response. A particular presentation which will be used throughout this report is called the "handling diagram," first proposed by Pacejka [2] and found to be especially useful in this study for examining a vehicle's yaw stability while also locating the rollover threshold.

In Figure IV.8, the quantity $(L/R-\delta)$ is plotted against the lateral acceleration (V^2/R) to produce the handling diagrams which define each of three commonly-cited characteristics, namely,

$$\begin{aligned} &1) \quad U > 0 \quad \text{(understeer)} \\ &2) \quad U = 0 \quad \text{(neutral steer)} \\ &3) \quad U < 0 \quad \text{(oversteer)} \end{aligned} \tag{27}$$

Lines of constant velocity and constant path radius are superimposed on these diagrams using L/R as the abscissa. The lateral acceleration level corresponding to the rollover threshold is also marked. We see that the steer angle, δ, needed to execute a turn of given radius and velocity can be read directly off the handling diagram.



a_y
L/R = Constant
V = Constant
A
B
Rollover Threshold
U>0
(Understeer)
δ
(L/R − δ)
L/R
a_y
Rollover Threshold
U = 0
(Neutral steer)
δ
(L/R − δ)
L/R
V > Vc
a_y
Vc = Critical velocity
V < Vc
Rollover Threshold
Yaw Divergence
δ
U<0
(Oversteer)
(L/R − δ)
L/R

Figure IV.8

For an understeer vehicle, the steer angle needed to execute a turn of constant radius increases with increasing velocity, and the yaw rate gain, $r/\delta)_{ss}$, remains finite for all forward velocities. The understeer vehicle, therefore, cannot exhibit a yaw divergence type of directional instability; its steady turning performance is limited only by the possibility of a rollover. Hence, we find the vehicle to be stable for all maneuvers which result in lateral acceleration levels which are lower than the rollover threshold.

In the case of the neutral steer vehicle, the steer angle needed to negotiate a turn of fixed radius is independent of forward velocity and is determined only by the radius of the turn. For this vehicle, the yaw rate gain remains finite for all forward velocities and the steady turning performance is limited only by the possibility of a rollover.

For an oversteer vehicle, the steer angle decreases with increasing velocity. As the velocity approaches the "critical velocity," V_c, the δ level needed for any turn diminishes toward zero and the yaw rate gain goes to infinity. The vehicle therefore is said to be statically unstable or "yaw divergent" for all $V \geq V_c$. For single unit vehicles, such as passenger cars, this divergent type of directional instability results in a spinout. For tractor-trailer vehicles, depending on the distribution of cornering stiffness, two types of divergent behavior are possible: (1) tractor jackknife - an unstable response which results in an exponential growth of the articulation angle with the vehicle "folding up" into the inside of the turn and (2) trailer swing - an instability which results in the trailer swinging out of the turn and the vehicle folding up to the outside of the turn. Either of these unstable phenomena can ultimately result in a roll over.

It should be noted that oscillatory-type directional instabilities are at least <u>theoretically</u> possible for tractor-trailer vehicles. Such instabilities are due to dynamic interactions and are not revealed by a static analysis. A perturbation analysis reveals the possibility of oscillatory- and divergent-type instabilities. Since the oscillatory modes of typical commercial tractor-trailer vehicles are well damped, the only type of directional instability that can possibly be exhibited by a practical commercial tractor-trailer vehicle is the monotonically divergent type. The rest of this appendix, therefore, would deal only with this divergent type of directional instability.

IV.4 Features of the Handling Diagram Describing the Response of the Nonlinear Tractor

During a steady turn, the slip angle established at an axle is, in general, a nonlinear function of (1) the lateral force that is generated at the axle and (2) the amount of side-to-side load transfer that takes place at that axle, i.e.,

$$\alpha_i = f_i(F_{y_i}, \text{ load transfer at axle } i) \quad i=1,2,3 \qquad (28)$$

From Equation (15) we know that, for the case of a two-axle tractor coupled to a single-axle trailer, the steady-state lateral force generated at an axle is directly proportional to the lateral acceleration of the turn. Therefore, rewriting Equation (15) we get

$$F_{y_i} = F_{z_i} a_y \quad i=1,2,3 \qquad (29)$$

The load transfer that takes place at an axle is also a function of the lateral acceleration of the turn and is influenced by such suspension properties as roll center height and roll stiffness.

Therefore, Equation (28) can be rewritten to show α_i simply as a function of lateral acceleration,

$$\alpha_i = f_i(a_y) \qquad (30)$$

In other words, the slip angle at each axle is uniquely determined by the severity of the turn and, in general, is a nonlinear function of the lateral acceleration of the turn. Hence, a handling diagram constructed using $((\alpha_1-\alpha_2), a_y)$ or $((L/R-\delta), a_y)$ as coordinates constitutes a unique curve which is independent of forward velocity, and can be used for studying the nonlinear steady turning behavior and stability over a range of forward velocities and turn radii.

Depending upon the cornering force properties of the tires mounted on the tractor front and rear axles and the amount of load transfer that takes place at each axle, any of three generic types of nonlinear steady turning behavior can commonly be expected, namely,

1) The tractor is understeer at low levels of lateral acceleration and is progressively more understeer as the lateral acceleration of the turn is increased.

Two handling diagrams which are representative of this type of behavior are shown in Figure IV.9. A vehicle whose steady turning behavior is described by either of these handling diagrams will not exhibit a divergent type of directional instability. In the case of handling curve (a), as the severity of the turn is increased, the vehicle arrives at a limit condition only by exceeding the rollover threshold. The handling diagram (b) results for the case of a vehicle whose front-tire cornering forces saturate at a lateral acceleration level "A" which is below the rollover threshold. The steady turning performance of such a vehicle is therefore limited by the characteristics of the front tires such that the vehicle "plows out" of the turn.

2) The tractor is understeer at low levels of lateral acceleration but suffers a transition to oversteer at higher levels of lateral acceleration.

A handling diagram which is representative of this type of steady turning behavior is shown in Figure IV.10. Since the vehicle changes to an oversteer behavior as the lateral acceleration level is increased, it is possible for the steady turning performance to be limited by the onset of directional instability at acceleration levels which are lower than the rollover threshold. For a vehicle exhibiting nonlinear handling

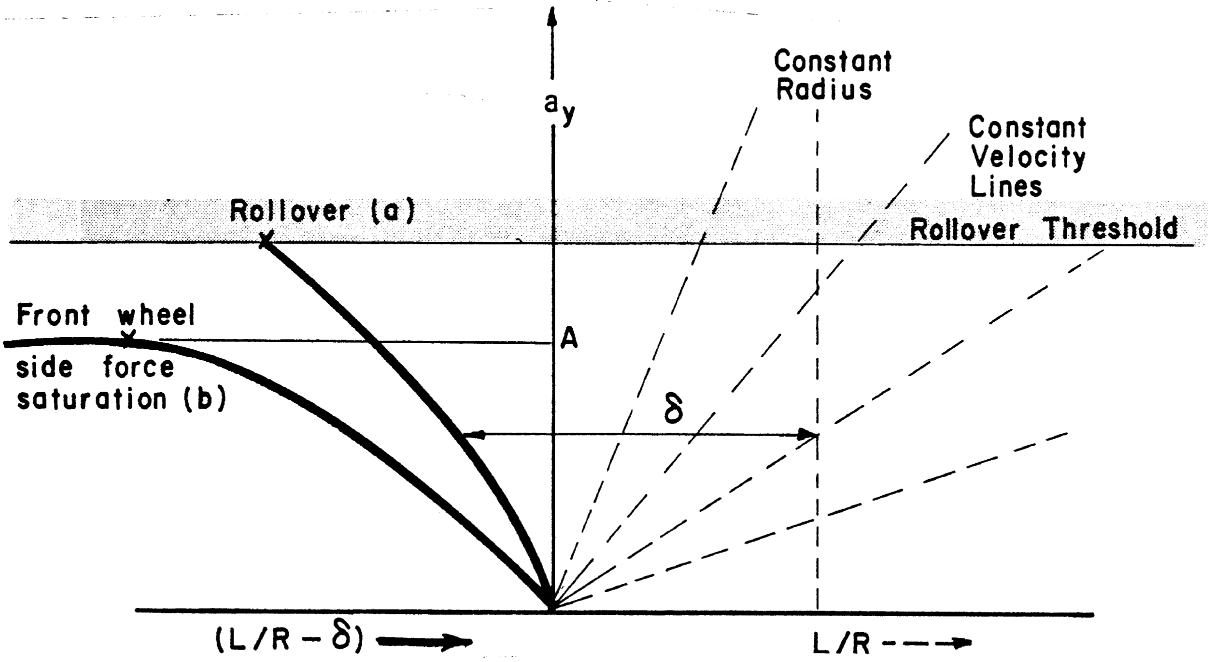


Figure IV.9

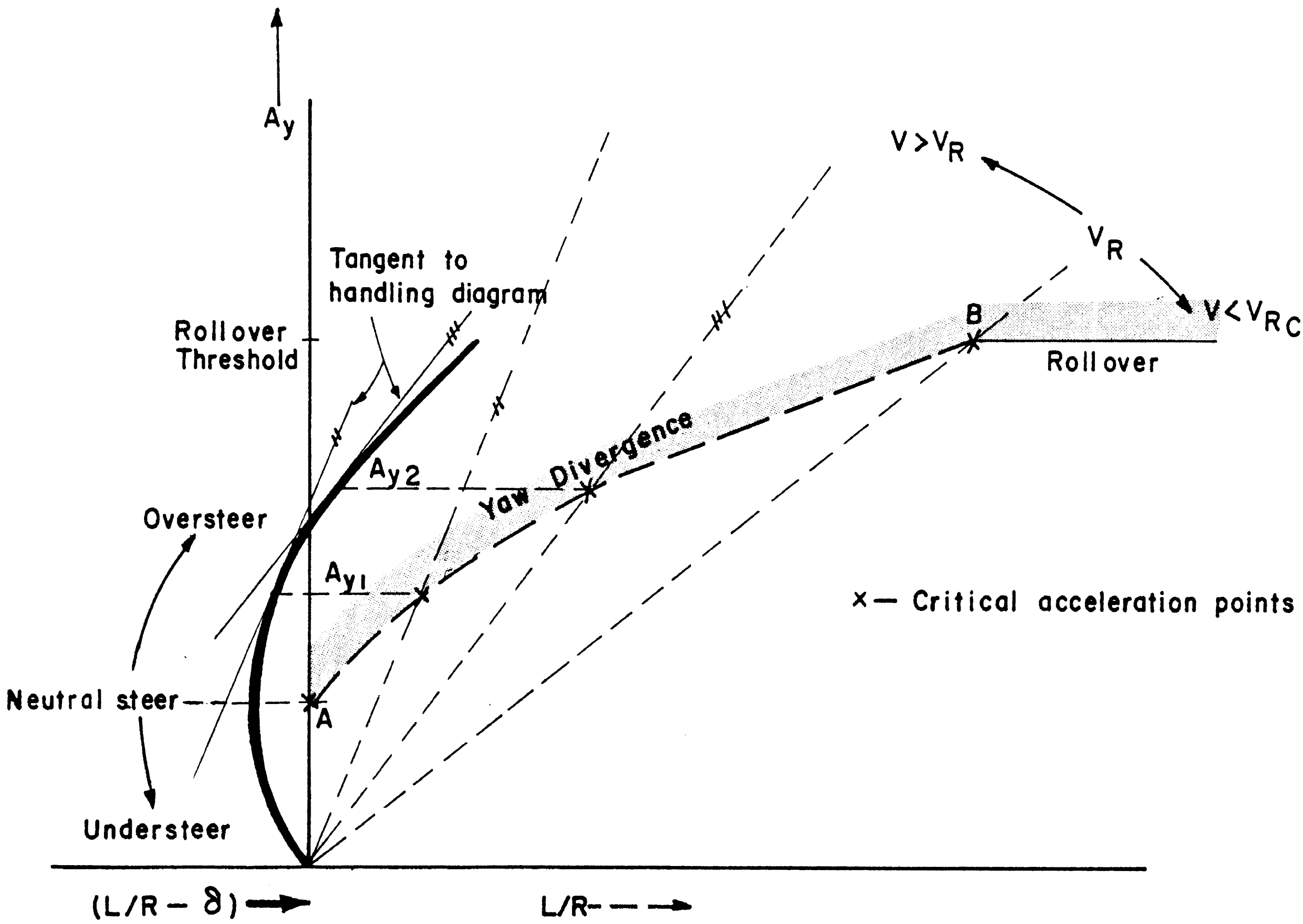


Figure IV.10

behavior, the criterion for the directional stability of a steady turn is given by the inequality

$$\frac{\partial(\delta)}{\partial a_y} > 0 \qquad (31)$$

(Note: The above condition can be derived from the linear differential equations which describe the motion of the tractor-semitrailer for small perturbations about a steady state.) The inequality (31) can also be written as

$$\frac{\partial(L/R - \delta)}{\partial a_y} < L/V^2$$

or

$$\frac{\partial(a_y)}{\partial(L/R - \delta)} > V^2/L \qquad (32)$$

When the stability condition is expressed in the form of the inequality (32), the left-hand side corresponds to the slope of the handling diagram and the right-hand side corresponds to the slope of the constant velocity line (which is superimposed on the handling diagram, using $(L/R, a_y)$ coordinates). Therefore, the condition for directional stability can also be stated as follows:

A two-axle tractor/single-axle trailer combination traveling with a forward velocity, V, is directionally stable (does not exhibit yaw divergence) at lateral acceleration levels for which the local slope of the handling diagram is steeper than the slope of the constant velocity line that corresponds to velocity, V .

Therefore, for each forward velocity, V_i, we can use the handling diagram to determine the "critical lateral acceleration" level, a_{y_i}, above which the vehicle exhibits yaw divergence. Upon connecting these critical acceleration points which are marked off on the constant velocity lines we can obtain a stability boundary in the $(L/R, a_y)$ coordinate system, the construction of which is shown in Figure IV.10. It can be seen that, for velocities less than V_R, the steady turning performance is limited by rollover. For velocities greater than V_R, the vehicle is yaw-stable only within that steady-state operating space lying beneath the line AB (which comprises an envelope of critical acceleration rates).

3) The tractor is oversteer at low levels of lateral acceleration and is increasingly oversteer as the lateral acceleration level of the turn is increased.

As shown in Figure IV.11a and IV.11b, two kinds of limit behaviors are possible and directional instability can occur in both cases. The criteria for directional stability is once again the satisfaction of the condition expressed in Equation (32).

A vehicle which exhibits a handling character which is similar to that shown in Figure IV.11a, is directionally stable for all velocities less than V_R, and its steady turning performance for such velocities is limited only by the occurrence of rollover at lateral acceleration levels which exceed the rollover threshold. For velocities greater than V_R, the steady turning performance is limited by the onset of yaw divergence and the "directional stability boundary" A-B can be constructed in a manner similar to that shown in Figure IV.10.

In the case of the handling behavior shown in Figure IV.11b, the cornering force generated at the tractor rear axle saturates at a lateral acceleration level C' which is below the rollover threshold and the steady turning performance is, at all forward velocities, limited by the occurrence of directional instability. (Note: the analysis is not valid for a maneuver in which the forward velocity is very small and lateral accelerations high. In such maneuvers, the front-wheel angles and articulation angles tend to be large and the geometric linearity assumptions made in this analysis lead to considerable errors.)

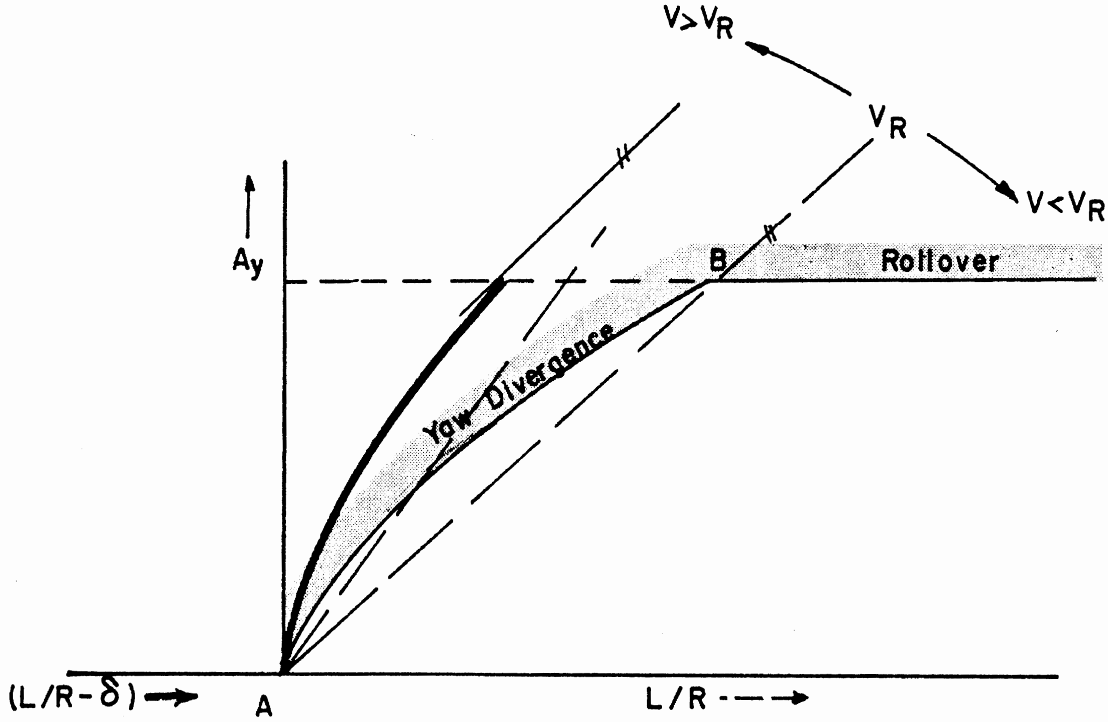


Figure IV.11a

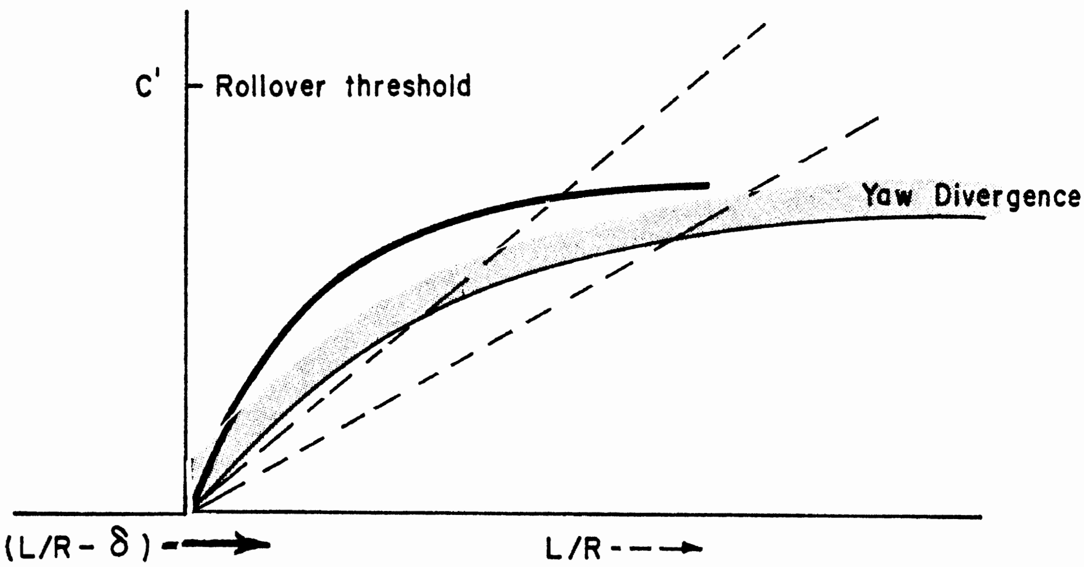


Figure IV.11b

IV.5 Influence of Tandem Axles on the Steady Turning Behavior of Tractor-Semitrailers

In this section, the steady turning behavior of a tractor-trailer combination consisting of a single-axle trailer and a three-axle tractor (a tractor which has a single front axle and tandem rear axles) is analyzed in order to illustrate the influence of tandem axles on steady turning behavior. A plan view of the vehicle is shown in Figure IV.12. The simplifying assumptions made in analyzing the steady turning behavior of the two-axle tractor/single-axle trailer are used in this analysis as well.

The kinematic relationships between the slip angles and the motion variables are as follows:

$$\alpha_{11} = \frac{(v_1 + x_{11}r)}{V} - \delta \tag{33}$$

$$\alpha_{12} = \frac{(v_1 - x_{12}r)}{V} \tag{34}$$

$$\alpha_{13} = \frac{(v_1 - x_{13}r)}{V} \tag{35}$$

$$\alpha_{21} = \frac{v_1 - (x_{1A}+x_{2A}+x_{21})r}{V} + \Gamma \tag{36}$$

also

$$\alpha_{12} - \alpha_{13} = \frac{\Delta}{R} \tag{37}$$

$$\left[\alpha_{11} - \frac{(\alpha_{12}+\alpha_{13})}{2}\right] = \frac{\left[x_{11} + \frac{(x_{12}+x_{13})}{2}\right]r}{V} - \delta$$

$$= \frac{L}{R} - \delta \tag{38}$$

and

$$\left[\frac{\alpha_{12} + \alpha_{13}}{2} - \alpha_{21}\right] = \frac{L_T}{R} - \Gamma \tag{39}$$

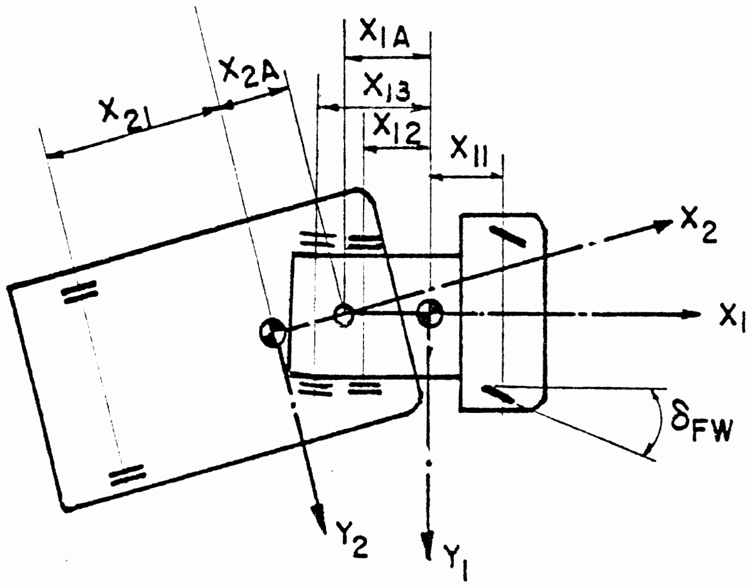


Figure IV.12

where

- R is the turn radius = V/r
- Δ is the longitudinal distance between the tandem axles, also called the tandem spread
- L is defined as the tractor wheelbase, which is the longitudinal distance from the tractor front axle to the midpoint of the tandem suspension
- L_T is defined as the trailer wheelbase, which is the longitudinal distance from the midpoint of the tractor tandem axles to the trailer axle.

The differential equations of motion are similar to those of the two-axle tractor/single-axle trailer combination except for the addition of a third lateral tire force at the third axle of the tractor. The differential equations are therefore:

$$-m_2(x_{1A}+x_{2A})\dot{r}_1 + (m_1+m_2)(Vr_1 + \dot{v}_1) - m_2x_{2A}\ddot{\Gamma} = F_{y11}+F_{y12}+F_{y13}+F_{y21} \tag{40}$$

$$[I_1+I_2+m_2(x_{1A}+x_{2A})^2]\dot{r}_1 - m_2(x_{1A}+x_{2A})[Vr_1 + \dot{v}_1] + (I_2+m_2(x_{2A}+x_{1A})x_{2A})\ddot{\Gamma}$$
$$= x_{11}F_{y11} - x_{12}F_{y12} - x_{13}F_{y13} - (x_{1A}+x_{2A}+x_{21})F_{y21} \tag{41}$$

$$[I_2+m_2x_{2A}(x_{1A}+x_{2A})]\dot{r}_1 - m_2x_{2A}(\dot{v}_1 + Vr_1) + [I_2+m_2x_{2A}^2]\ddot{\Gamma} = -(x_{2A}+x_{21})F_{y21} \tag{42}$$

In the steady state $\dot{v}$, $\dot{r}_1$, $\dot{\Gamma}$, $\ddot{\Gamma}$ are zero and the differential equations reduce to a set of equilibrium equations:

$$(m_1+m_2)a_{y1} = F_{y11} + F_{y12} + F_{y13} + F_{y21} \tag{43}$$

$$-m_2(x_{1A}+x_{2A})a_{y1} = x_{11}F_{y11} - x_{12}F_{y12} - x_{13}F_{y13} - (x_{1A}+x_{2A}+x_{21})F_{y21} \tag{44}$$

$$-m_2x_{2A}\,a_{y1} = -(x_{2A}+x_{21})F_{y21} \tag{45}$$

Equation (45) can be solved for F_{y21} as an explicit function of a_{y1} and upon substituting in (43) and (44), we would be left with three unknown quantities, F_{y11}, F_{y12}, and F_{y13}, and two equations (43) and (44). Therefore, unlike the case of the two-axle tractor (see Equation (15)), it is not possible to solve for the lateral forces (and eventually the slip angles) at the tractor axles as explicit functions of the lateral acceleration of the steady turn alone. The situation is analogous to a statically indeterminate beam supported at three points, where the load carried by each support is not only a function of the load acting on the beam, but also of other classic properties such as stiffness of the support, the rigidity of the beam in bending, etc.

The influence of tandem axles on steady turning response in both the linear and nonlinear regime of operation is discussed in the next two sections.

IV.6 Handling Diagram for the Tandem-Axle Tractor with Linear Tires

For maneuvers which result in low levels of lateral acceleration, the tire forces are linear functions of the slip angles. Therefore, for a steady turn:

$$F_{y11} = -C_{\alpha11}\alpha_{11} = -C_{\alpha11}\left[\frac{(v_1 + x_{11}r)}{V} - \delta\right] \tag{46}$$

$$F_{y12} = -C_{\alpha12}\alpha_{12} = -C_{\alpha12}\frac{(v_1 - x_{12}r)}{V} \tag{47}$$

$$F_{y13} = -C_{\ 13}{}_{\ 13} = -C_{\ 13}\frac{(v_1 - x_{13}r)}{V} \tag{48}$$

$$F_{y21} = -C_{\alpha 21}\alpha_{21} = -C_{\alpha 21}\left[\frac{(v_1 - (x_{1A}+x_{2A}+x_{21})r)}{V} + \Gamma\right] \qquad (49)$$

Substituting for the tire forces, F_{ij}, in terms of the slip angles, α_{ij}, in Equations (43), (44), and (45) and using the kinematic relationship (37), we can solve for the slip angles, α_{ij}, in terms of the motion variables V and γ. Upon carrying out the algebra, we get

$$\alpha_{11} = \frac{-m_1(C_{\alpha 12}x_{12} + C_{\alpha 13}x_{13})Vr - \frac{m_2 x_{21}}{(x_{2A}+x_{21})}[C_{\alpha 12}(x_{12}-x_{1A}) + C_{\alpha 13}(x_{13}-x_{1A})]Vr - C_{\alpha 12}\cdot C_{\alpha 13}\frac{(x_{13}-x_{12})^2}{R}}{C_{\alpha 11}[C_{\alpha 12}(x_{11}+x_{12}) + C_{\alpha 13}(x_{11}+x_{13})]} \qquad (50)$$

$$\alpha_{12} = \frac{-x_{11}m_1 Vr - \frac{(x_{11}+x_{1A})m_2 x_{21}Vr}{(x_{2A}+x_{21})} + C_{\alpha 13}\frac{(x_{13}-x_{12})(x_{11}+x_{13})}{R}}{C_{\alpha 12}(x_{11}+x_{12}) + C_{\alpha 13}(x_{11}+x_{13})} \qquad (51$$

$$\alpha_{13} = \frac{\left[-x_{11}m_1 Vr - \frac{(x_{11}+x_{1A})m_2 x_{21}Vr}{(x_{2A}+x_{21})} - \frac{C_{\alpha 12}(x_{13}-x_{12})(x_{11}+x_{12})}{R}\right]}{[C_{\alpha 12}(x_{11}+x_{12}) + C_{\alpha 13}(x_{11}+x_{13})]} \qquad (52)$$

$$\alpha_{21} = \frac{m_2 x_{2A}\ Vr}{(x_{2A}+x_{21})C_{\alpha 21}} \qquad (53)$$

We find that the slip angles at the tractor tires are not only influenced by the lateral acceleration of the turn (a_y), but also by the turn radius (R). The slip angles α_{11}, α_{12}, and α_{13} are related to the steer input by Equation (38), hence

$$\frac{L}{R} - \delta = \left[\alpha_{11} - \frac{\alpha_{12} + \alpha_{13}}{2}\right]$$

$$= \frac{\left[[x_{11}C_{11} - x_{12}C_{12} - x_{13}C_{13}]m_1 + [(x_{1A}+x_{11})C_{11} - (x_{12}-x_{1A})C_{12} - (x_{13}-x_{1A})C_{13}]\frac{m_2 x_{21}}{(x_{2A}+x_{21})}\right] Vr + \frac{(x_{13}-x_{12})}{R}\left[C_{11}C_{12}\frac{(x_{11}+x_{12})}{2} - C_{11}C_{13}\frac{(x_{11}+x_{13})}{2} - C_{12}C_{13}(x_{13}-x_{12})\right]}{C_{11}[C_{12}(x_{11}+x_{12}) + C_{13}(x_{11}+x_{13})]} \tag{54}$$

which is of the form

$$\delta = \frac{L}{R} + U\,Vr + \frac{B}{R} \tag{55}$$

where U and B are defined in Equation (54) and are quantities which depend on tire cornering stiffness, C_{ij}, and other vehicle parameters.

For steady turning maneuvers which are within the linear regime, the cornering stiffnesses, C_{ij}, are constant and hence U and B are also constant. Therefore, for linear operation, Equation (55) can be rewritten as

$$\delta = \frac{L_e}{R} + U \cdot Vr \tag{56}$$

where L_e = (L+B) and is called the effective wheelbase

U = the under- or oversteer gradient.

A handling diagram similar to that shown in Figure IV.13 can therefore be constructed using ($L_e/R - \delta$) and Vr as the abscissa and the ordinate, respectively.

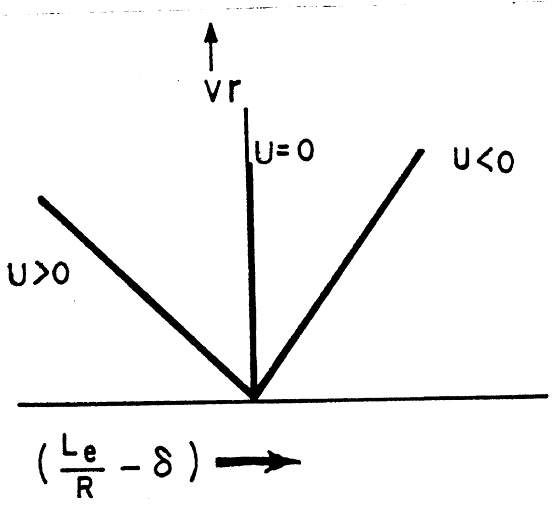


Figure IV.13

The discussion in Section IV.3 with regard to criterion for yaw divergence and rollover apply for the linear model of the three-axle tractor/single-axle trailer combination as well. The only difference being the effective wheelbase, L_e, is to be used in place of the tractor's actual wheelbase, L.

IV.7 Handling Diagram for the Tandem-Axle Tractor with Nonlinear Tires

For maneuvers which result in high levels of lateral acceleration and side-to-side load transfer, the lateral force generated by the tires is a nonlinear function of slip angle. Under such conditions, Equations (37), (43), (44), and (45) become a set of nonlinear algebraic equations in slip angles α_{11}, α_{12}, α_{13}, and α_{21} and cannot be solved except by numerical means. The solution of these equations would be of the general form

$$\alpha_{ij} = \phi_{ij}(a_y, 1/R) \tag{57}$$

since $a_y = V^2/R$.

The above equation can also be written as

$$\alpha_{ij} = \phi'_{ij}(a_y, 1/V^2) \tag{58}$$

but since

$$L/R - \delta = \alpha_{11} - \frac{\alpha_{12} + \alpha_{13}}{2}$$

then we see

$$L/R - \delta = \psi_{ij}(a_y, 1/V^2) \tag{59}$$

Hence, if a handling diagram relating $(L/R - \delta)$ with a_y were to be constructed, it would be sensitive to forward velocity, V. Unlike the case of a two-axle tractor/single-axle trailer combination, the treatment of a tractor with a tandem rear axle requires a family of handling diagrams, one for each forward velocity. Two such handling curves are shown in Figure IV.14 for forward speeds of 25 and 50 mph.

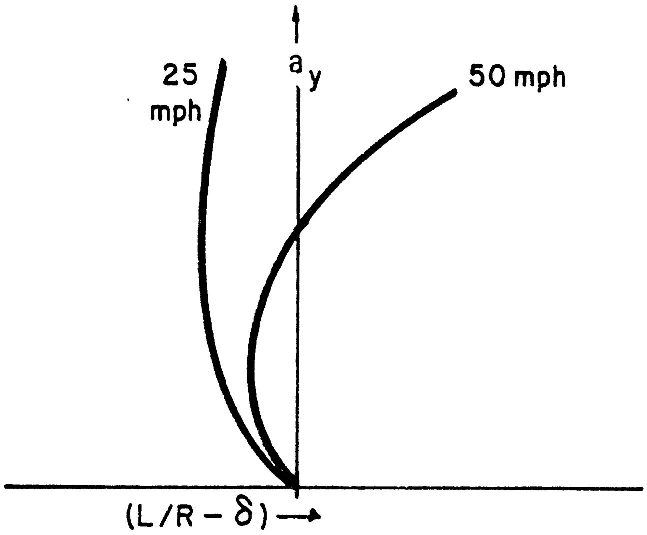


Figure IV.14

Since a unique handling diagram (valid for a range of forward velocities) can be constructed for a two-axle tractor/single-axle trailer combination, it is possible to make inferences about the under- or oversteer character and directional stability of the vehicle over an entire range of operating speeds and lateral acceleration levels by inspecting the results of steady turning experiments or simulations conducted at any single selected forward velocity. The existence of a family of handling curves for a three-axle tractor/single-axle trailer combination places a much greater burden for the gathering of data over a range of speeds in order to define vehicle response over the full operating range.

References

1. Fancher, P.S., Mallikarjunarao, C., Nisonger, R.L., Simulation of the Directional Response Characteristics of Tractor-Semitrailer Vehicles. Final Report, MVMA Project #1.39, March 1979.

2. Pacejka, H.B., Simplified Analysis of Steady-State Turning Behavior of Motor Vehicles. Vehicle System Dynamics, 2 (1973), pp. 161-204.

APPENDIX V

DETAILED RESULTS OF COMPUTERIZED PARAMETRIC SENSITIVITY STUDY

Results from the parametric sensitivity study (performed using the Phase II tractor-semitrailer model) are displayed here in the handling diagram format. Parameter values used in conducting the simulations are given in Appendix II.

First, handling diagrams are presented describing the sensitivity of vehicle response to roll stiffness distribution. This set of simulations was conducted using a ramp-type steer input, at a rate of 1.5 deg/sec. Note that the symbol, KRS1, which appears on the diagrams represents the value of auxiliary roll stiffness of the roll stabilizer on the tractor front axle (in-lb/deg). Each of the plots in this series describes the variation in handling curves which derives when KRS1 is varied, while the tractor frame stiffness parameter, TTC, is held fixed at the indicated value.

Next, the results from the parametric sensitivity study conducted on five typical tractor-semitrailer configurations are given. The matrix showing the parametric variation scheme is reproduced here in Figure V.1. The handling diagrams for each of the five basic vehicles are arranged in the same sequence as that shown from left to right along the bottom row of this figure, but are labeled using a continuous sequence of configuration numbers, from 1 to 240. The symbol, PZ, which appears in these diagrams corresponds to the height of the center of gravity of the payload above the ground (in). A ramp-type steer input of one deg/sec was used for this set of 240 runs.

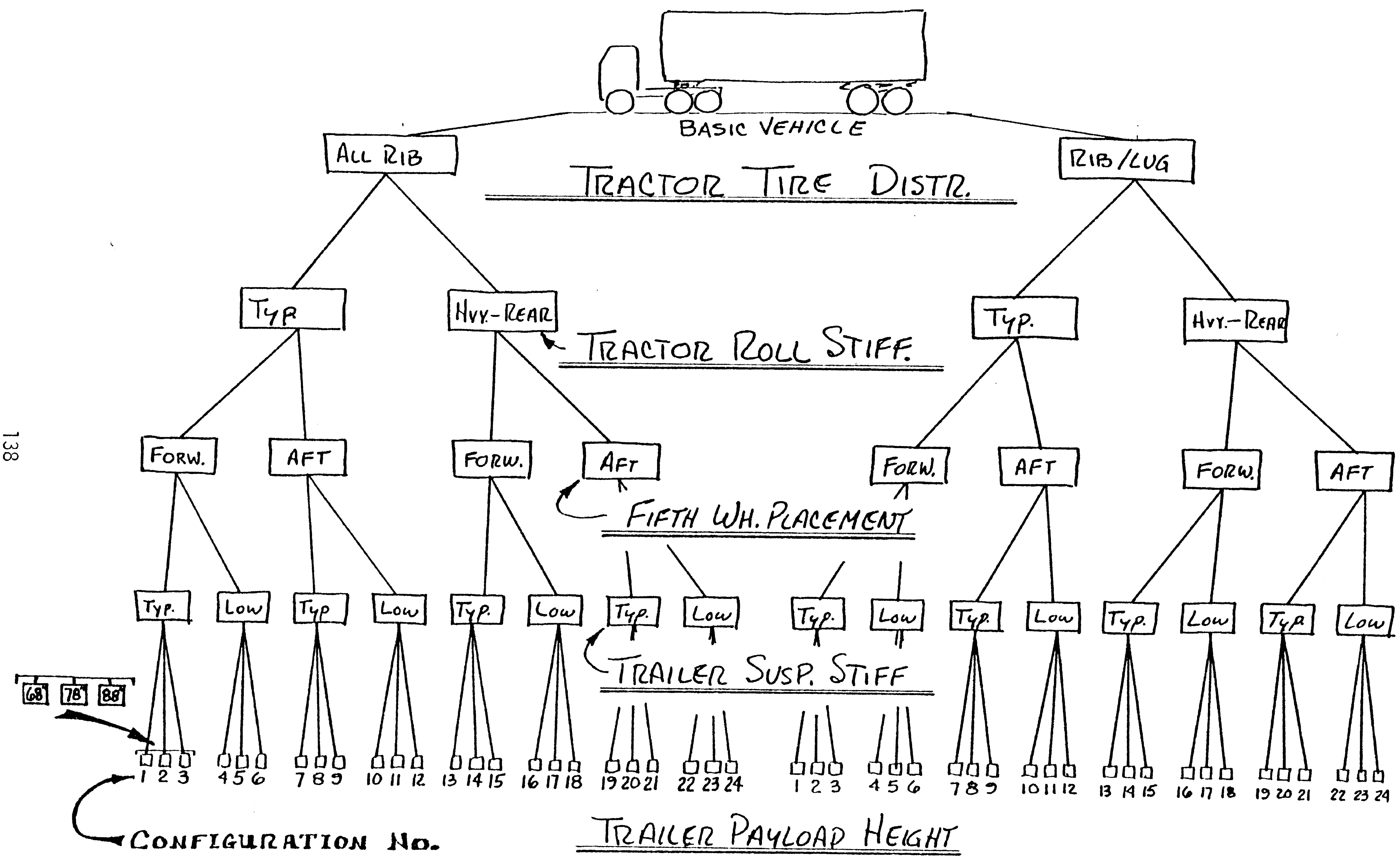
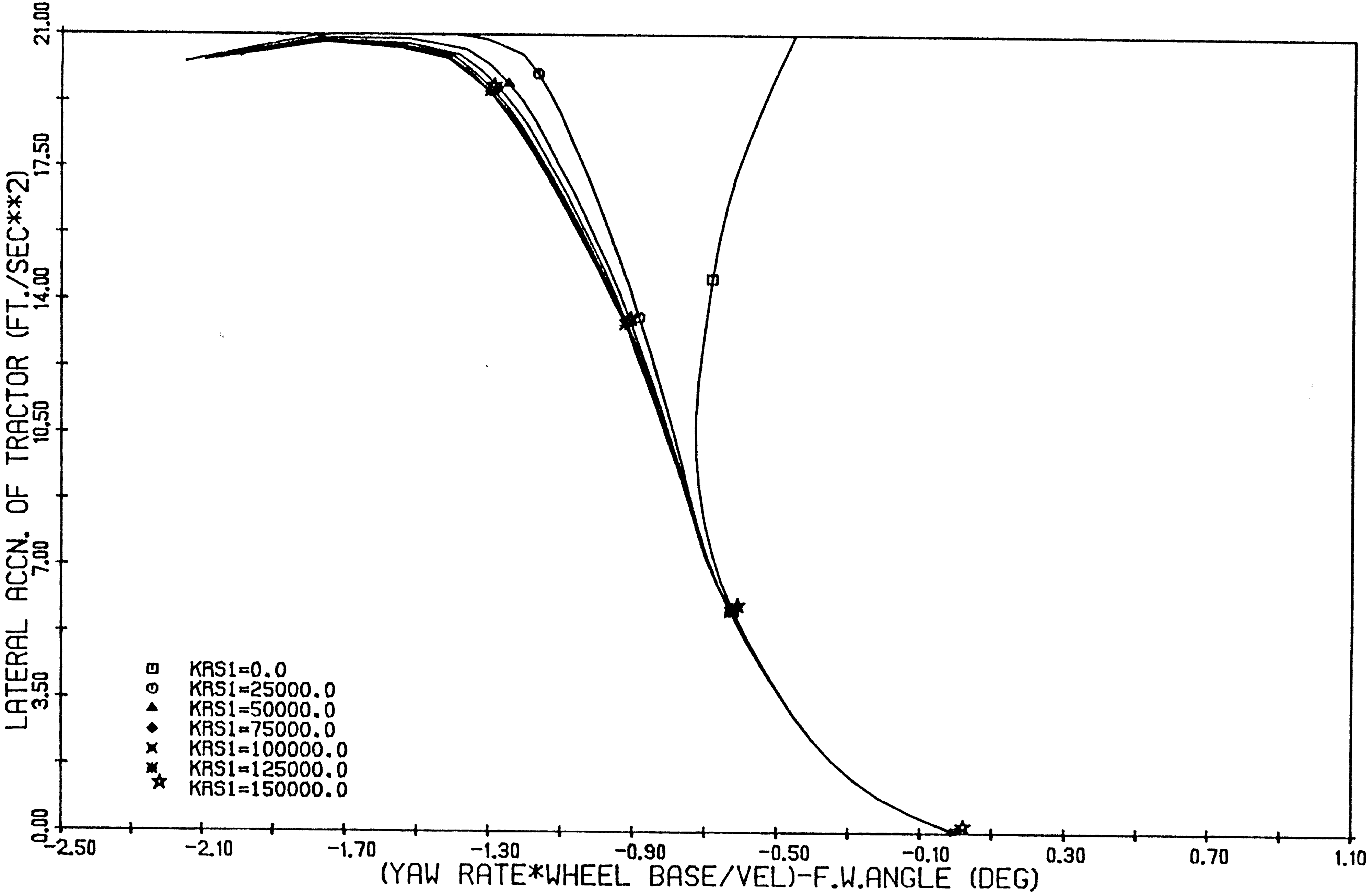
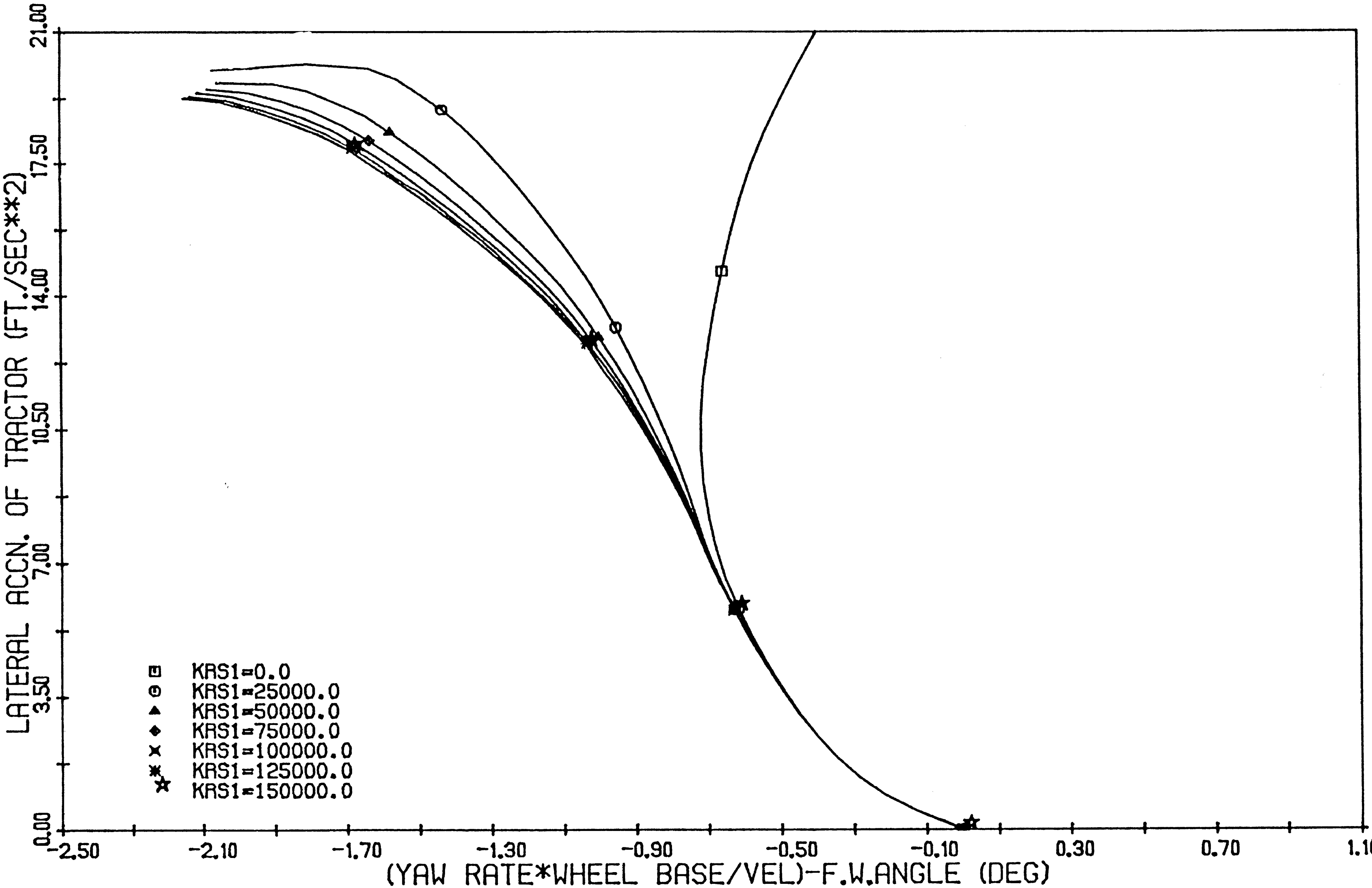

BASIC VEHICLE
ALL RIB
RIB/LUG
TRACTOR TIRE DISTR.
TYP
HVY.-REAR
TYP.
HVY.-REAR
TRACTOR ROLL STIFF.
FORW.
AFT
FIFTH WH. PLACEMENT
TYP.
LOW
TRAILER SUSP. STIFF
68"
78"
88"
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
CONFIGURATION NO.
TRAILER PAYLOAD HEIGHT

Figure V.1

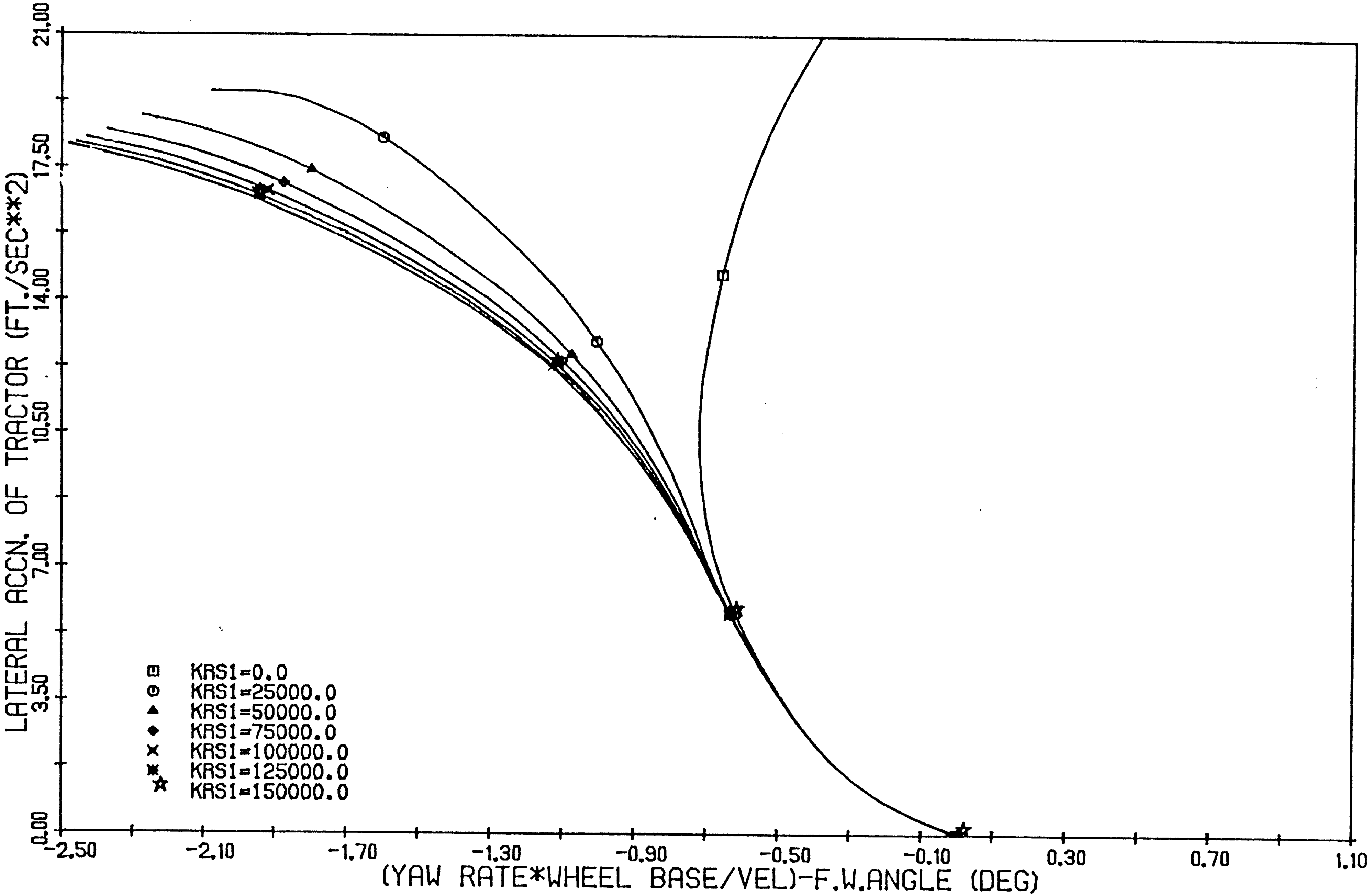
Handling diagrams showing sensitivity to changes in tractor auxiliary front roll stiffness and frame torsional stiffness.



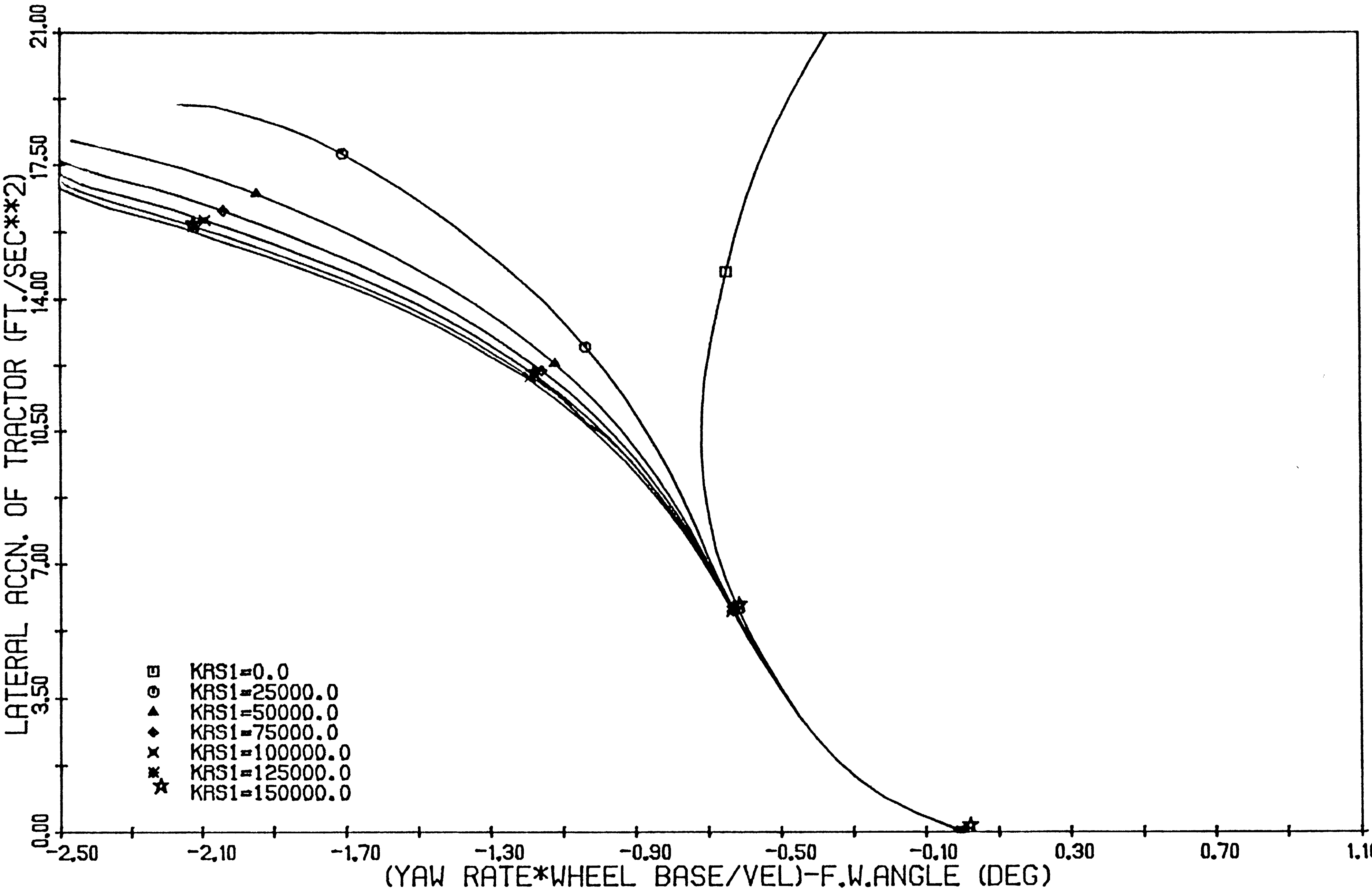
IHC-VAN TRAILER, RIB TIRES, FRAME 20000 IN.LB/DEG



IHC-VAN TRAILER, RIB TIRES, FRAME 40000 IN.LB/DEG



IHC-VAN TRAILER, RIB TIRES, FRAME 60000 IN.LB/DEG



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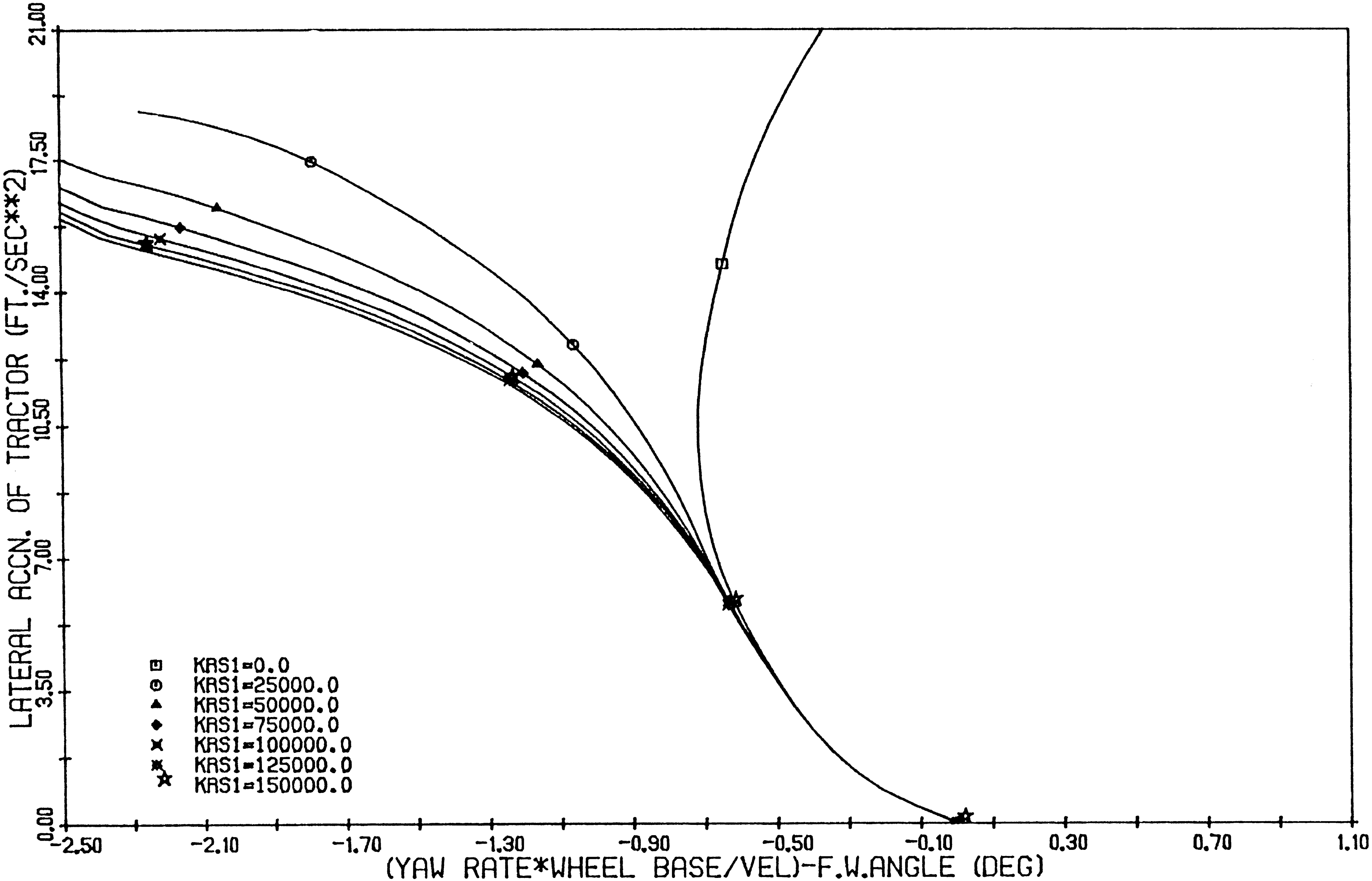
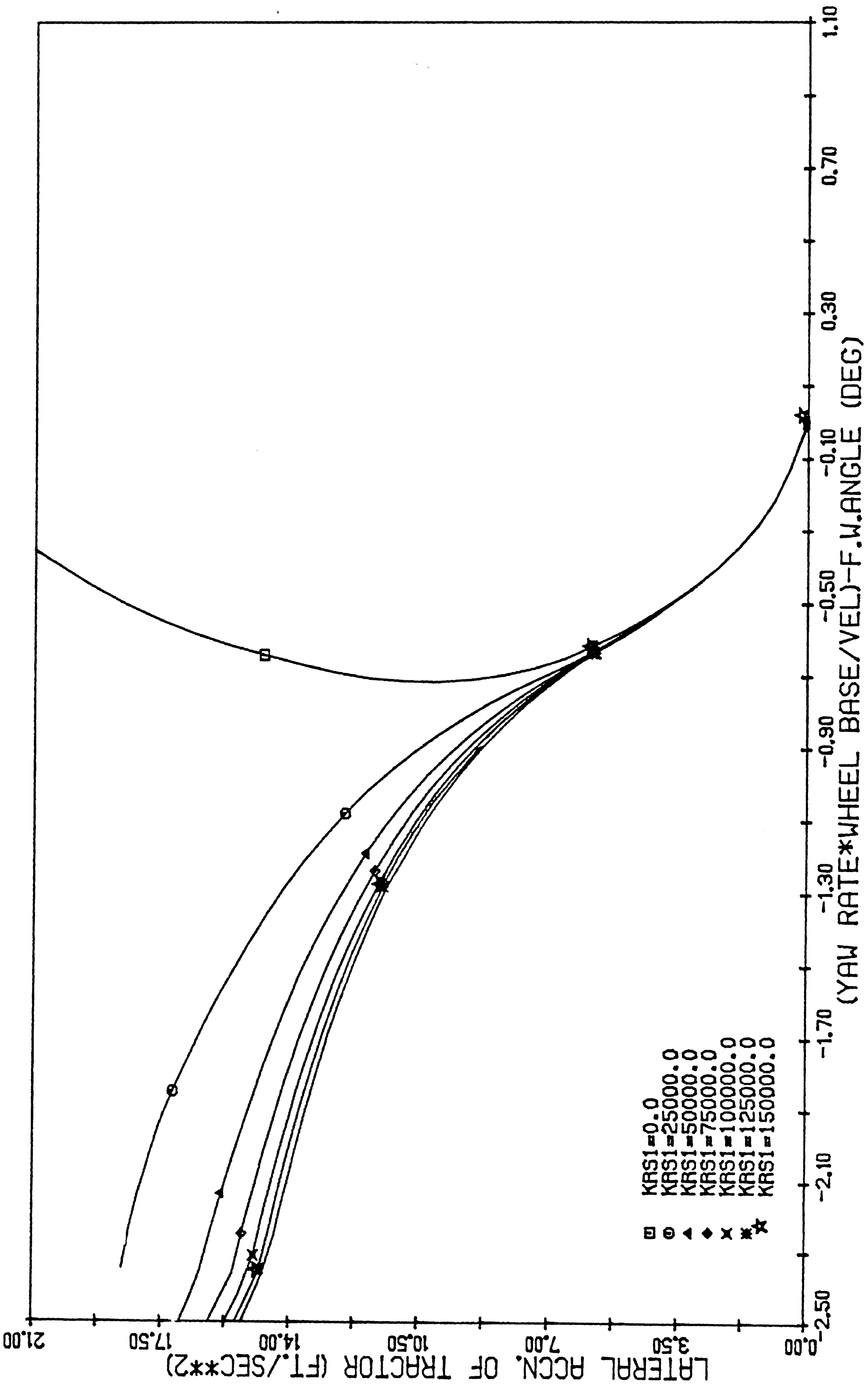
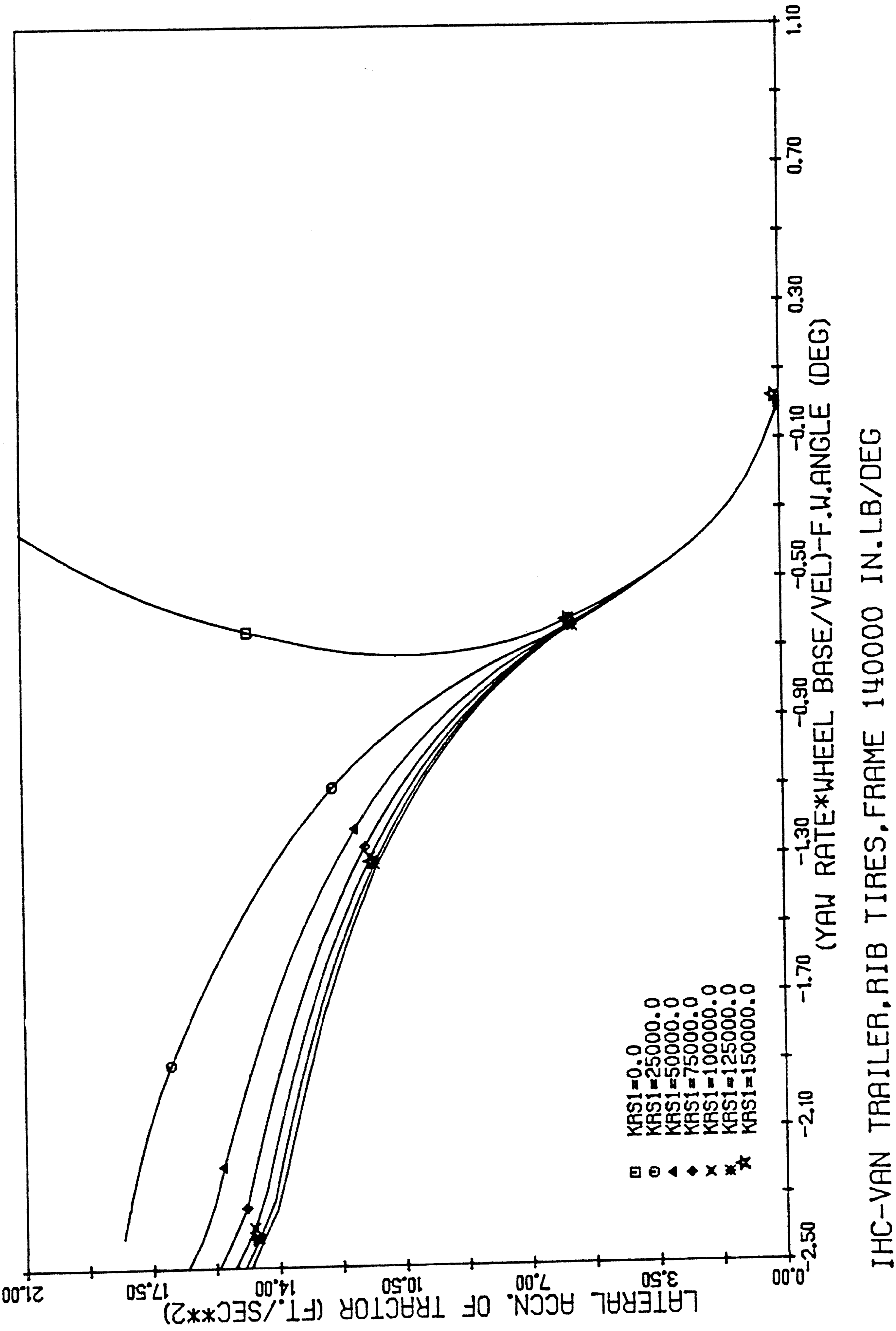
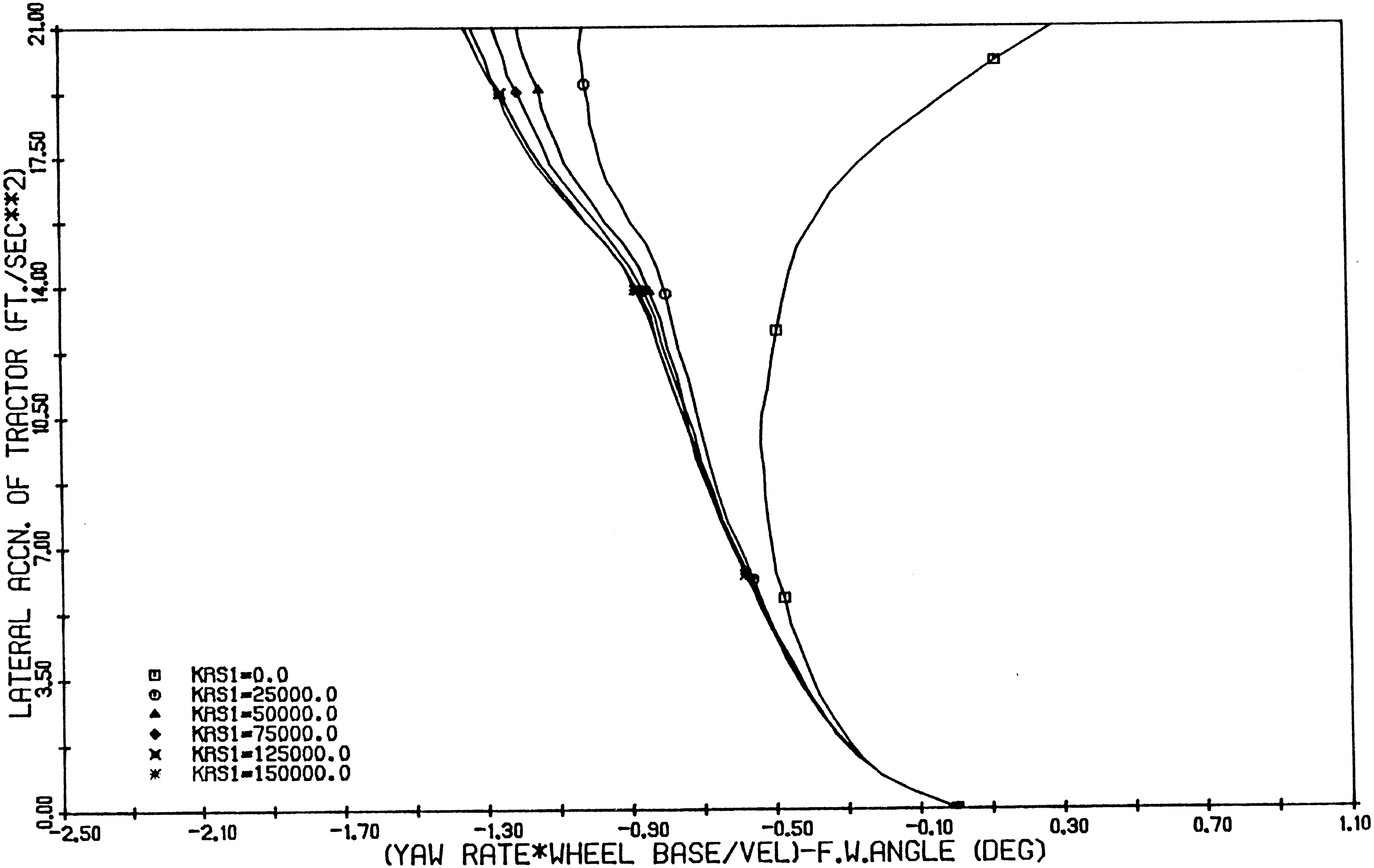


IHC-VAN TRAILER, RIB TIRES, FRAME 100000 IN.LB/DEG

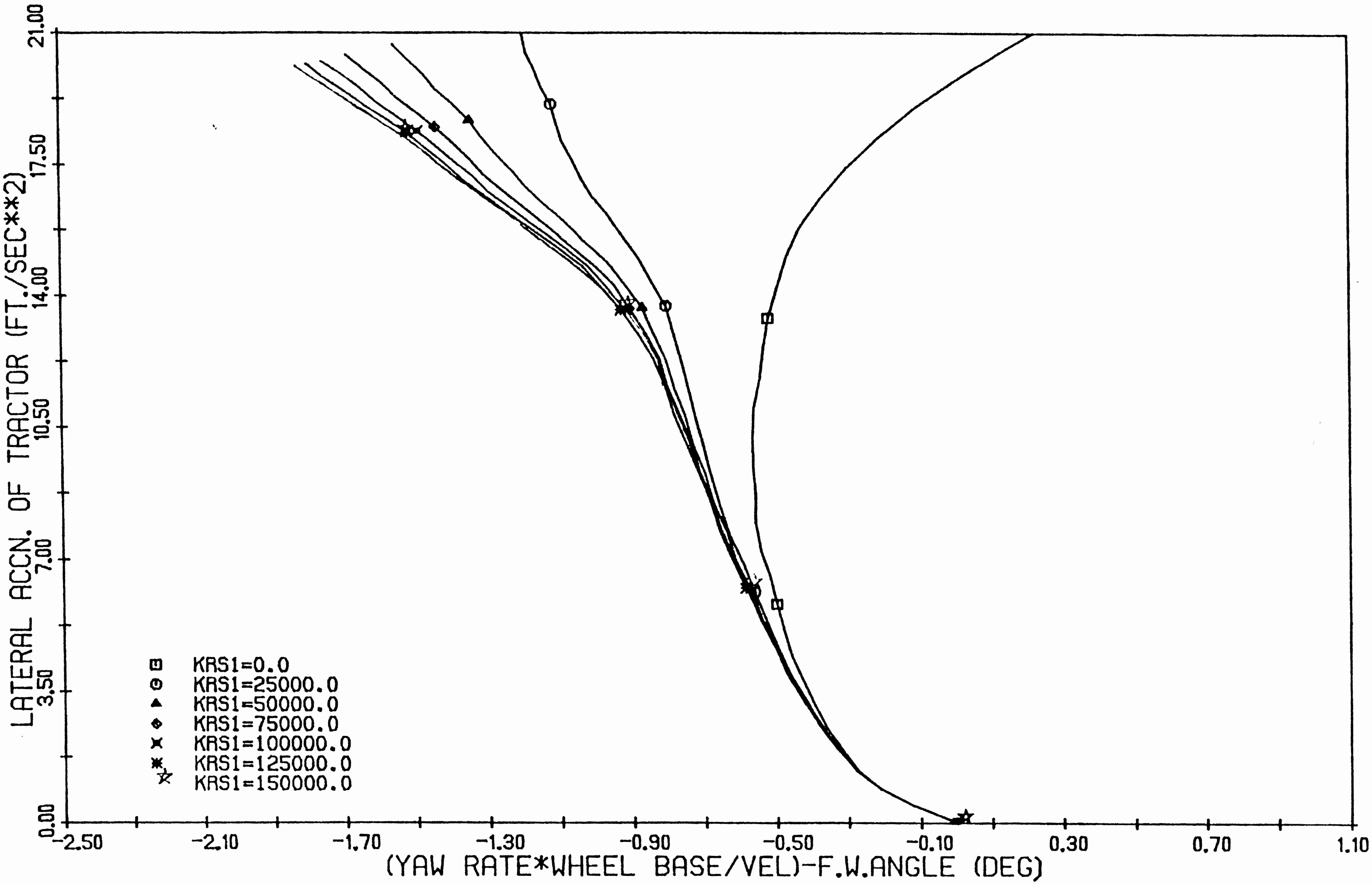


IHC-VAN TRAILER, RIB TIRES, FRAME 120000 IN.LB/DEG

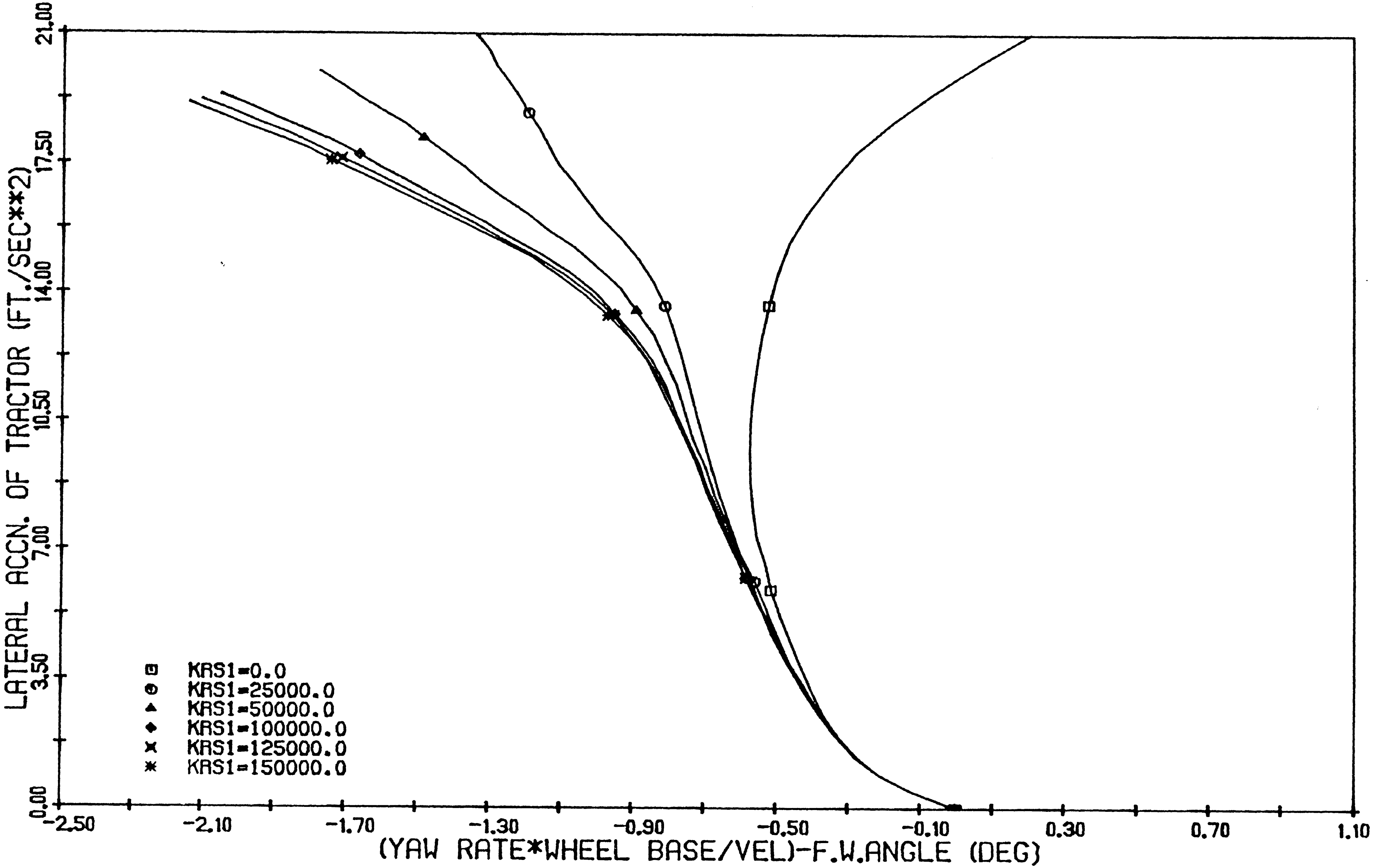

IHC-VAN TRAILER,RIB TIRES,FRAME 140000 IN.LB/DEG
(YAW RATE*WHEEL BASE/VEL)-F.W.ANGLE (DEG)
LATERAL ACCN. OF TRACTOR (FT./SEC**2)
-2.50
-2.10
-1.70
-1.30
-0.90
-0.50
-0.10
0.30
0.70
1.10
0.00
3.50
7.00
10.50
14.00
17.50
21.00
KRS1=0.0
KRS1=25000.0
KRS1=50000.0
KRS1=75000.0
KRS1=100000.0
KRS1=125000.0
KRS1=150000.0



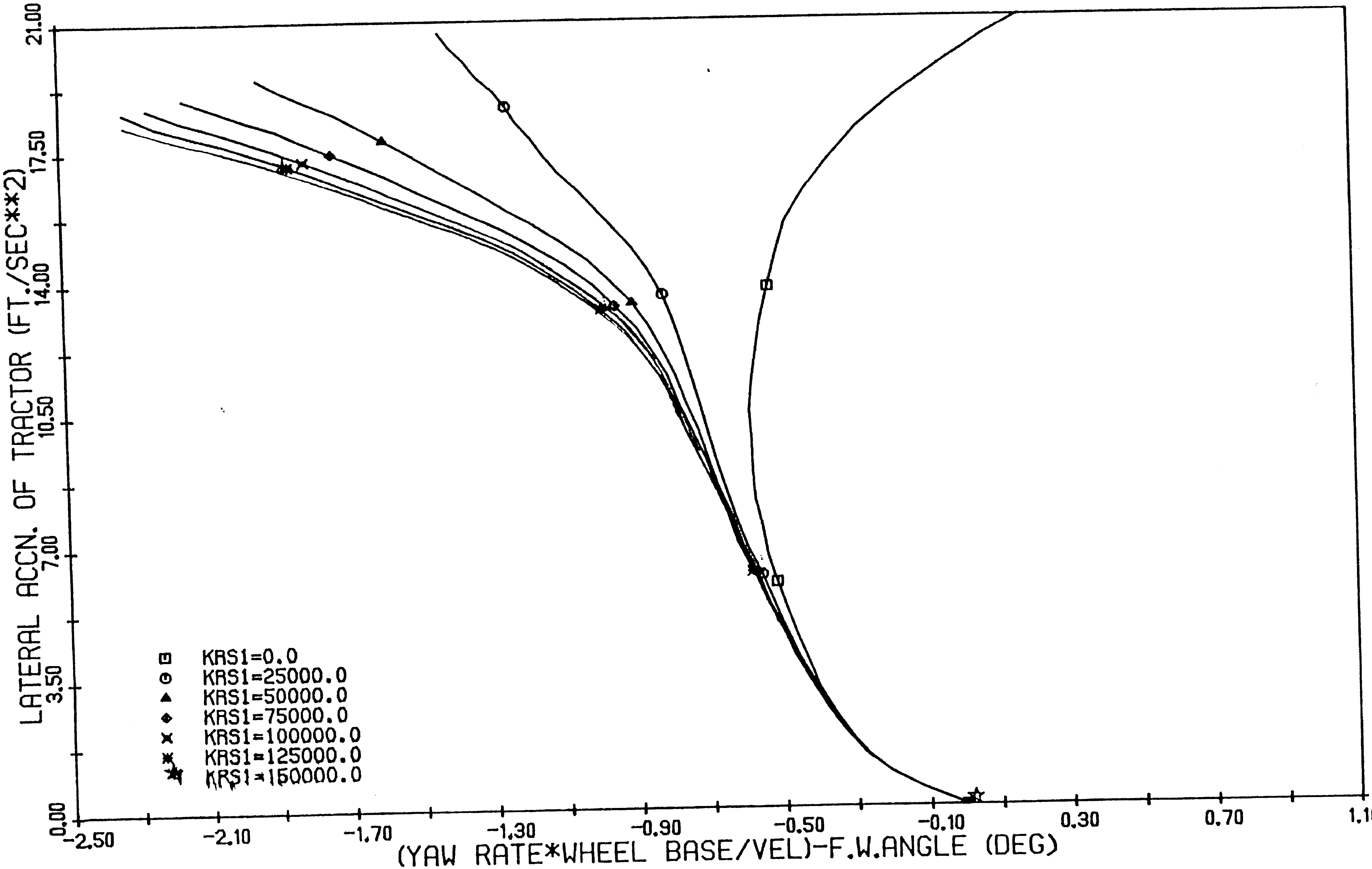
FORD-VAN TRAILER, RIB TIRES, FRAME 20000 IN.LB/DEG



FORD-VAN TRAILER, RIB TIRES, FRAME 40000 IN.LB/DEG



FORD-VAN TRAILER, RIB TIRES, FRAME 60000 IN.LB/DEG



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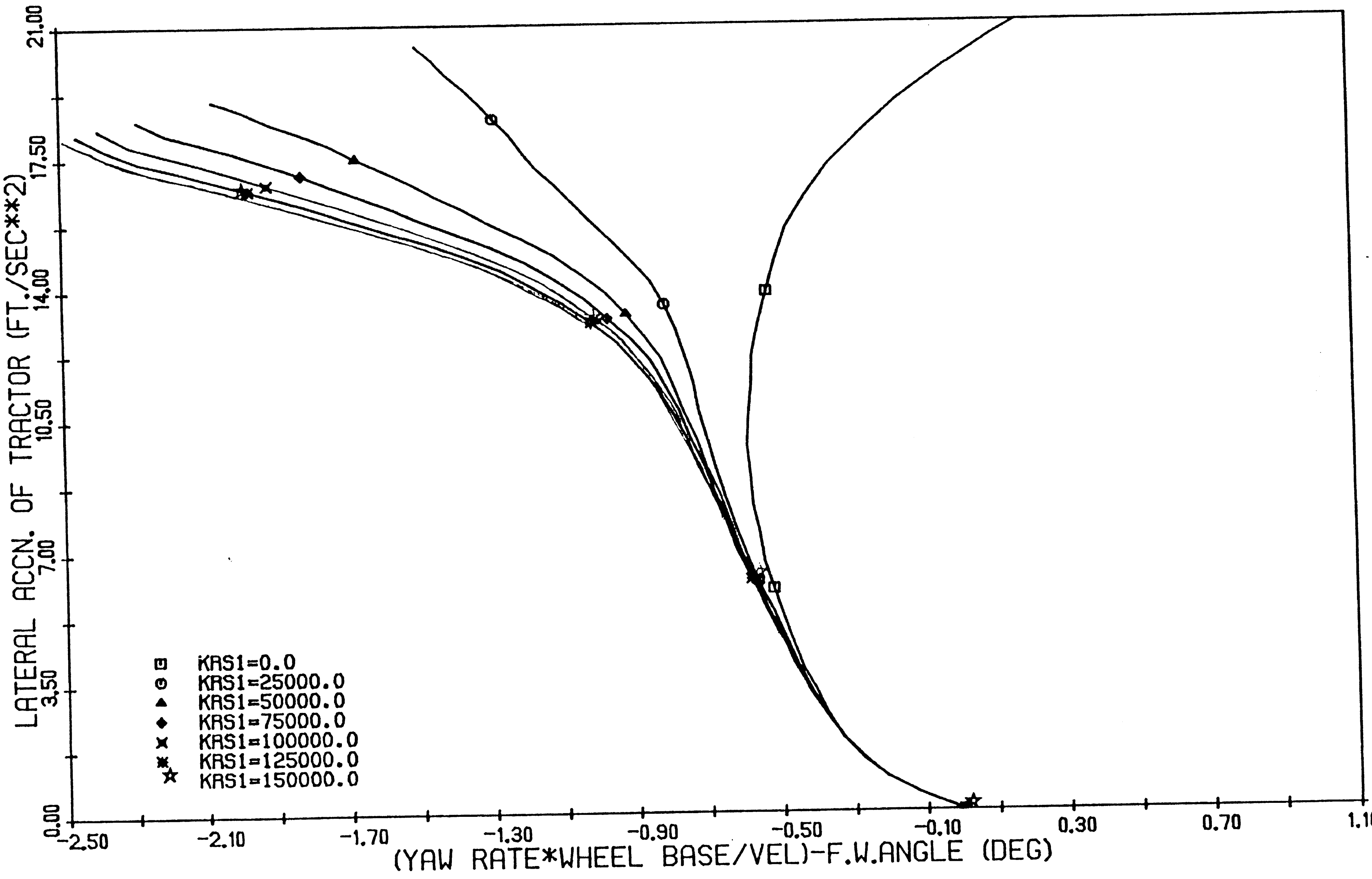
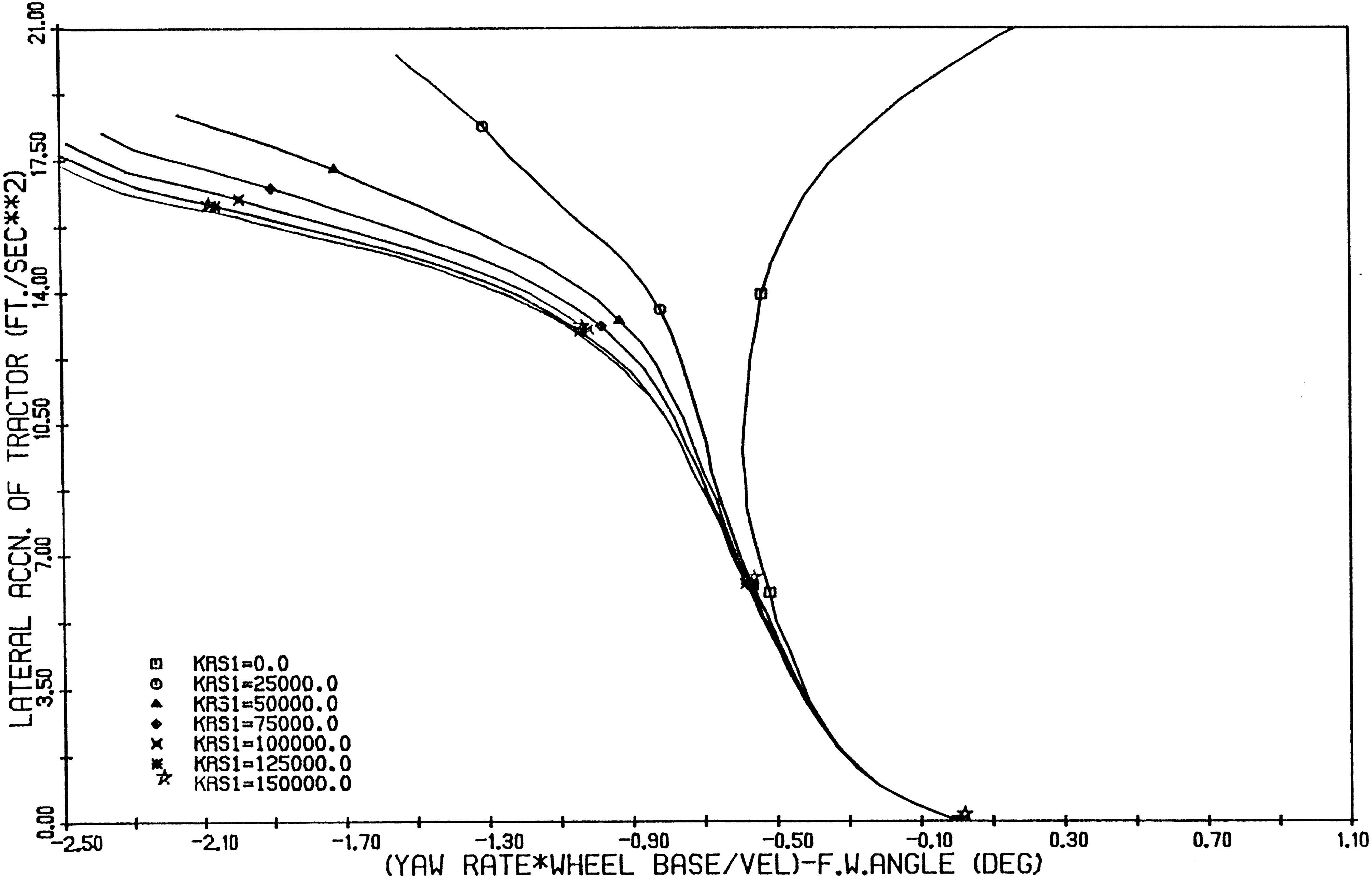
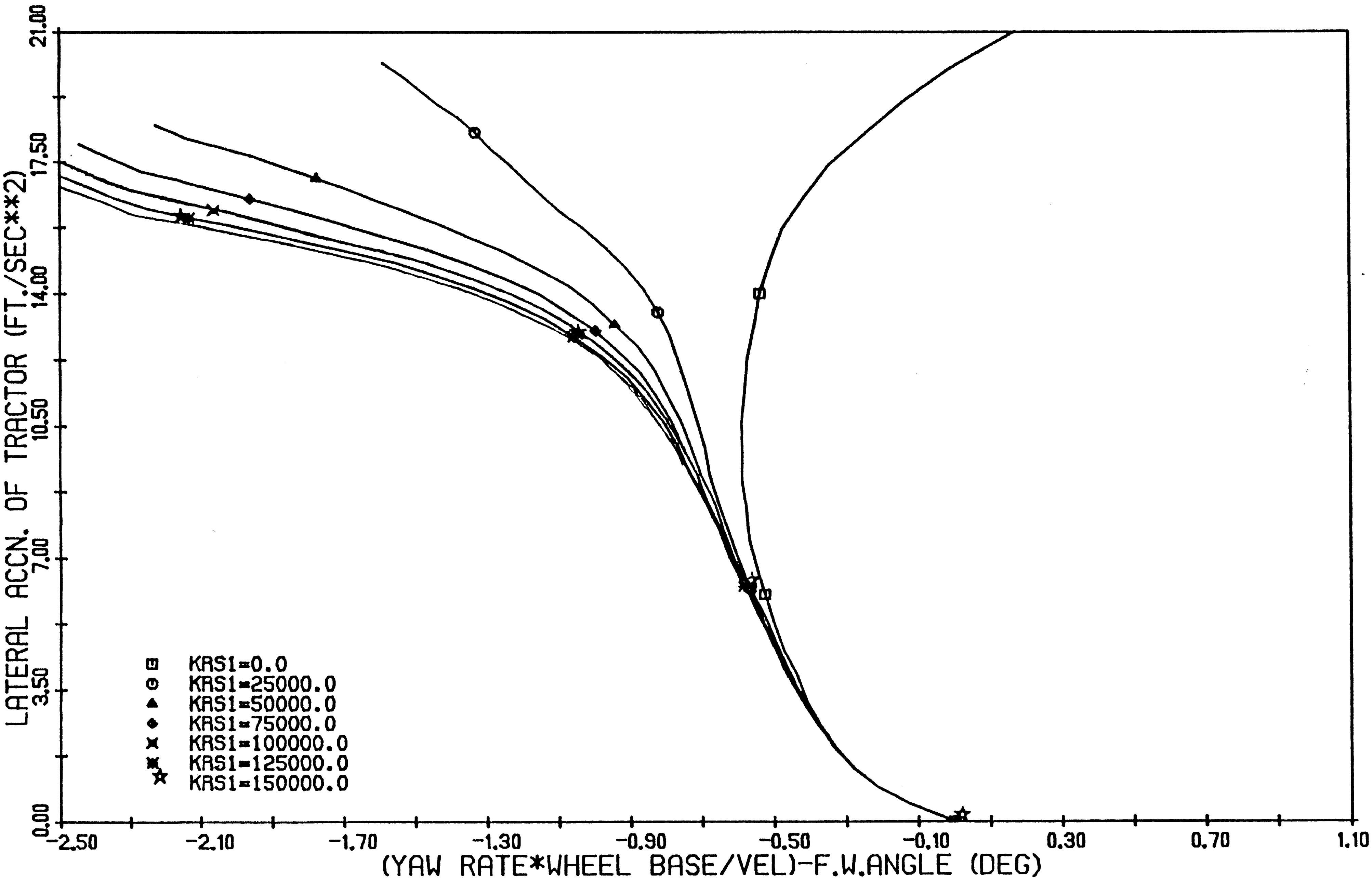


FORD-VAN TRAILER, RIB TIRES, FRAME 100000 IN.LB/DEG



FORD-VAN TRAILER, RIB TIRES, FRAME 120000 IN.LB/DEG



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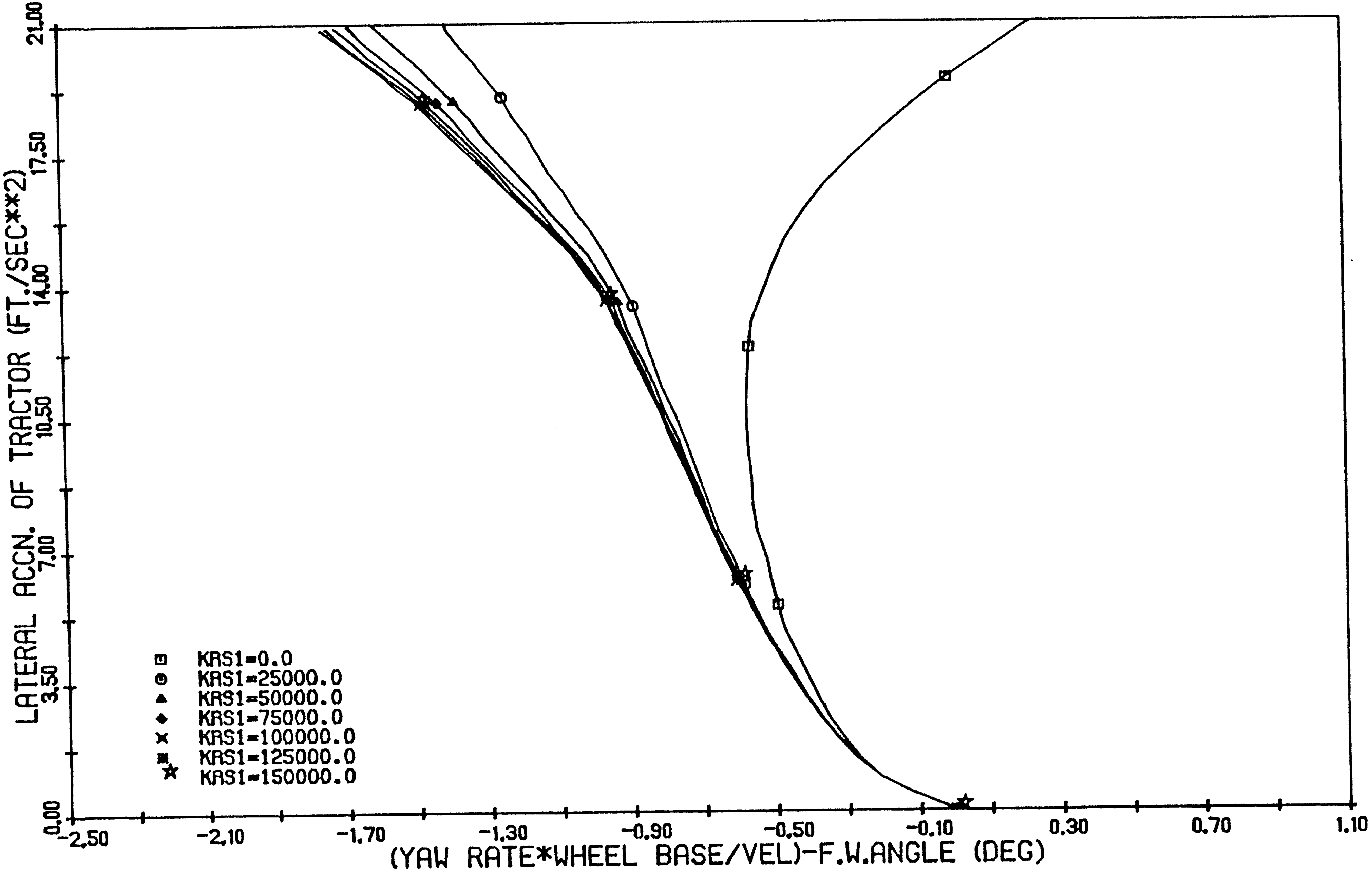
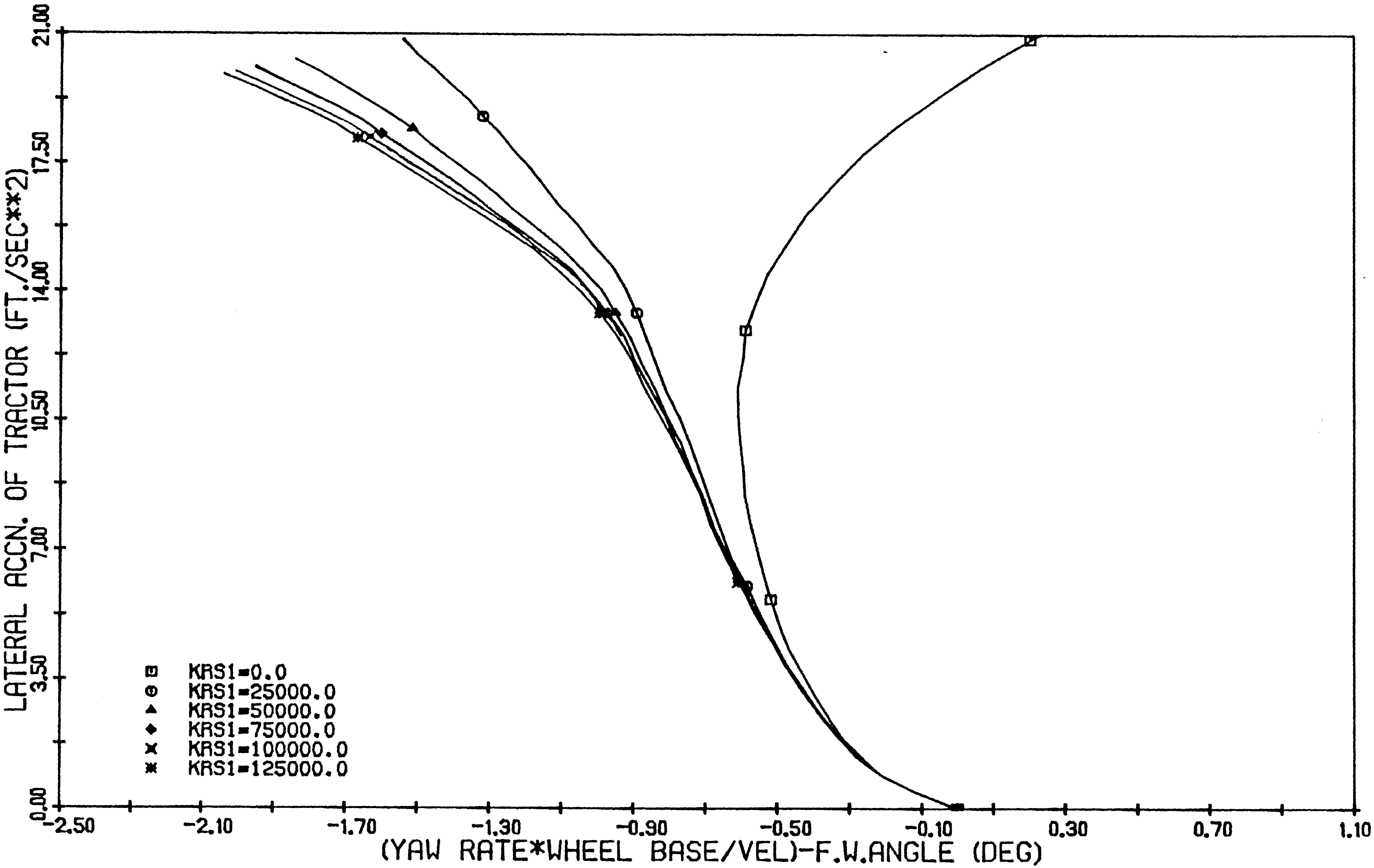


FORD-FLAT BED TRAILER, RIB , FRAME 20000 IN.LB/DEG



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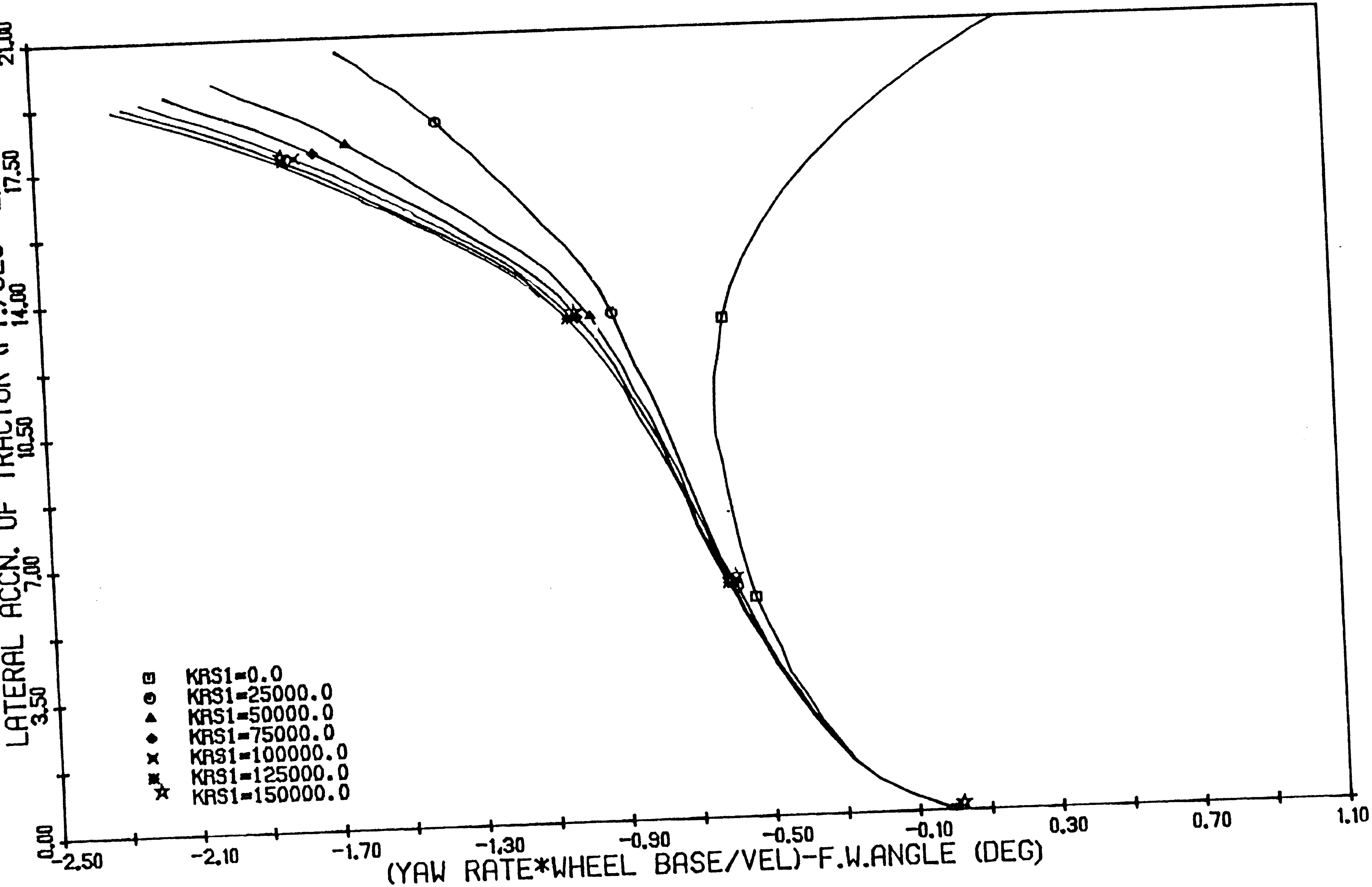

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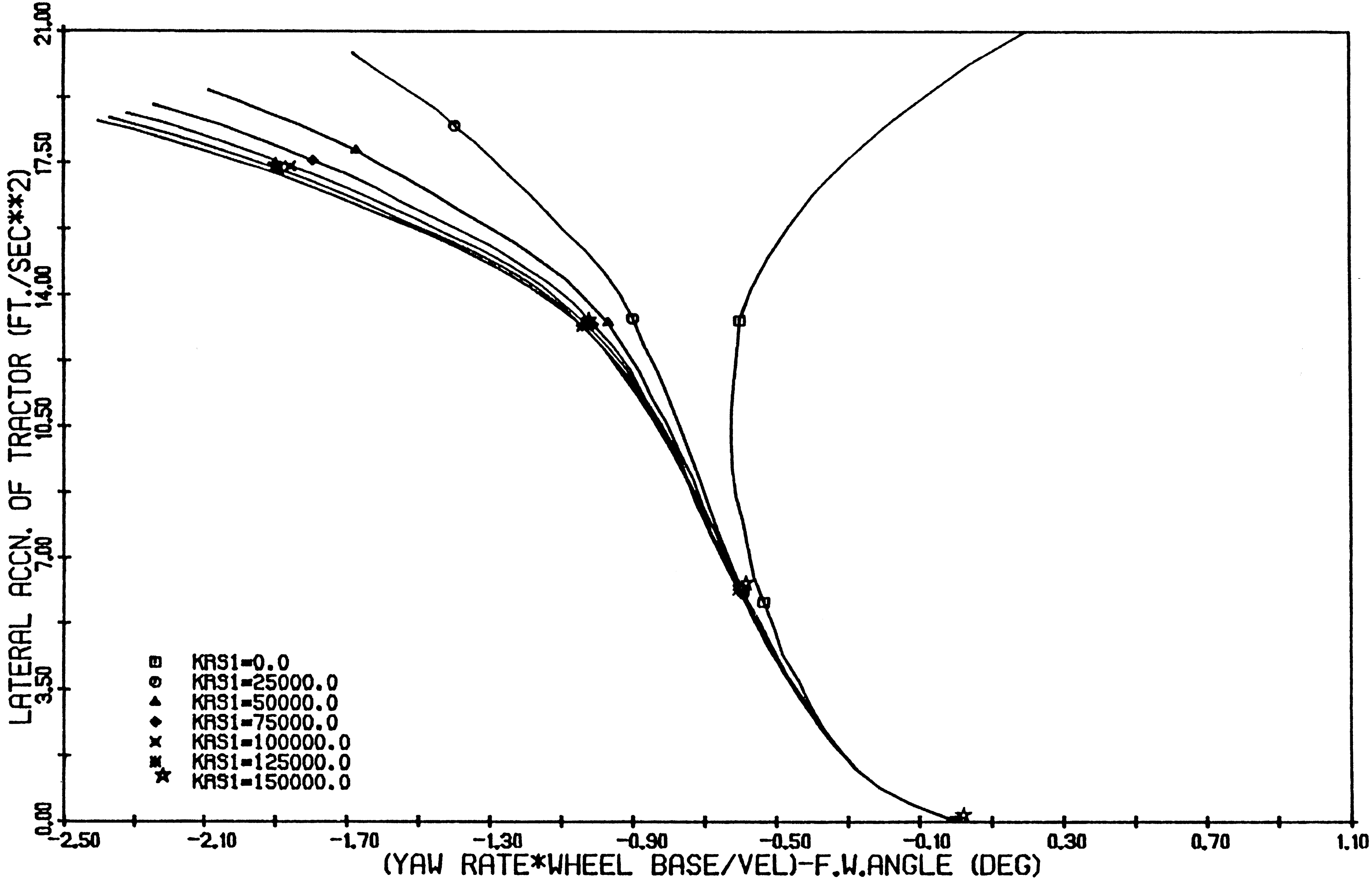

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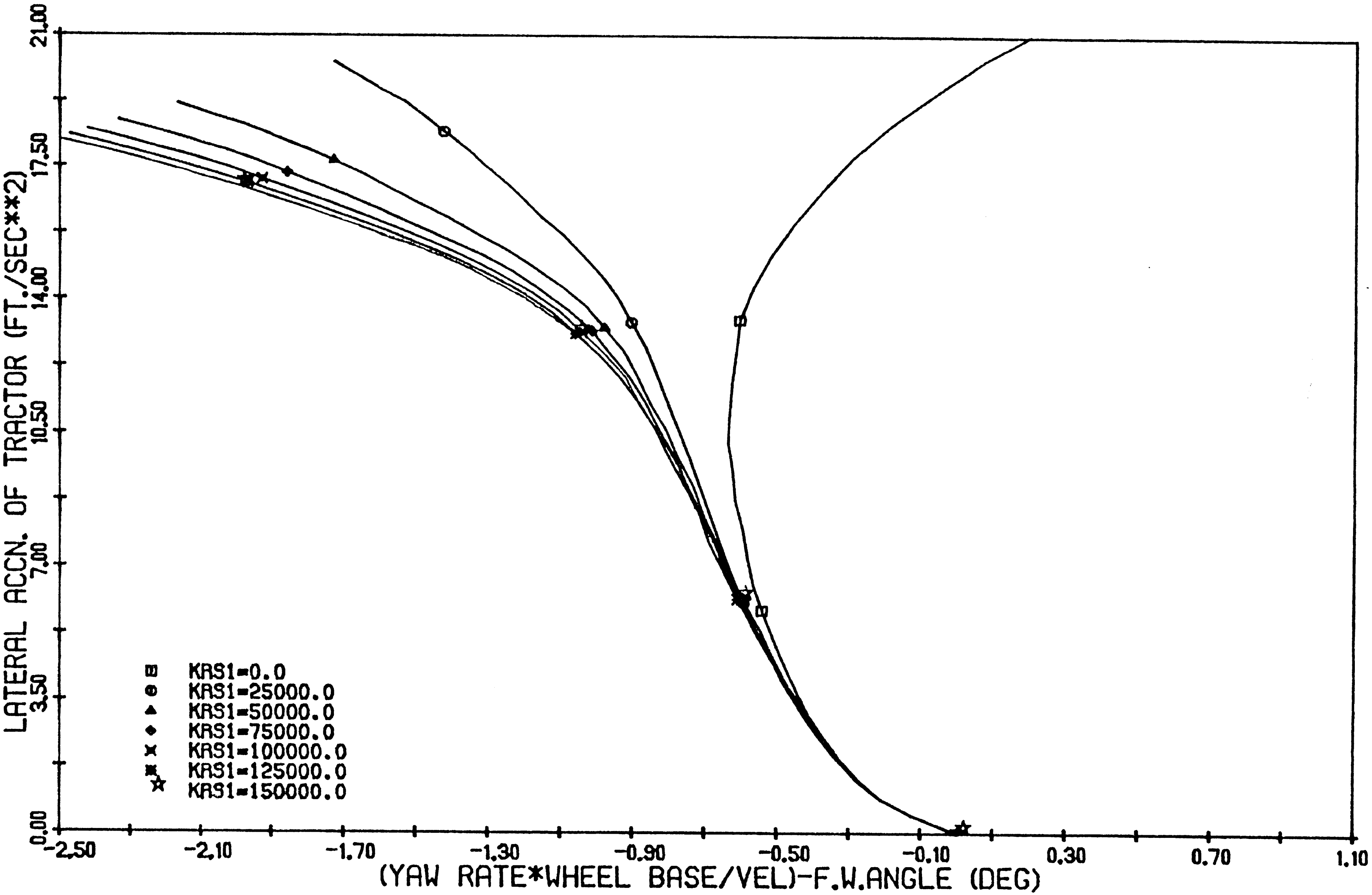
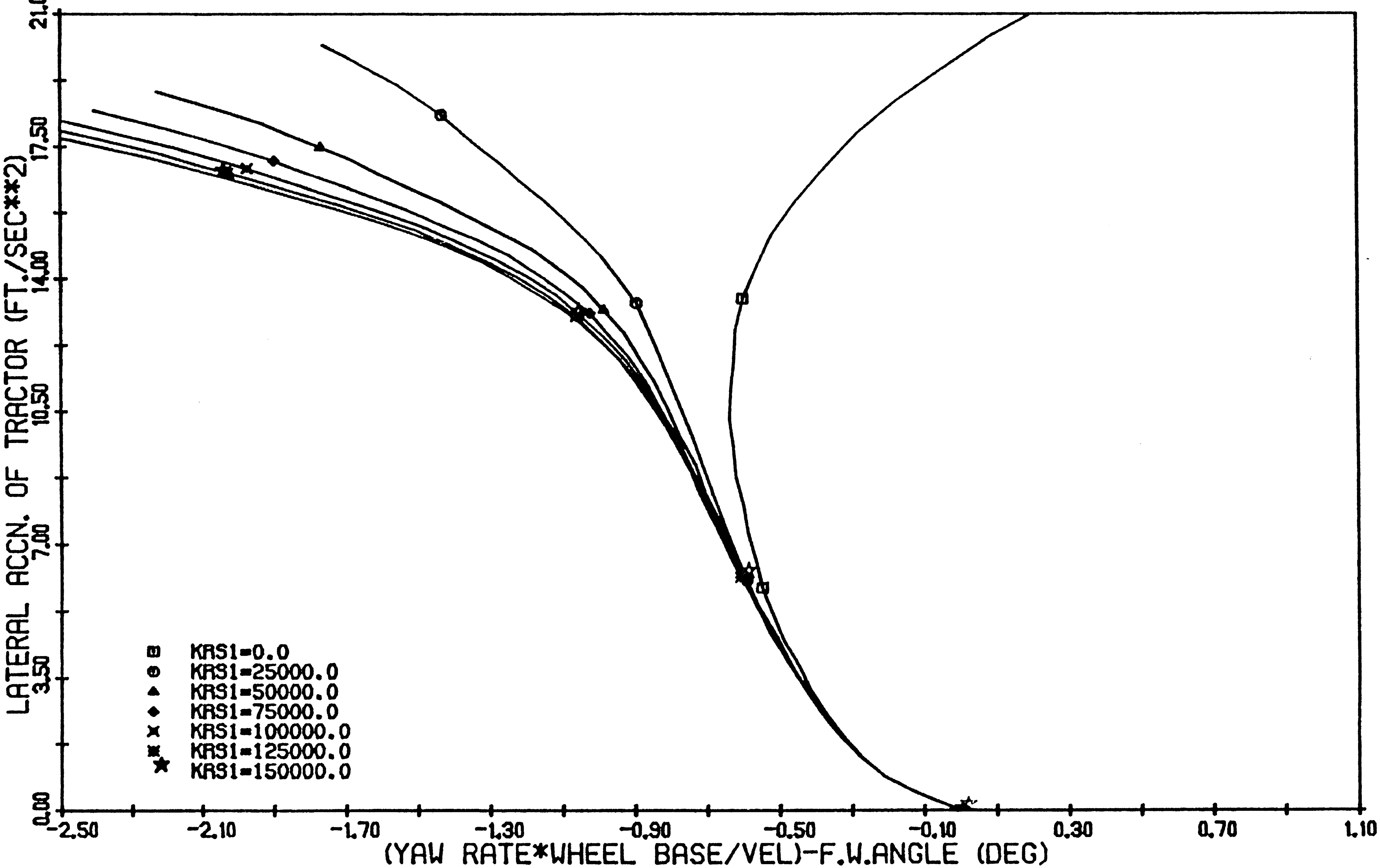
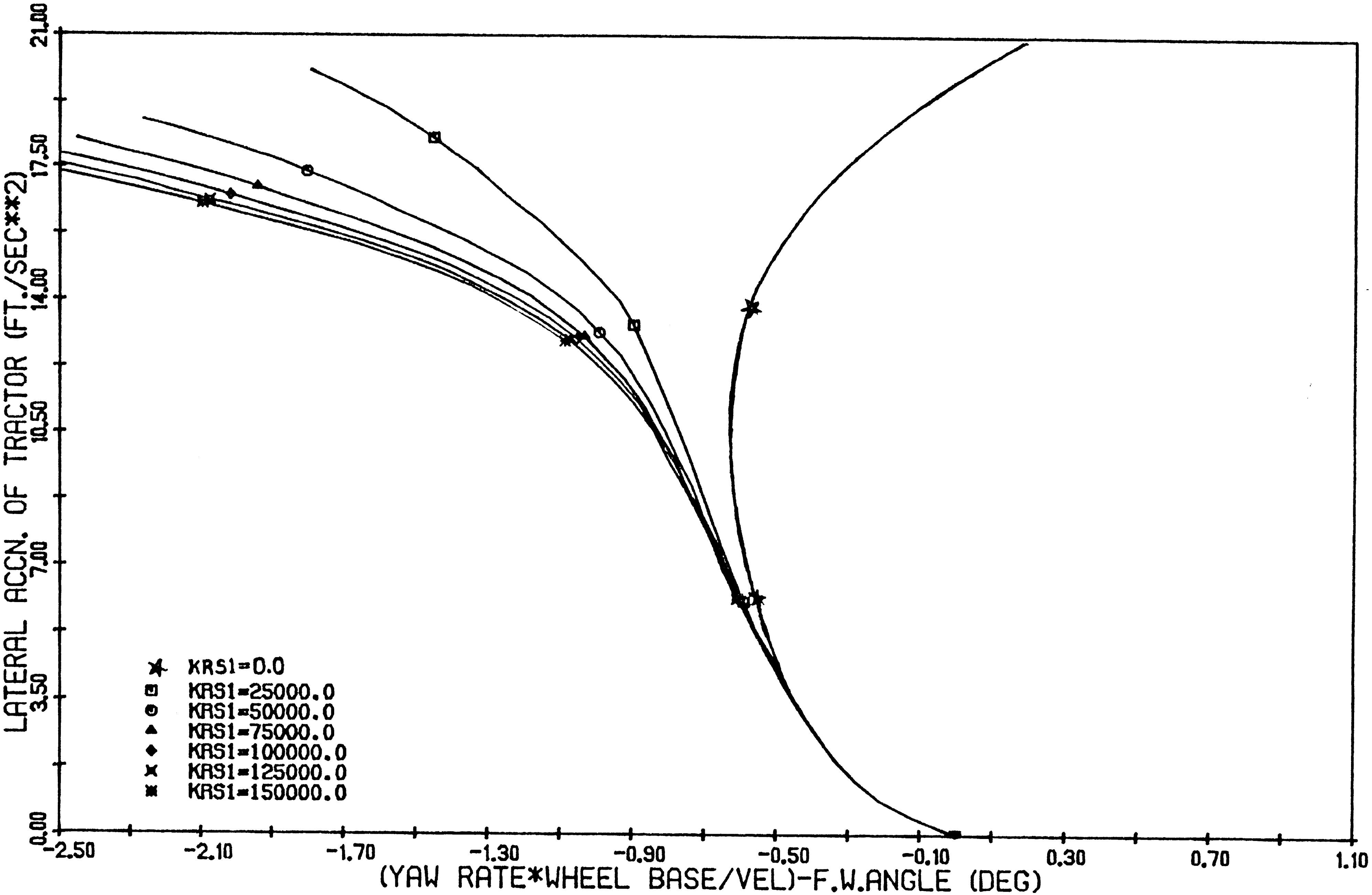


FORD-FLAT BED TRAILER, RIB , FRAME 100000 IN.LB/DEG

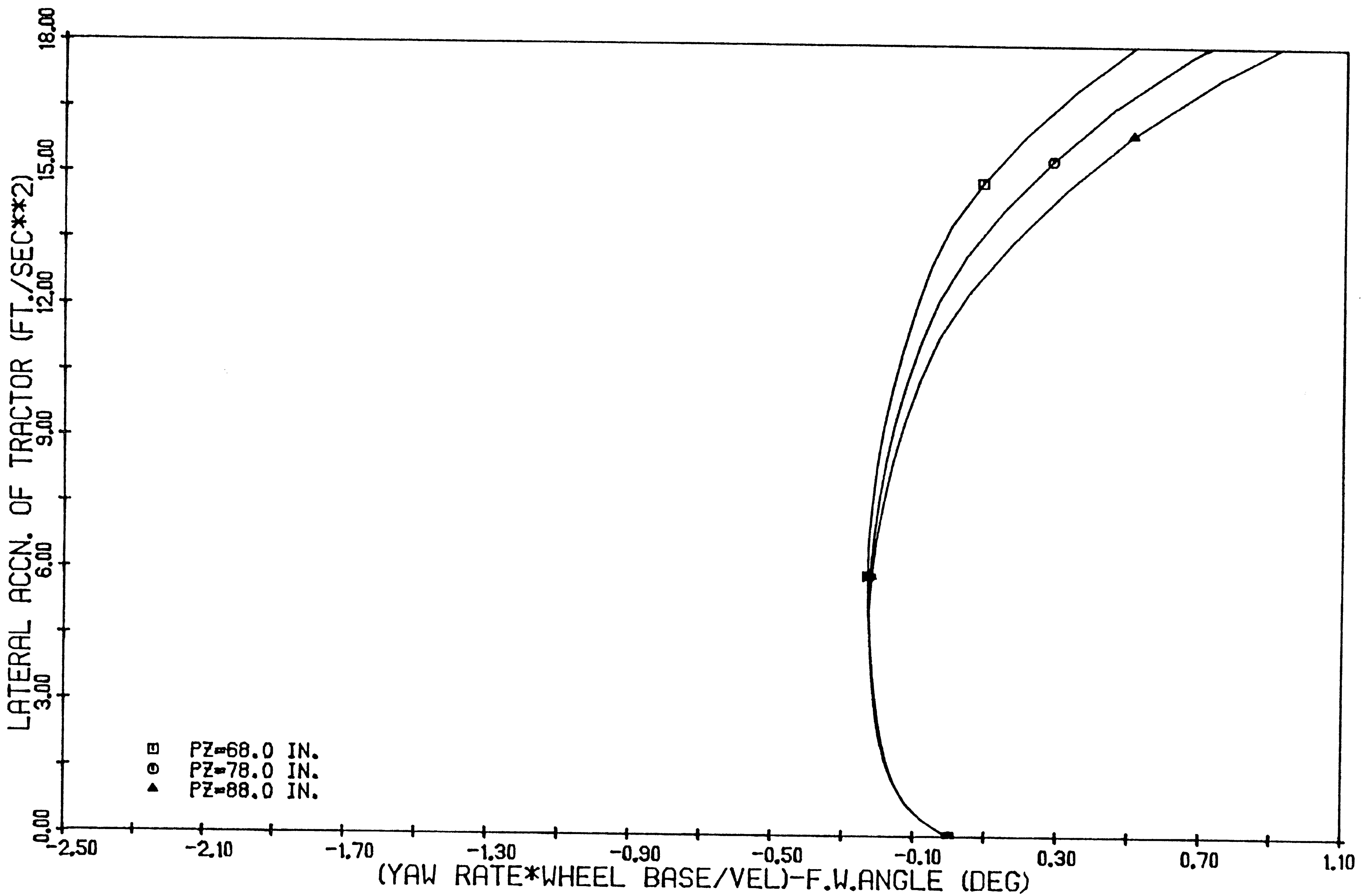


FORD-FLAT BED TRAILER,RIB ,FRAME 120000 IN.LB/DEG

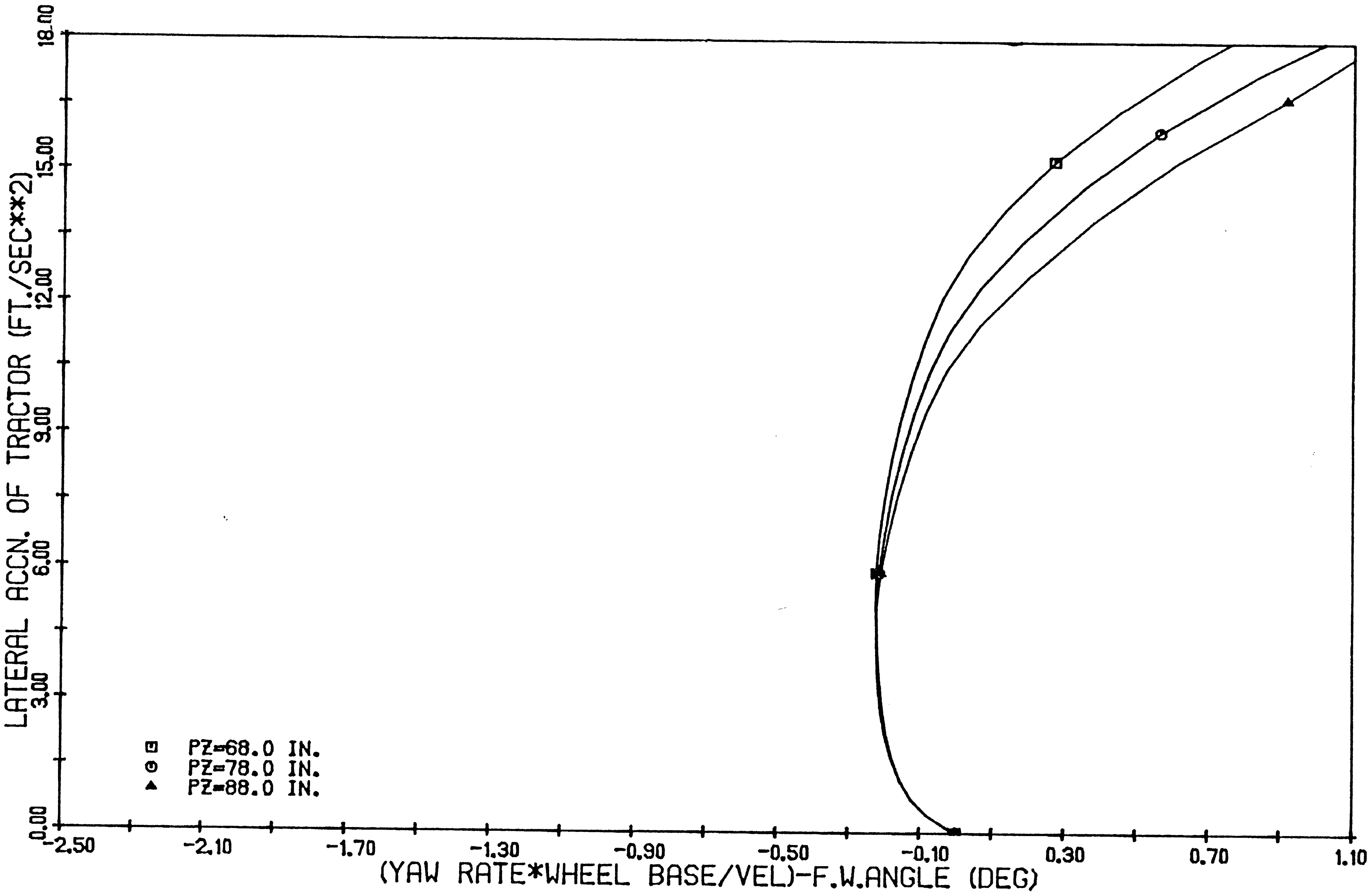


FORD-FLAT BED, RIB TIRES, FRAME 140000 IN.LB/DEG

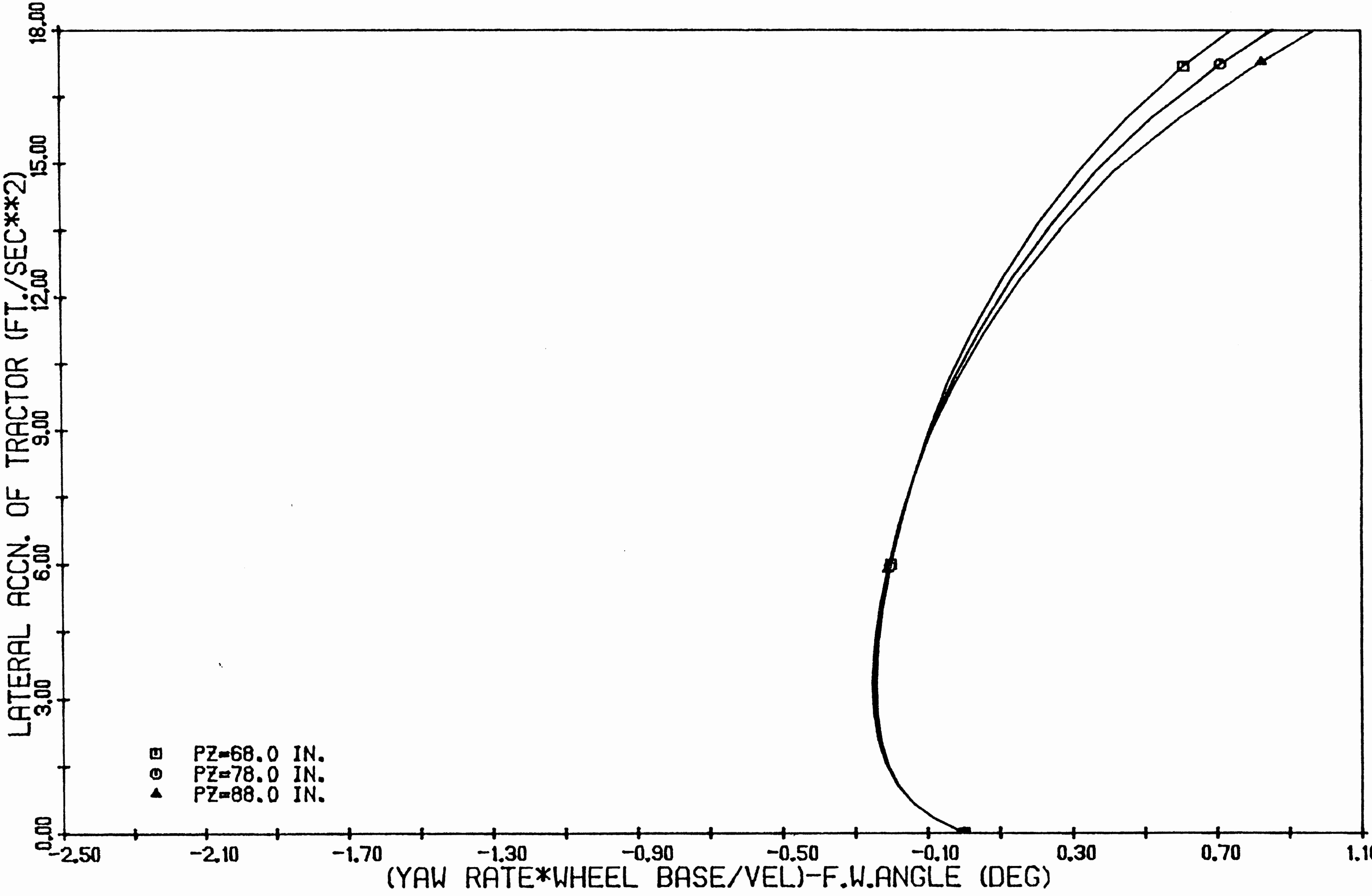
Handling diagrams for showing sensitivity to variation in operating conditions and design variables.



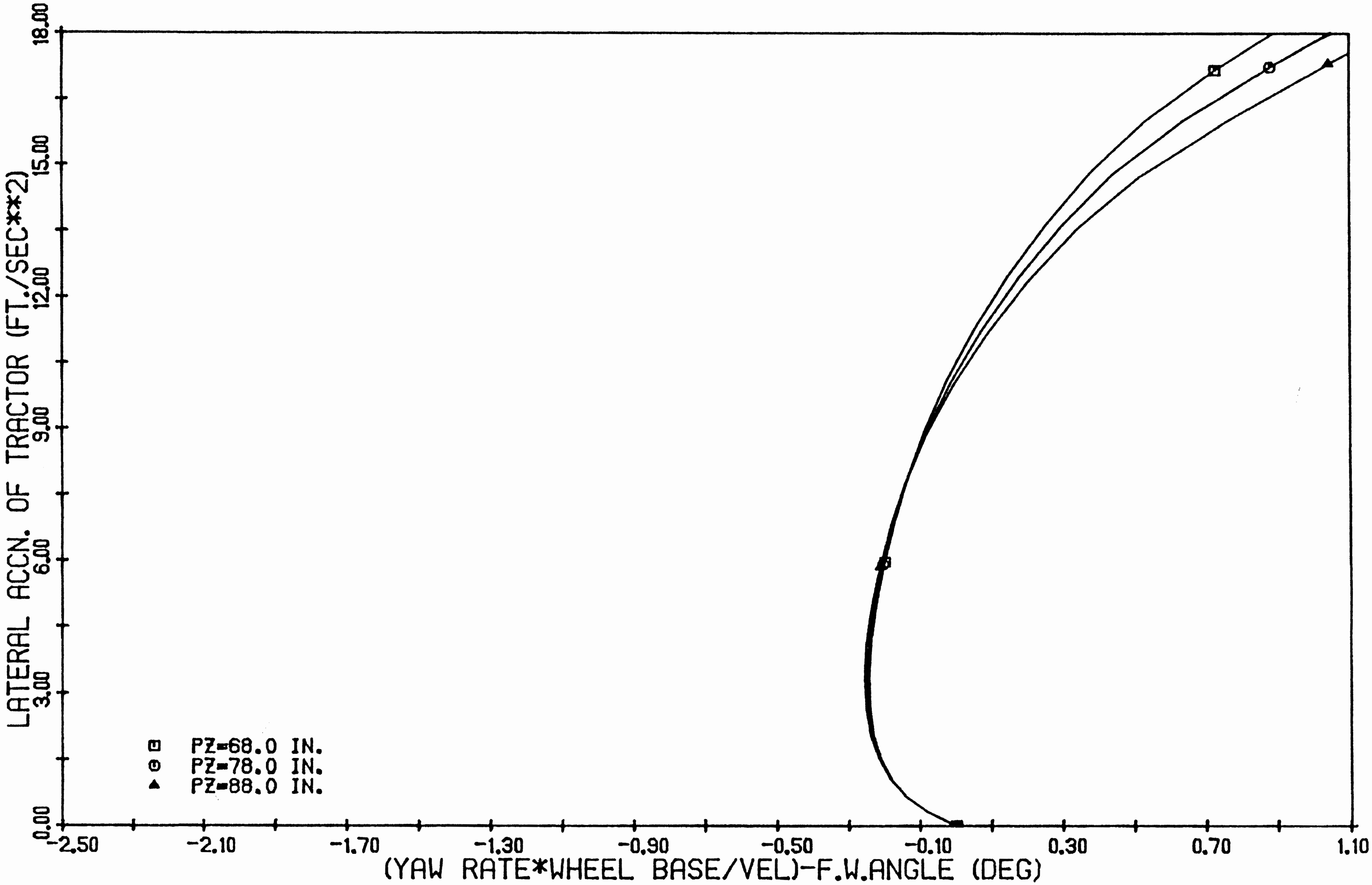
110 IN. WHEEL BASE TRACTOR, RIB TIRES, RUN # 1,2&3



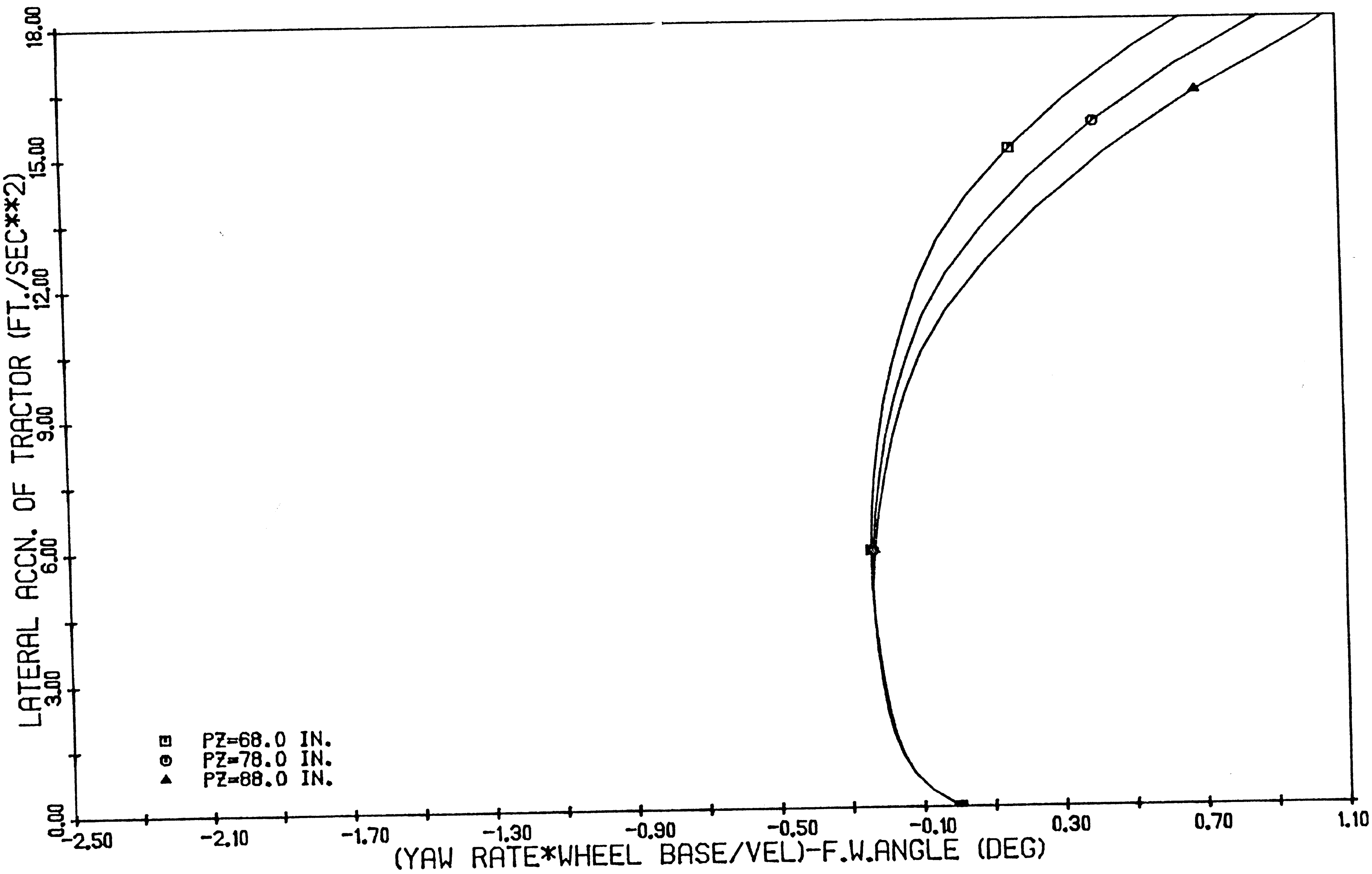
110 IN. WHEEL BASE TRACTOR, RIB TIRES, RUN # 4,5&6



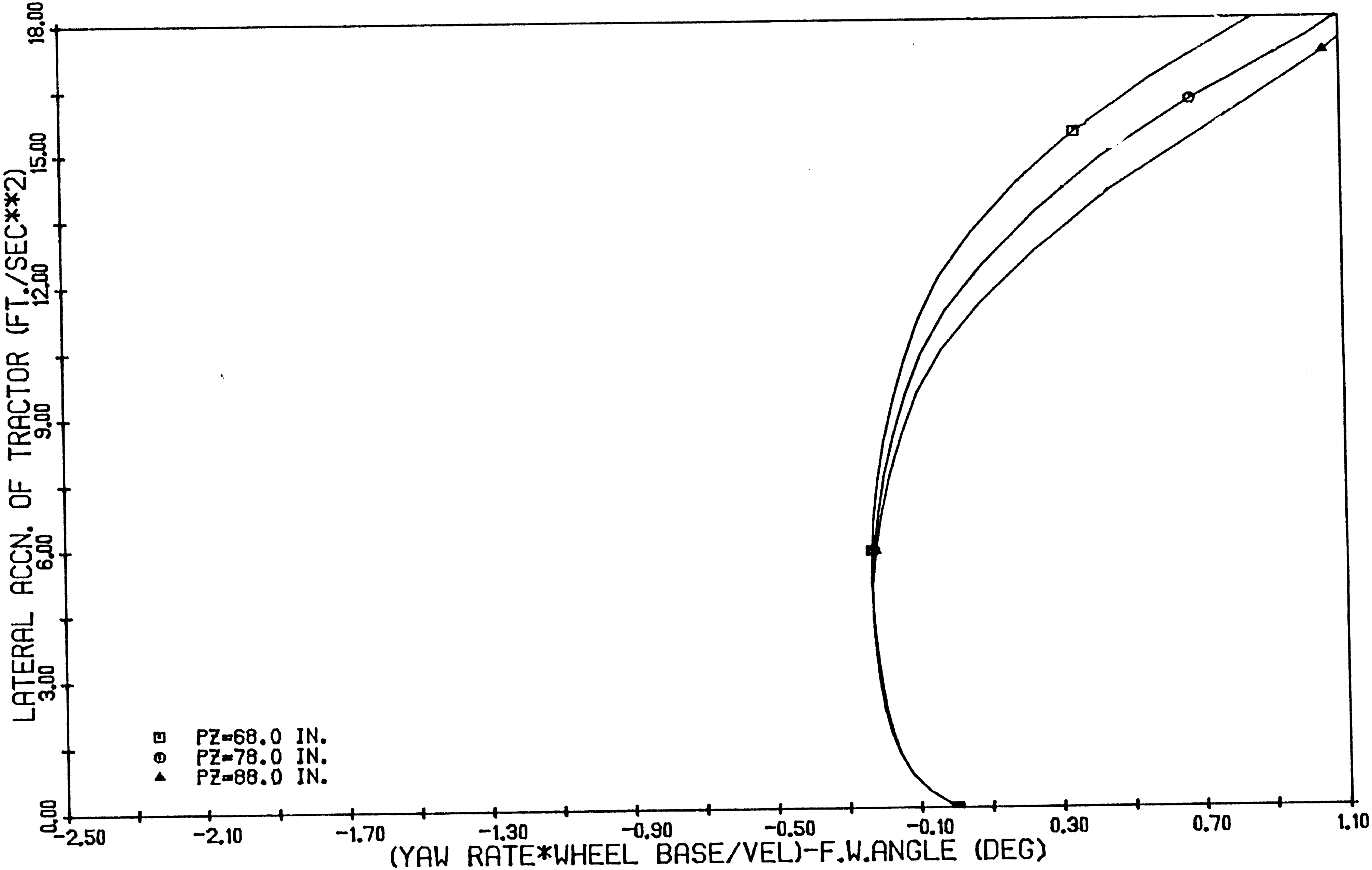
110 IN. WHEEL BASE TRACTOR, RIB TIRES, RUN # 7,8&9



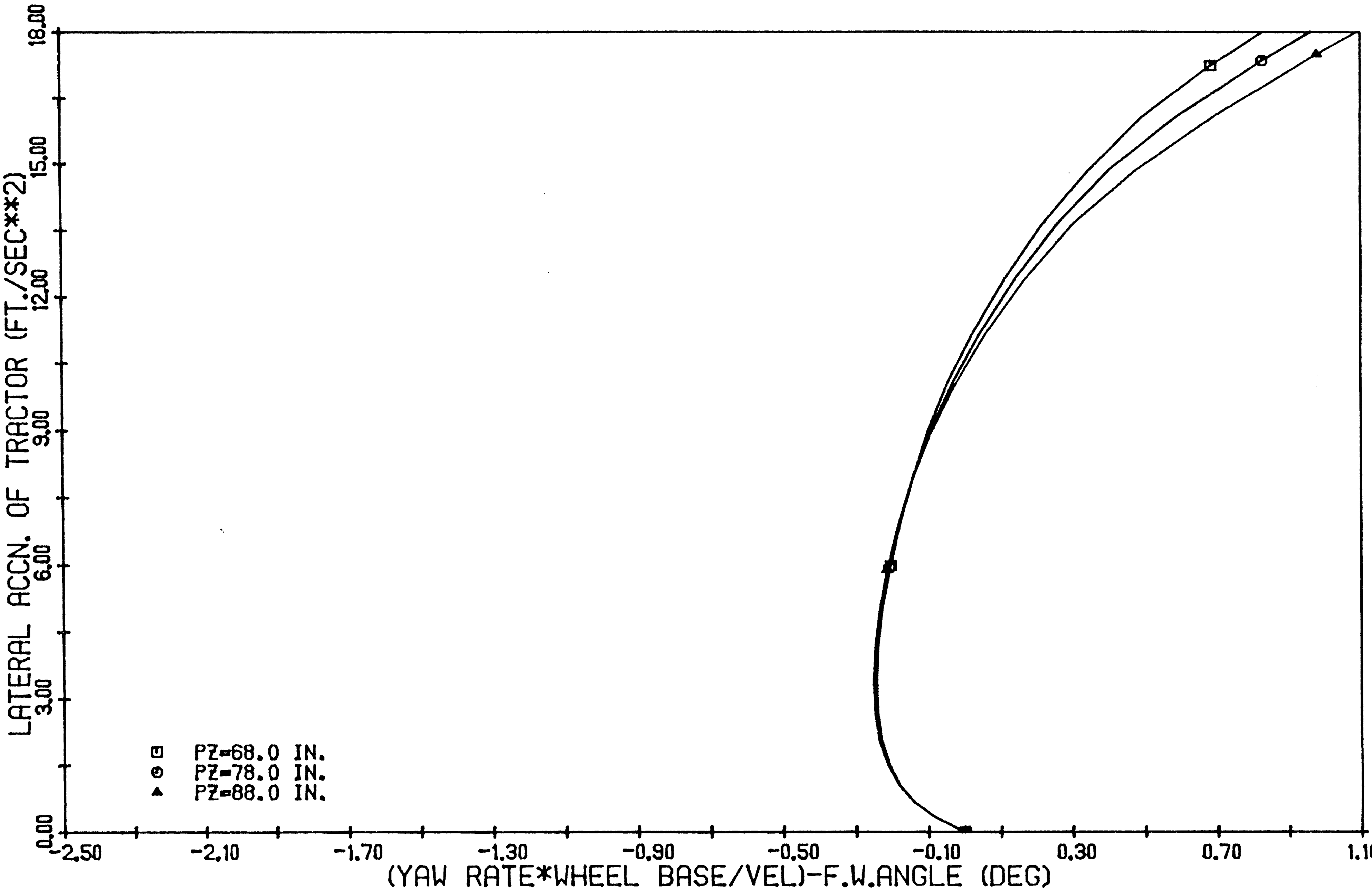
110 IN.WHEEL BASE TRACTOR,RIB TIRES,RUN # 10,11&12



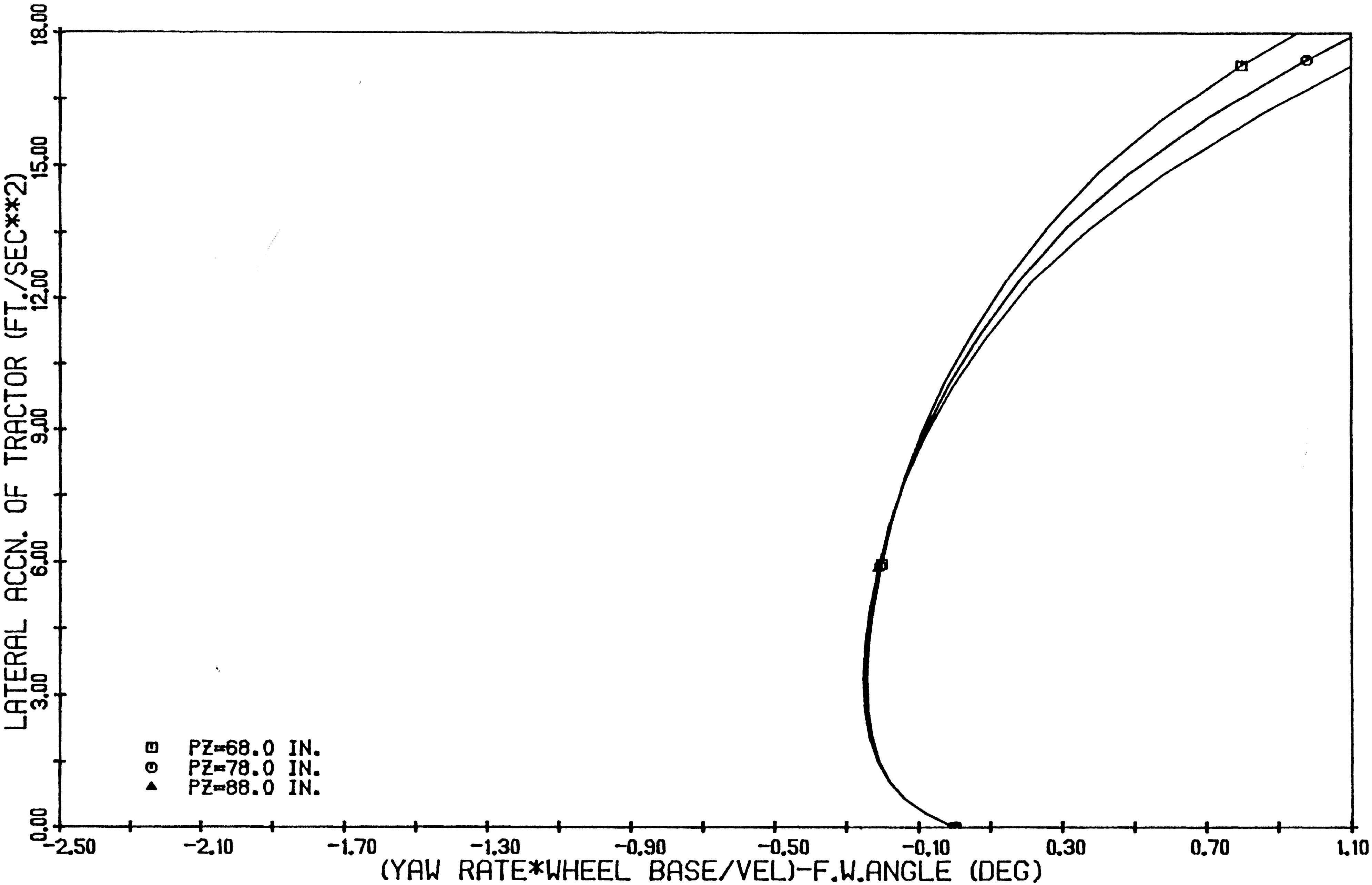
110 IN. WHEEL BASE TRACTOR, RIB TIRES, RUN # 13, 14&15



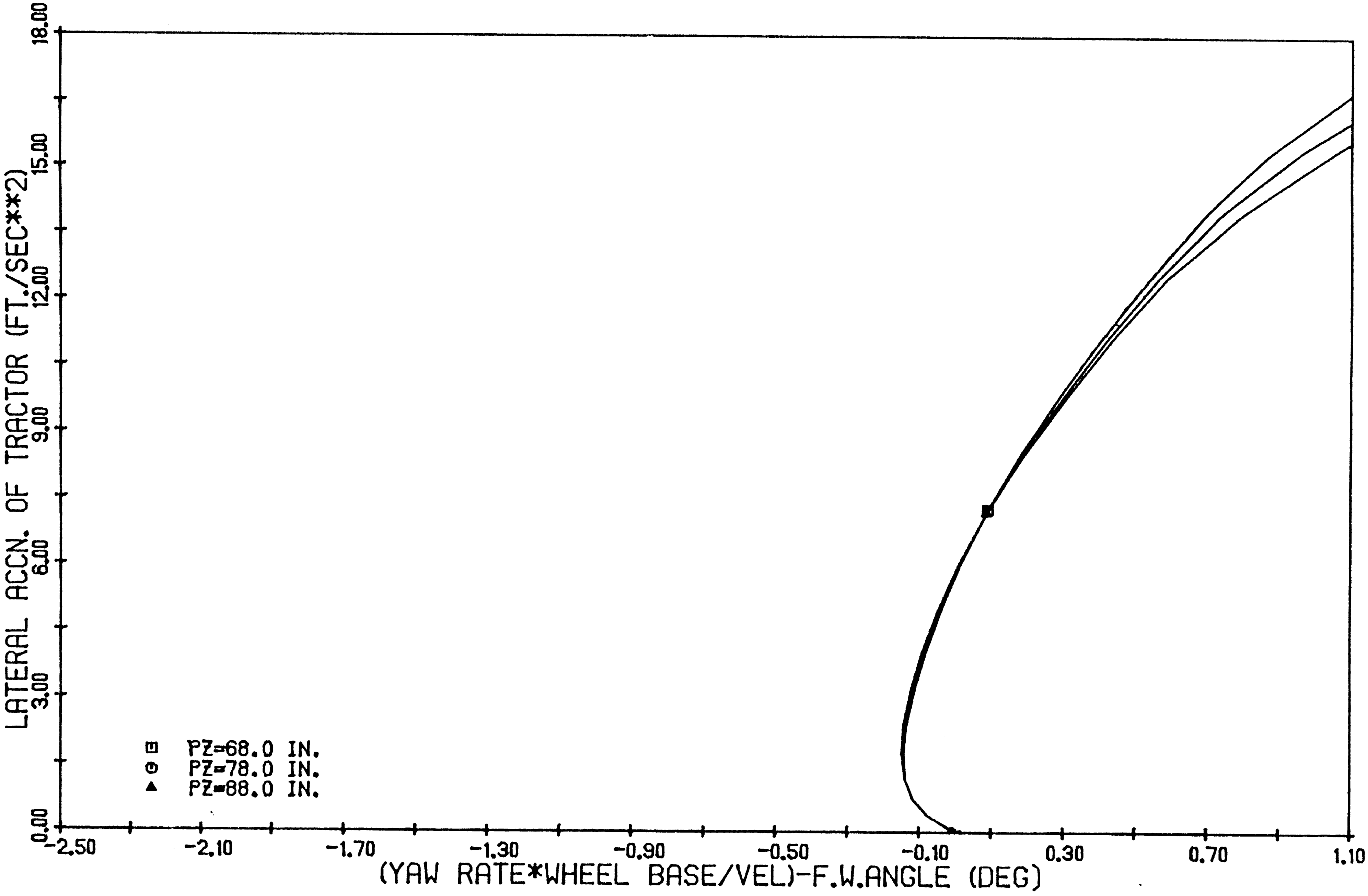
110 IN.WHEEL BASE TRACTOR,RIB TIRES,RUN # 16,17&18



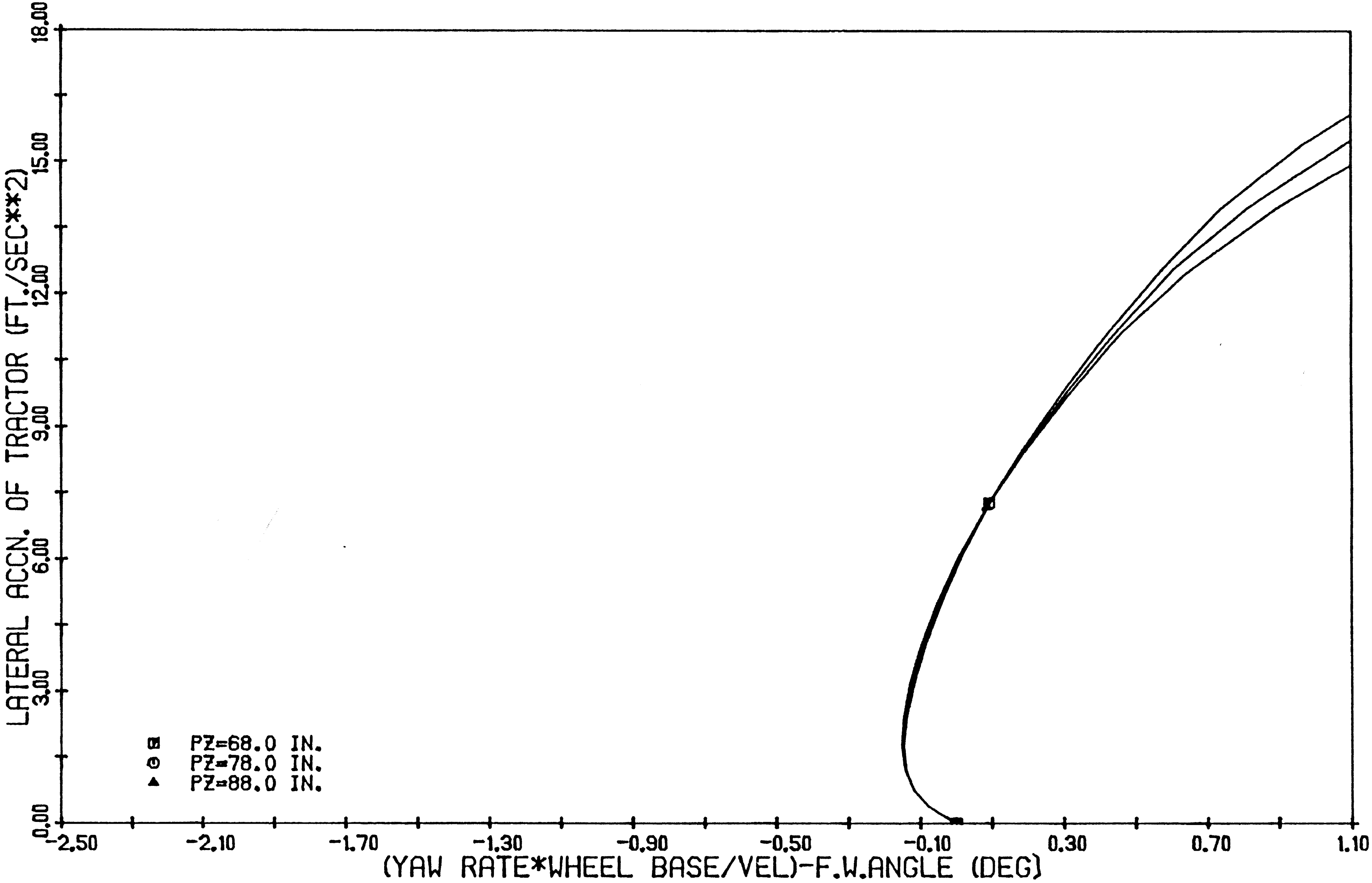
110 IN. WHEEL BASE TRACTOR, RIB TIRES, RUN # 19, 20&21



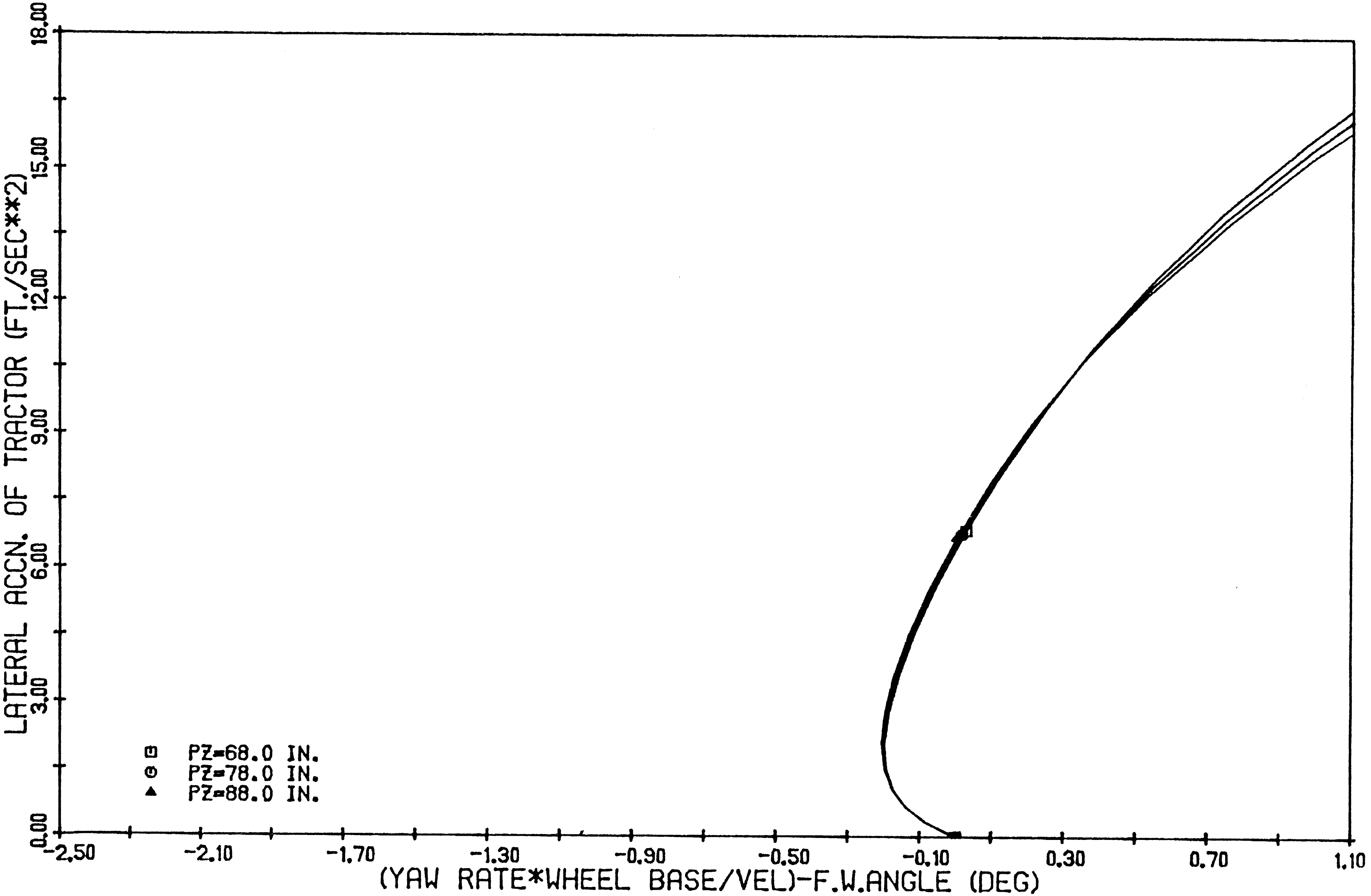
110 IN. WHEEL BASE TRACTOR, RIB TIRES, RUN # 22, 23&24



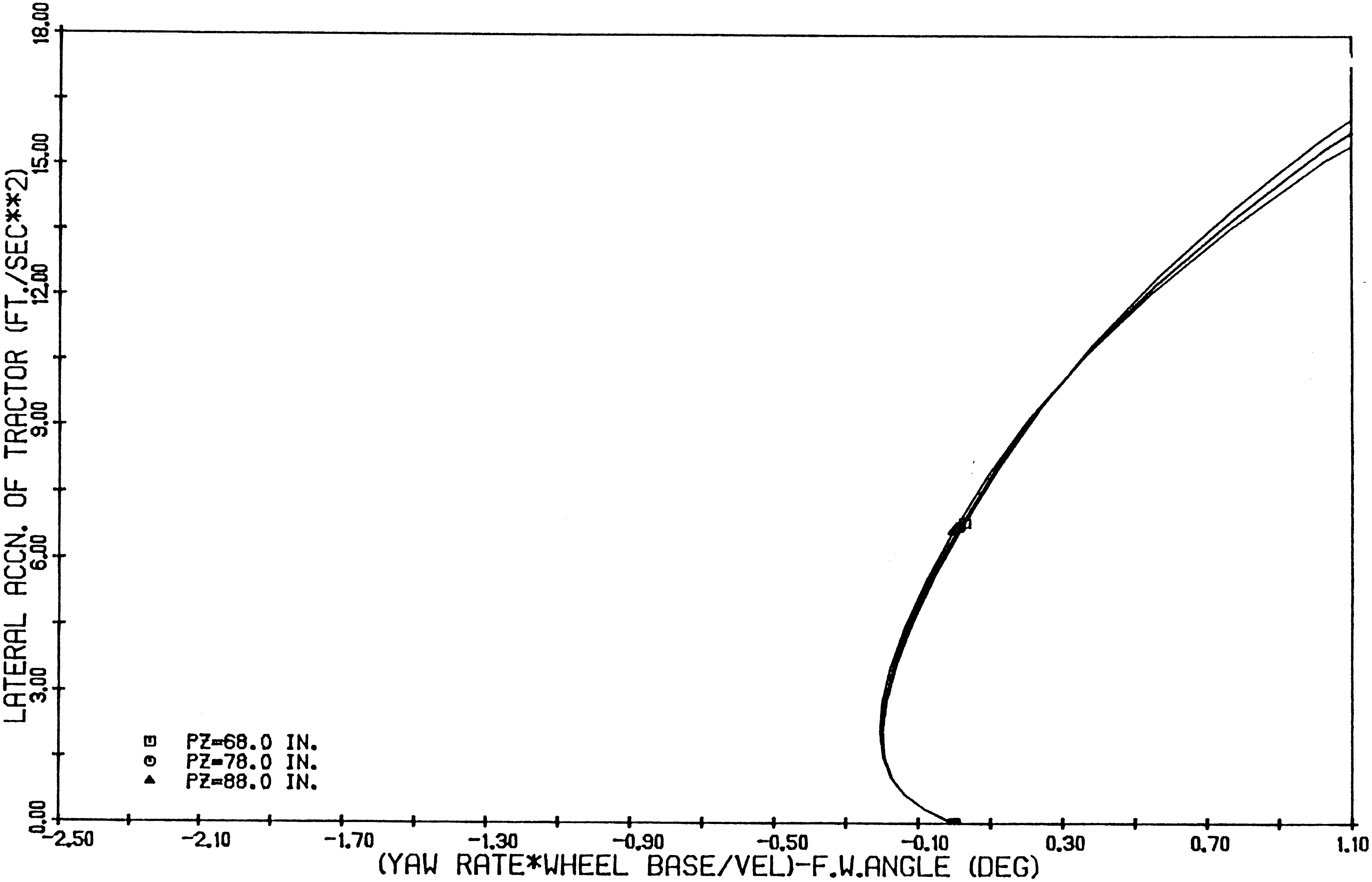
110 IN.WHEEL BASE TRACTOR,LUG TIRES,RUN # 25,26&27



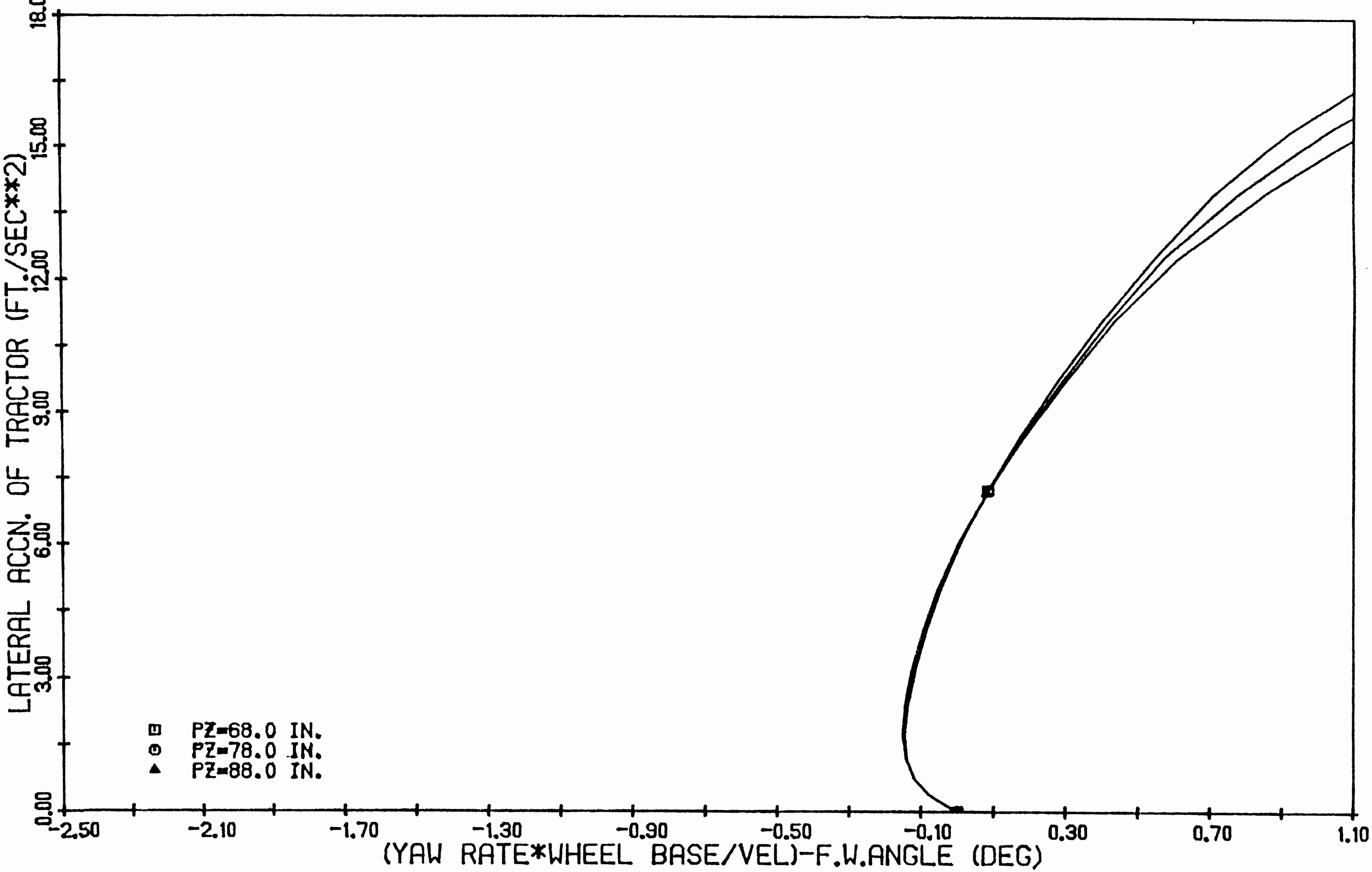
110 IN. WHEEL BASE TRACTOR, LUG TIRES, RUN # 28, 29&30



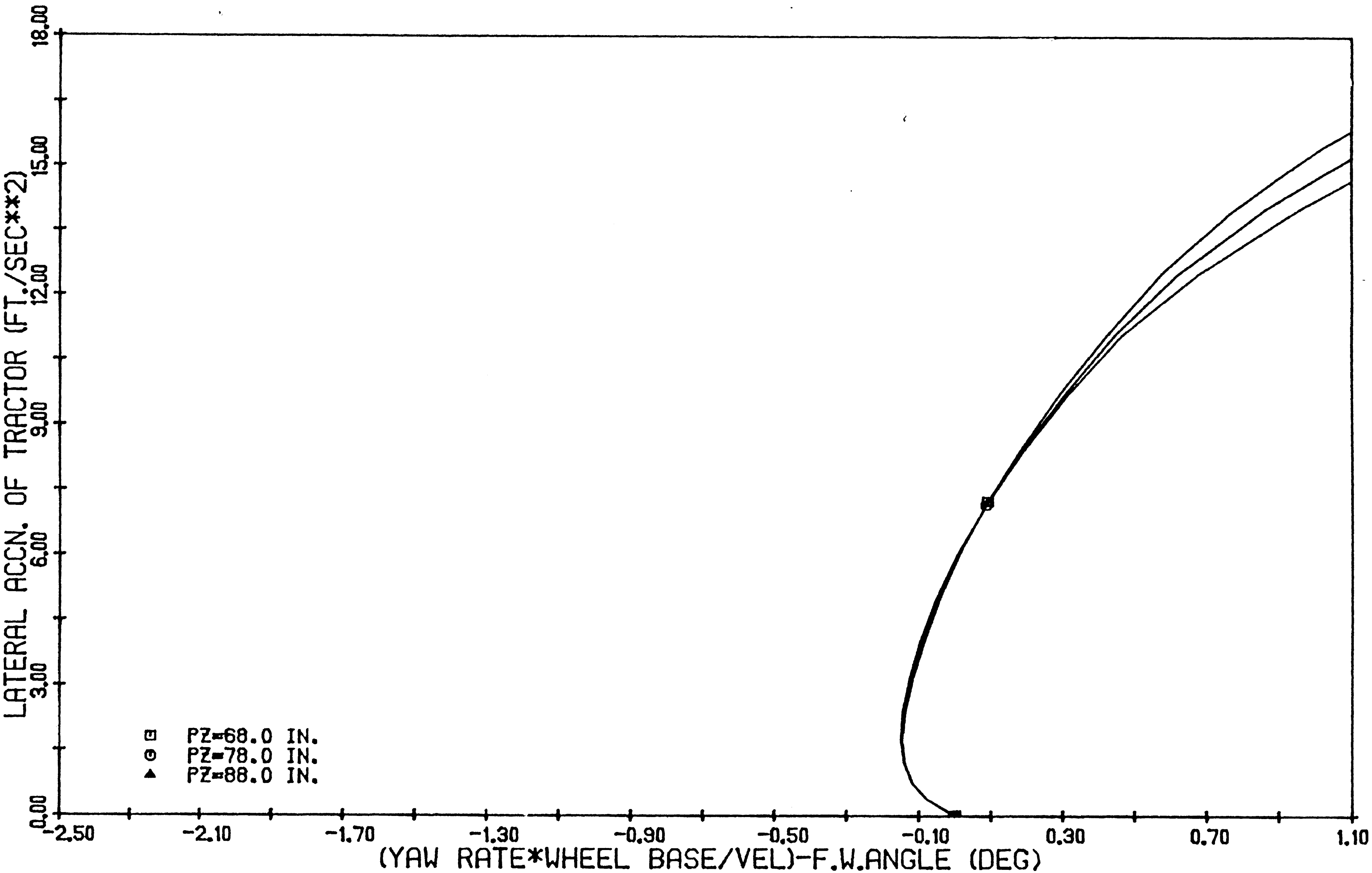
110 IN. WHEEL BASE TRACTOR, LUG TIRES, RUN # 31, 32&33



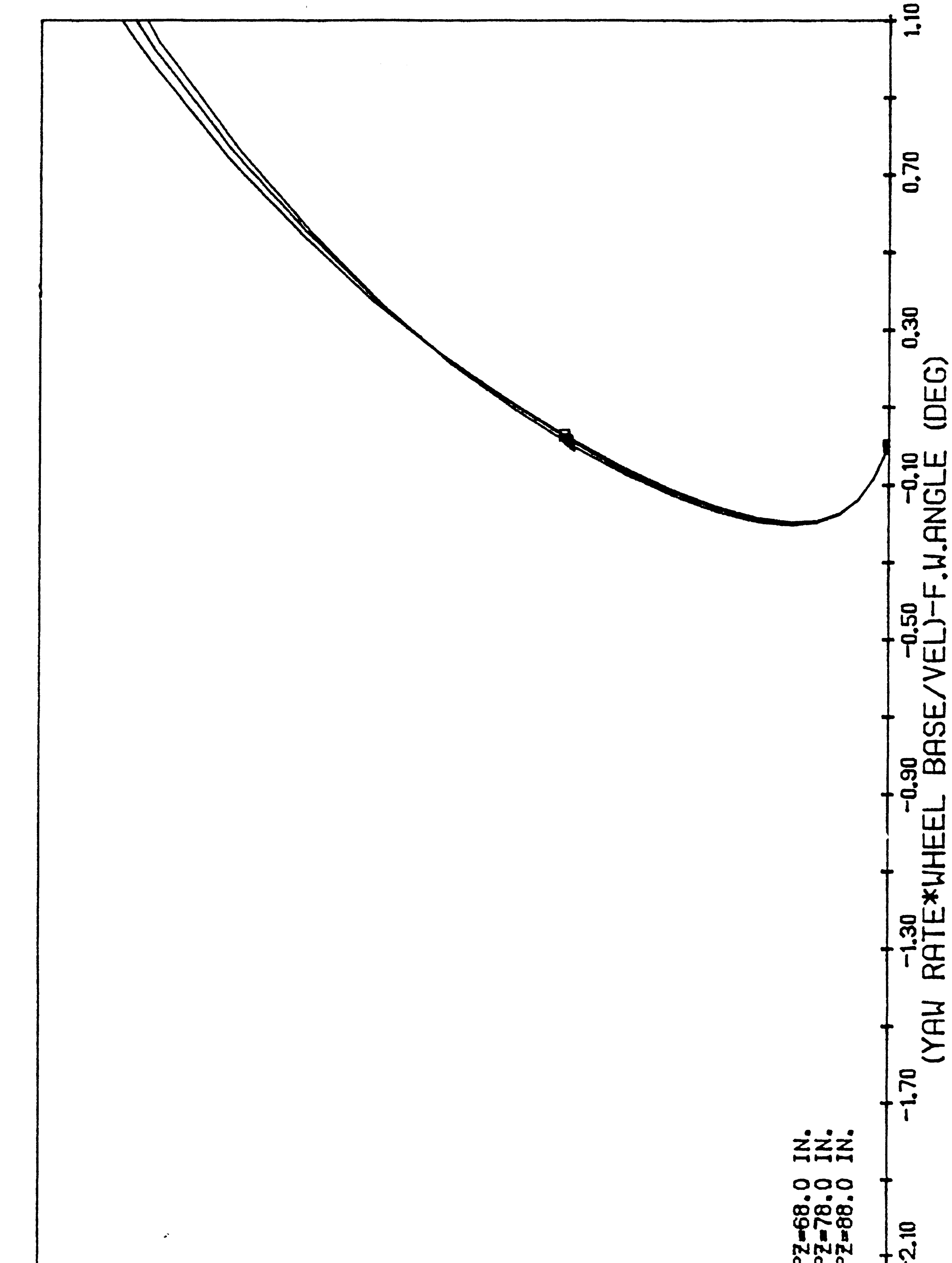
110 IN. WHEEL BASE TRACTOR, LUG TIRES, RUN # 34, 35&36



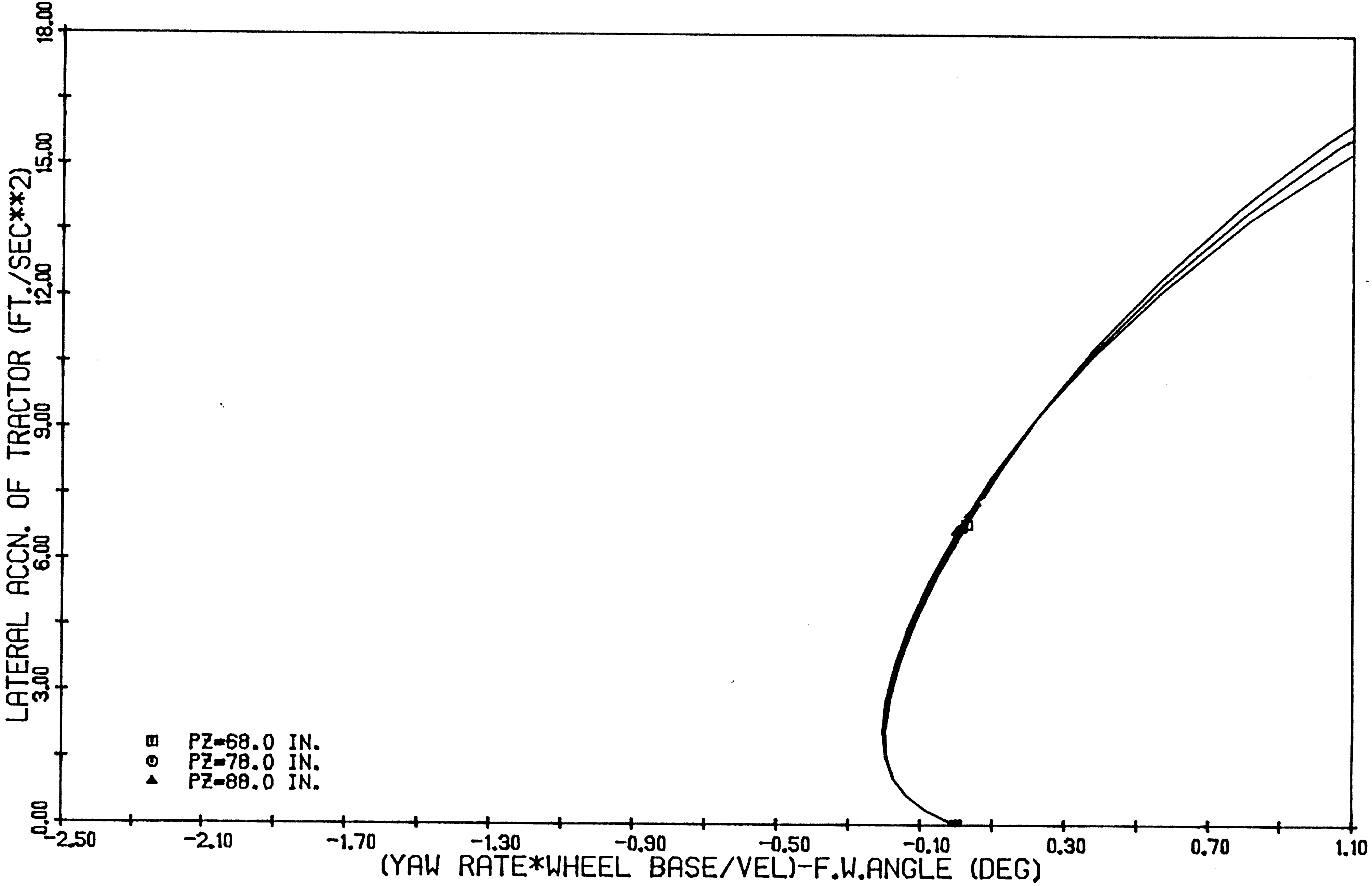
110 IN. WHEEL BASE TRACTOR, LUG TIRES, RUN # 37, 38&39



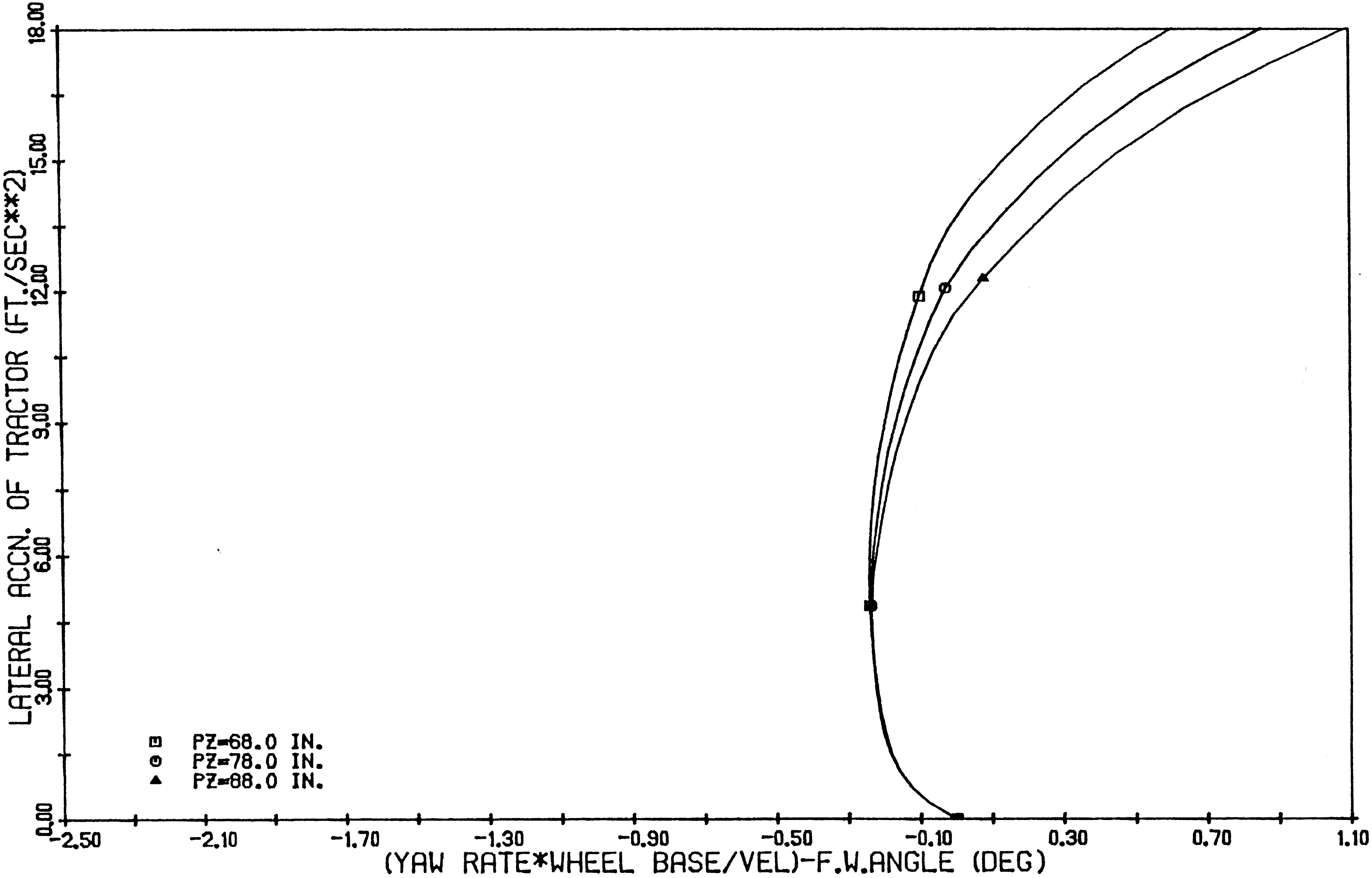
110 IN.WHEEL BASE TRACTOR,LUG TIRES,RUN # 40,41&42



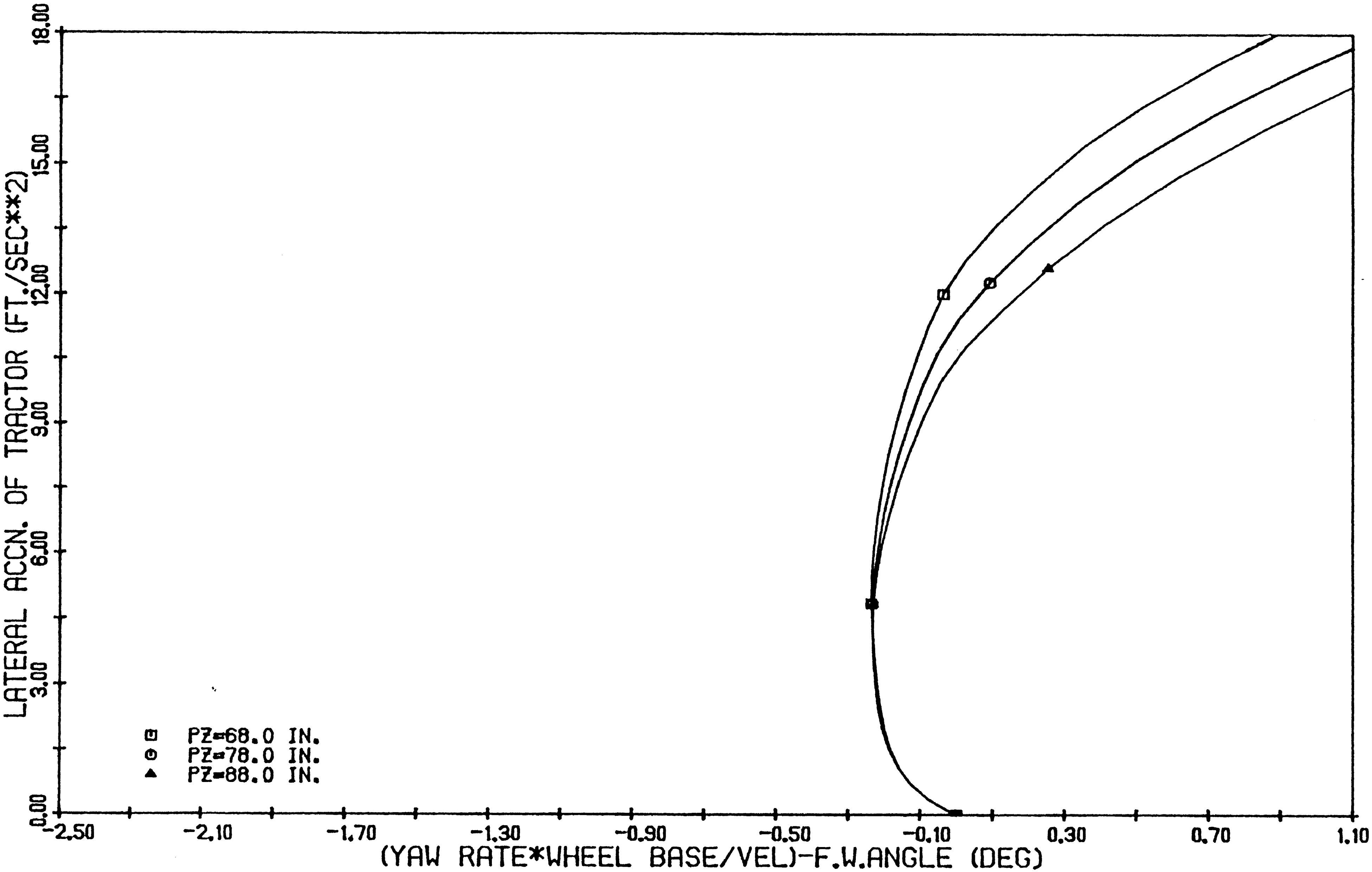
110 IN. WHEEL BASE TRACTOR, LUG TIRES, RUN # 43, 44&45



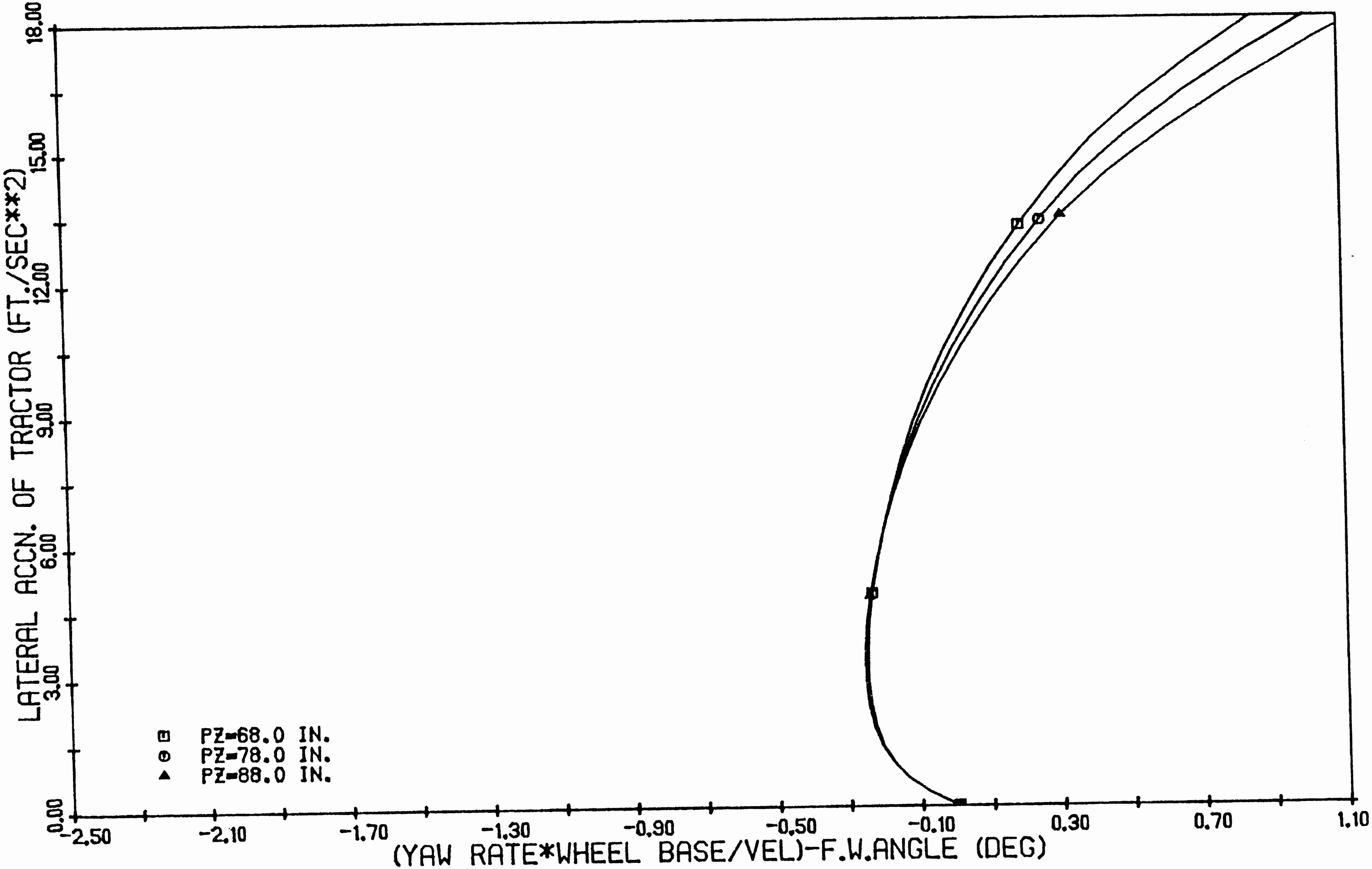
110 IN. WHEEL BASE TRACTOR, LUG TIRES, RUN # 46, 47&48



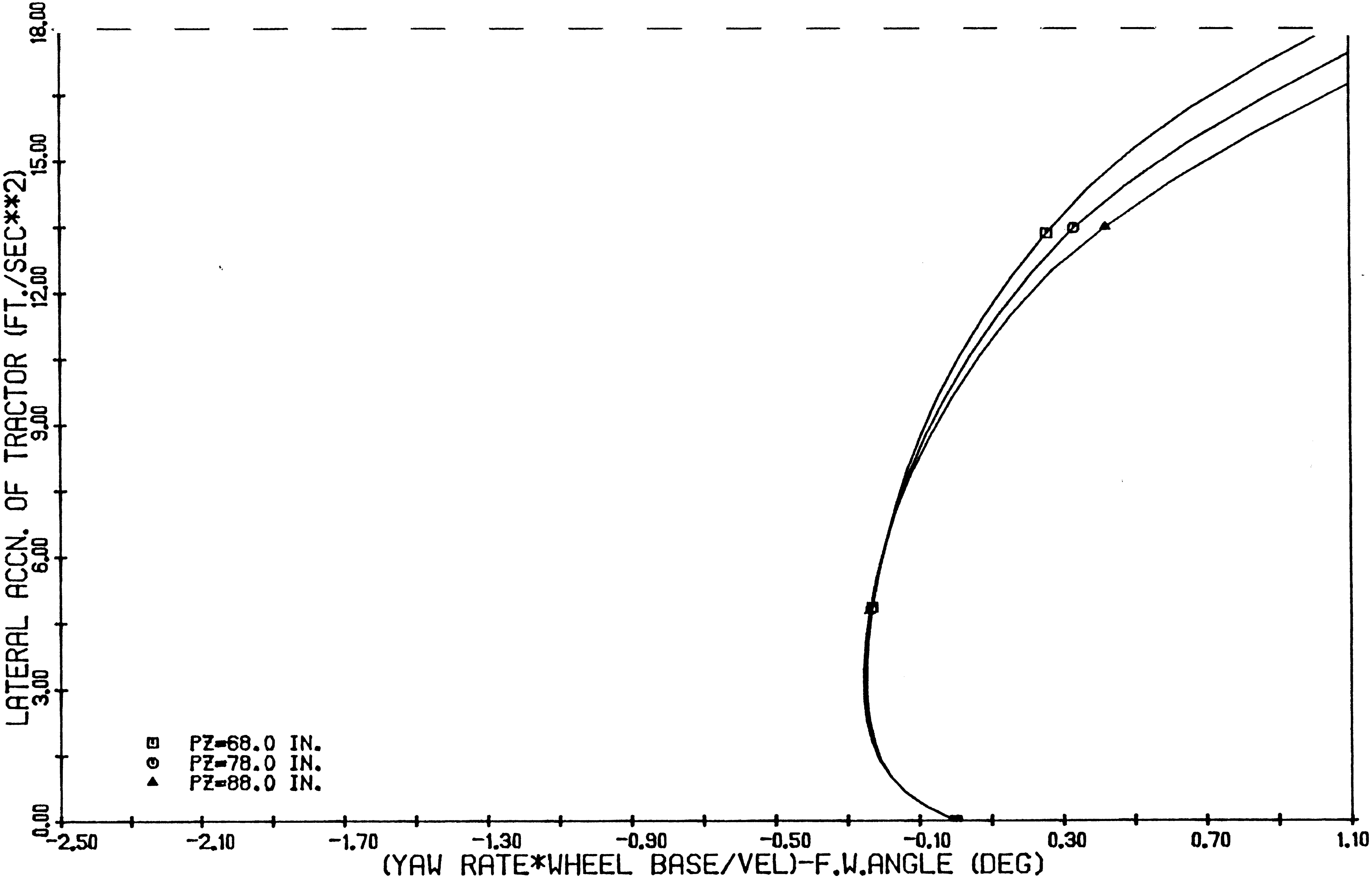
140 IN.WHEEL BASE TRACTOR,RIB TIRES,RUN # 49,50&51



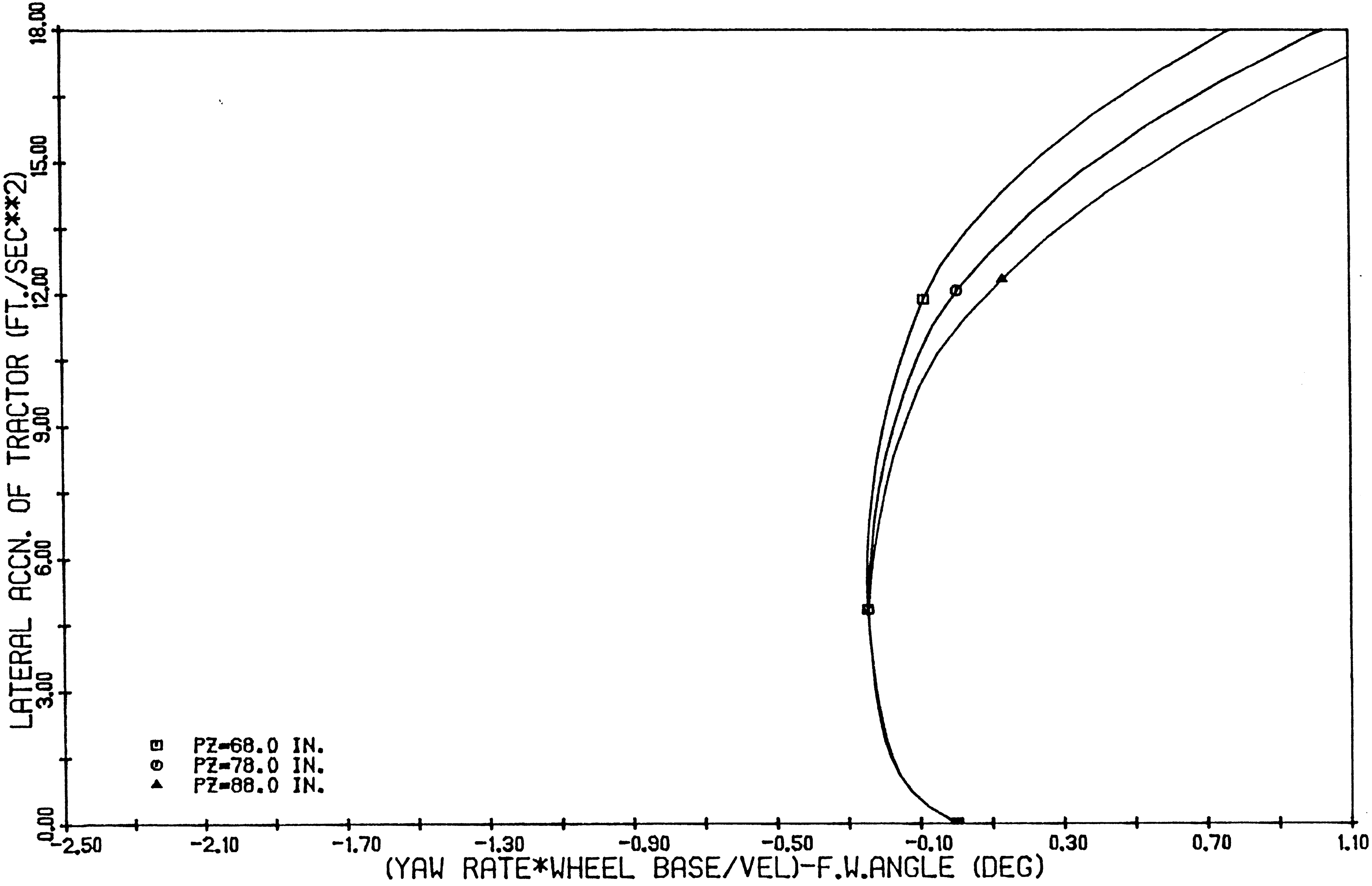
140 IN.WHEEL BASE TRACTOR.RIB TIRES.RUN # 52.53&54



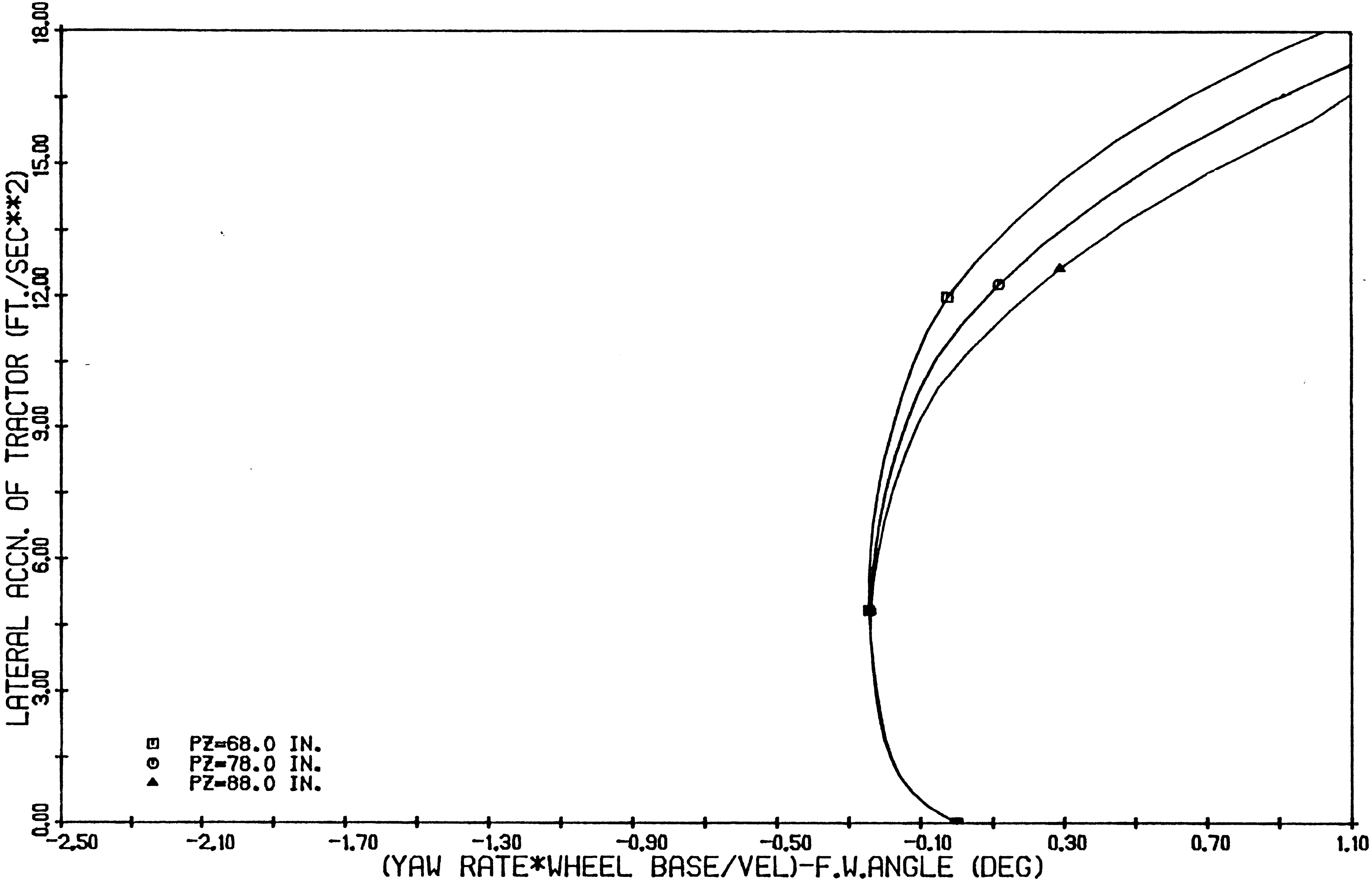
140 IN.WHEEL BASE TRACTOR,RIB TIRES,RUN # 55,56&57



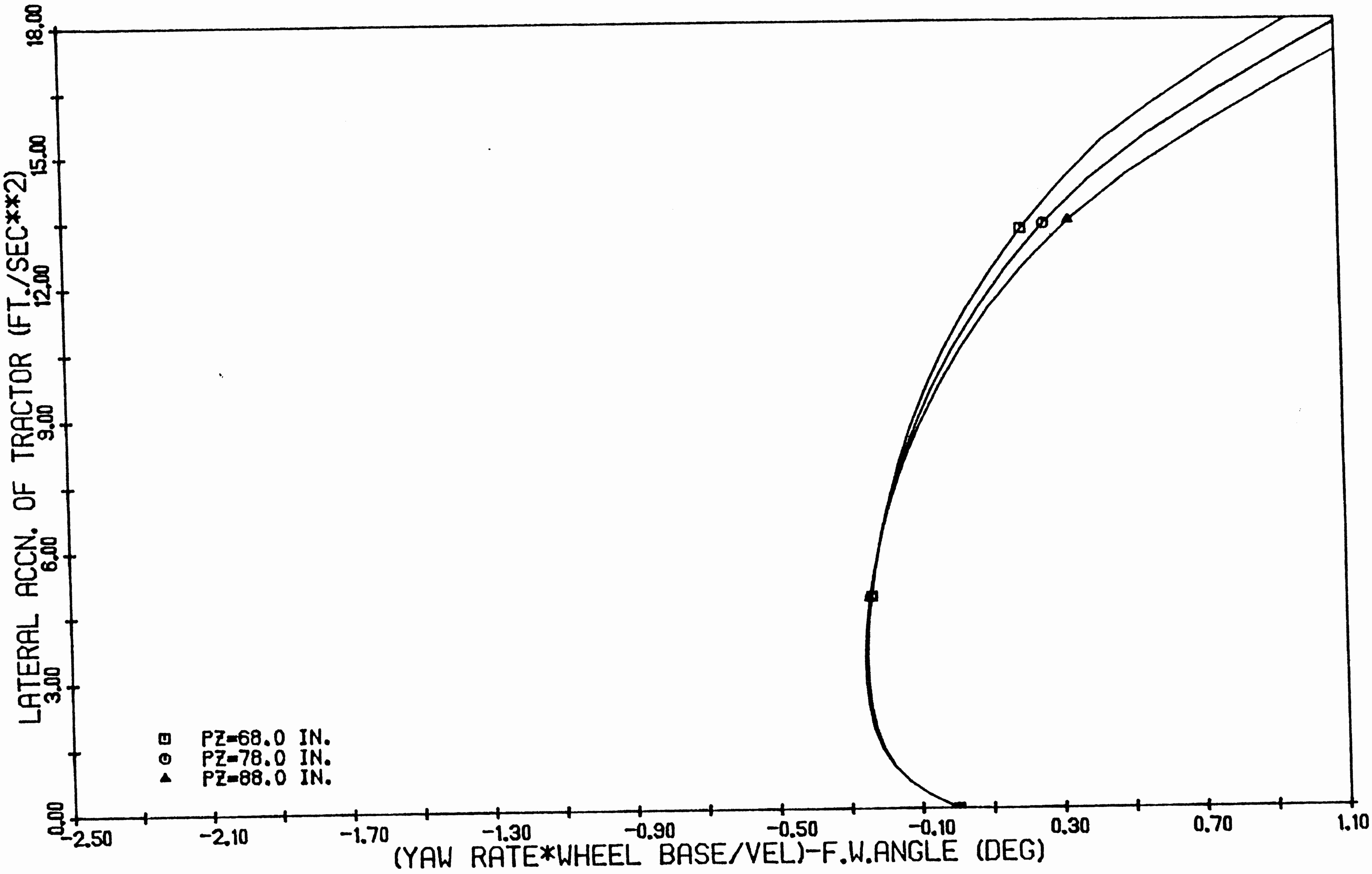
140 IN.WHEEL BASE TRACTOR,RIB TIRES,RUN # 58,59&60



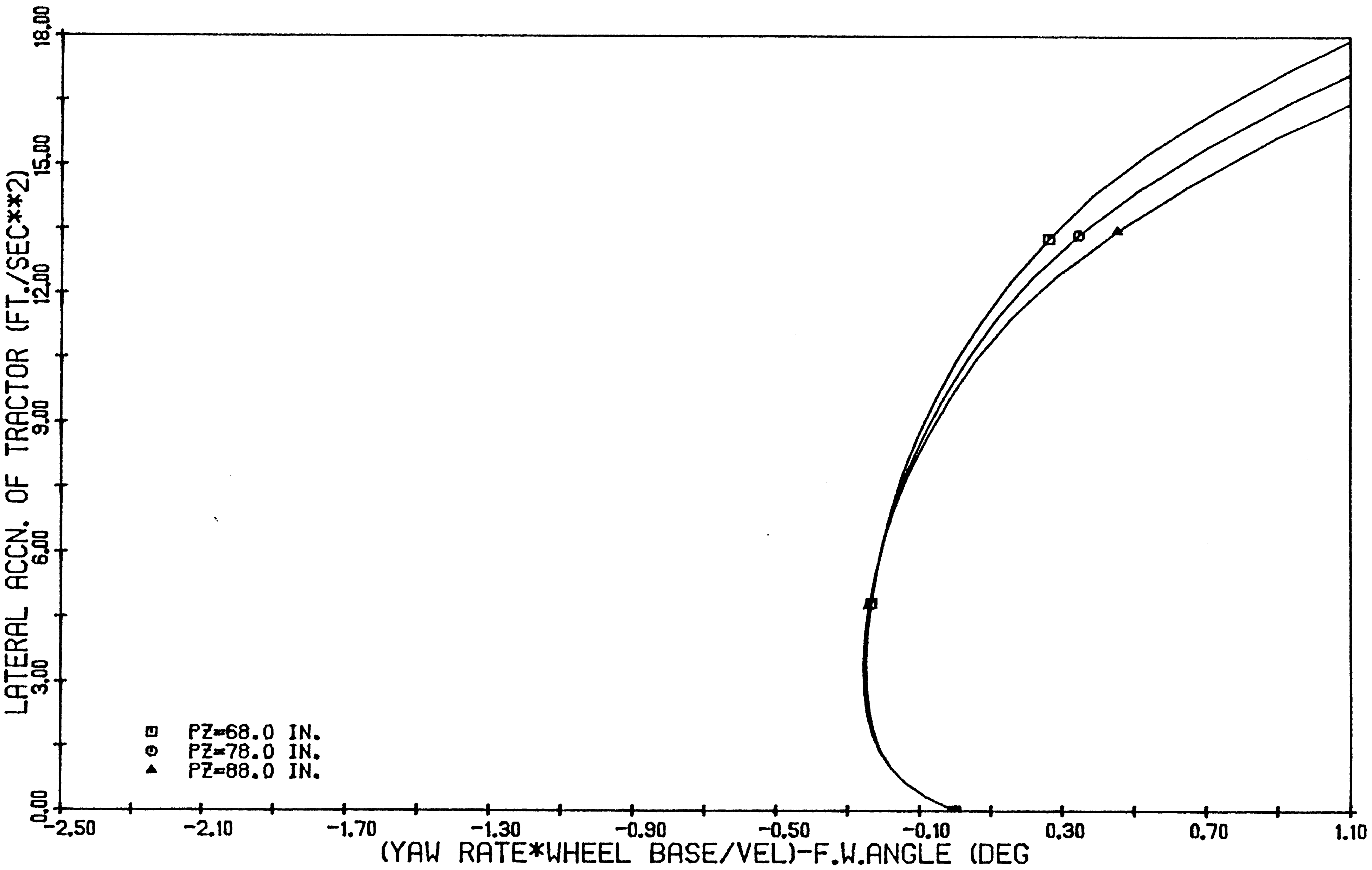
140 IN. WHEEL BASE TRACTOR, RIB TIRES, RUN # 61, 62&63



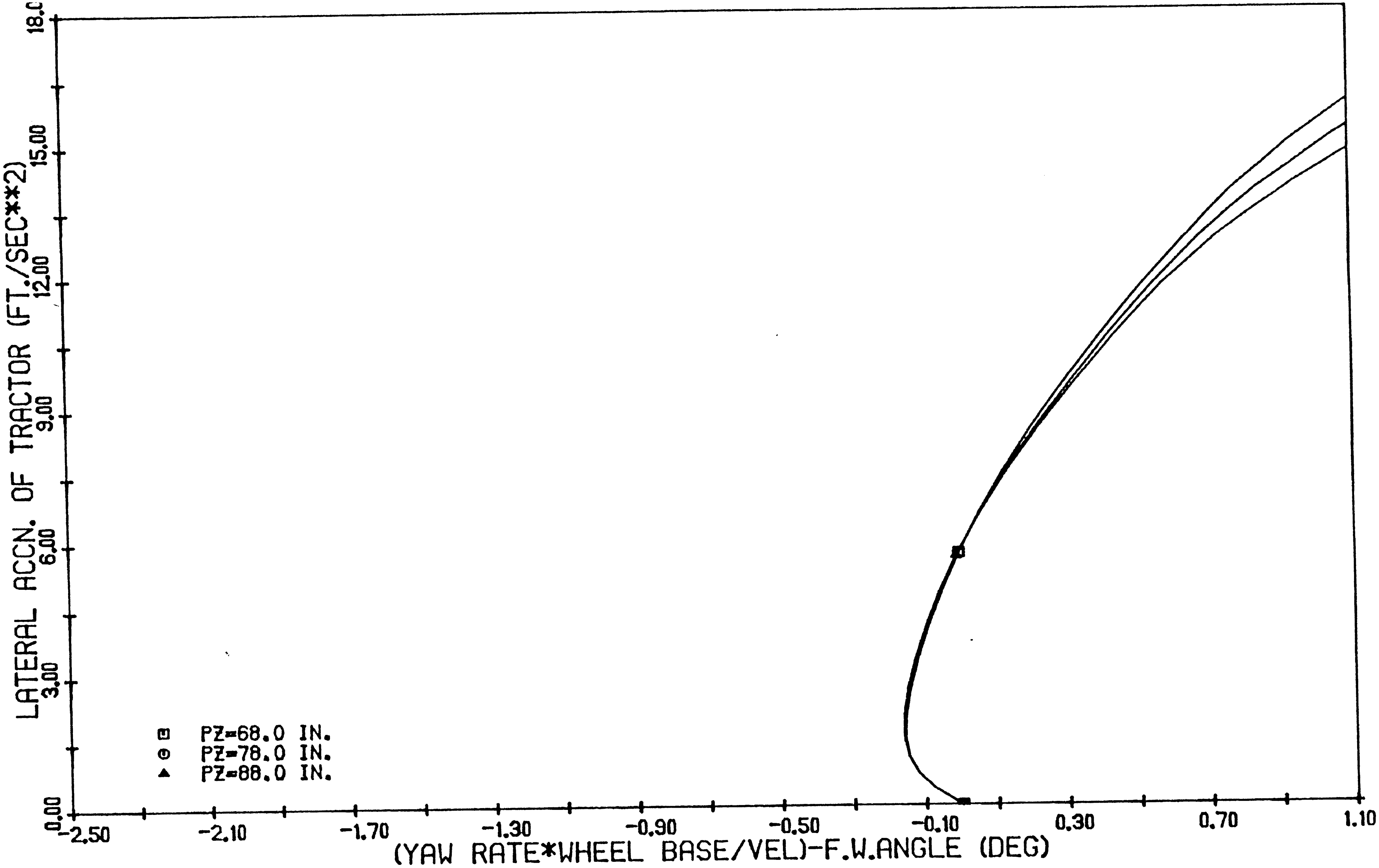
140 IN. WHEEL BASE TRACTOR, RIB TIRES, RUN # 64, 65&66



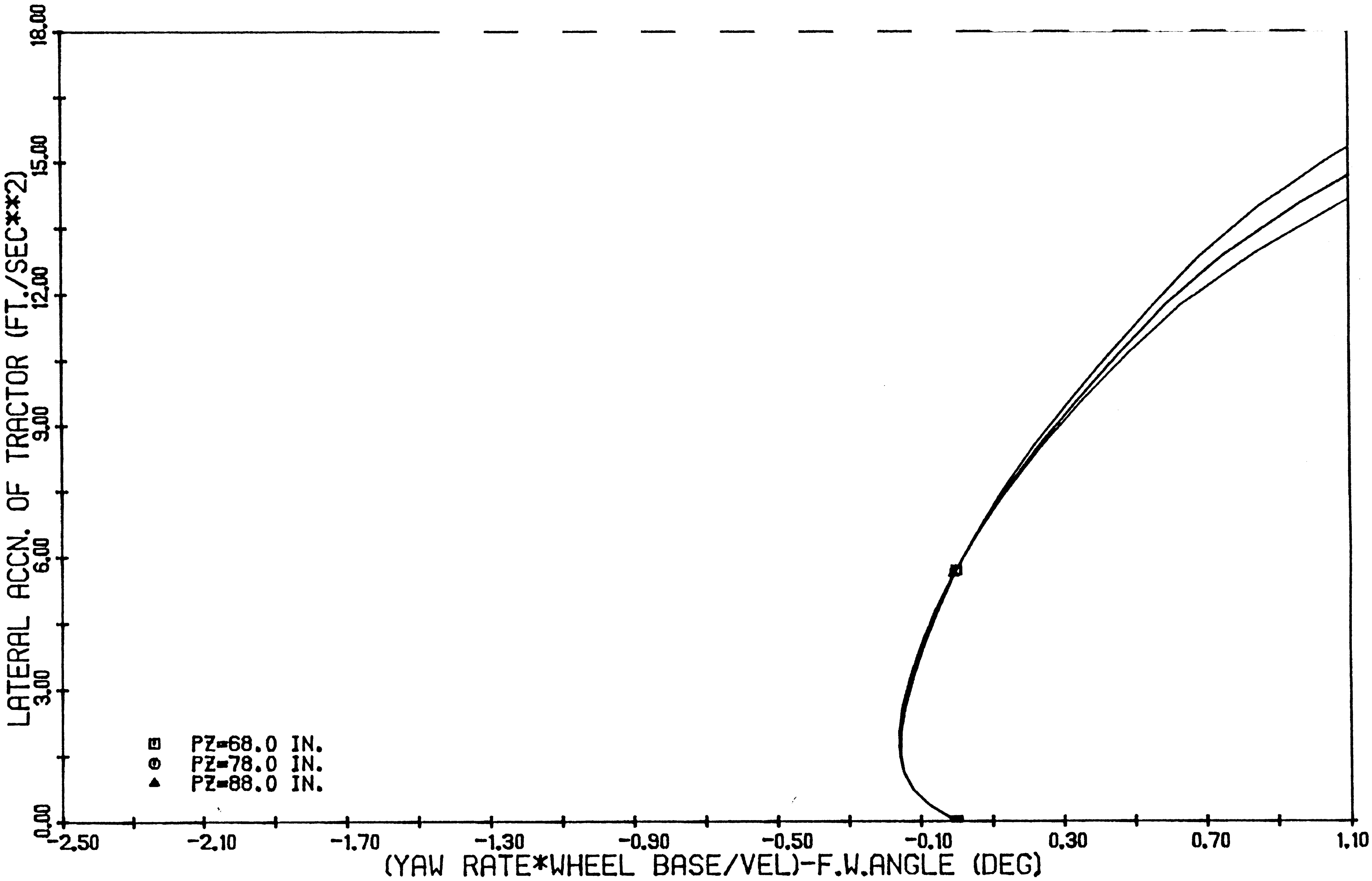
140 IN. WHEEL BASE TRACTOR, RIB TIRES, RUN # 67, 68&69



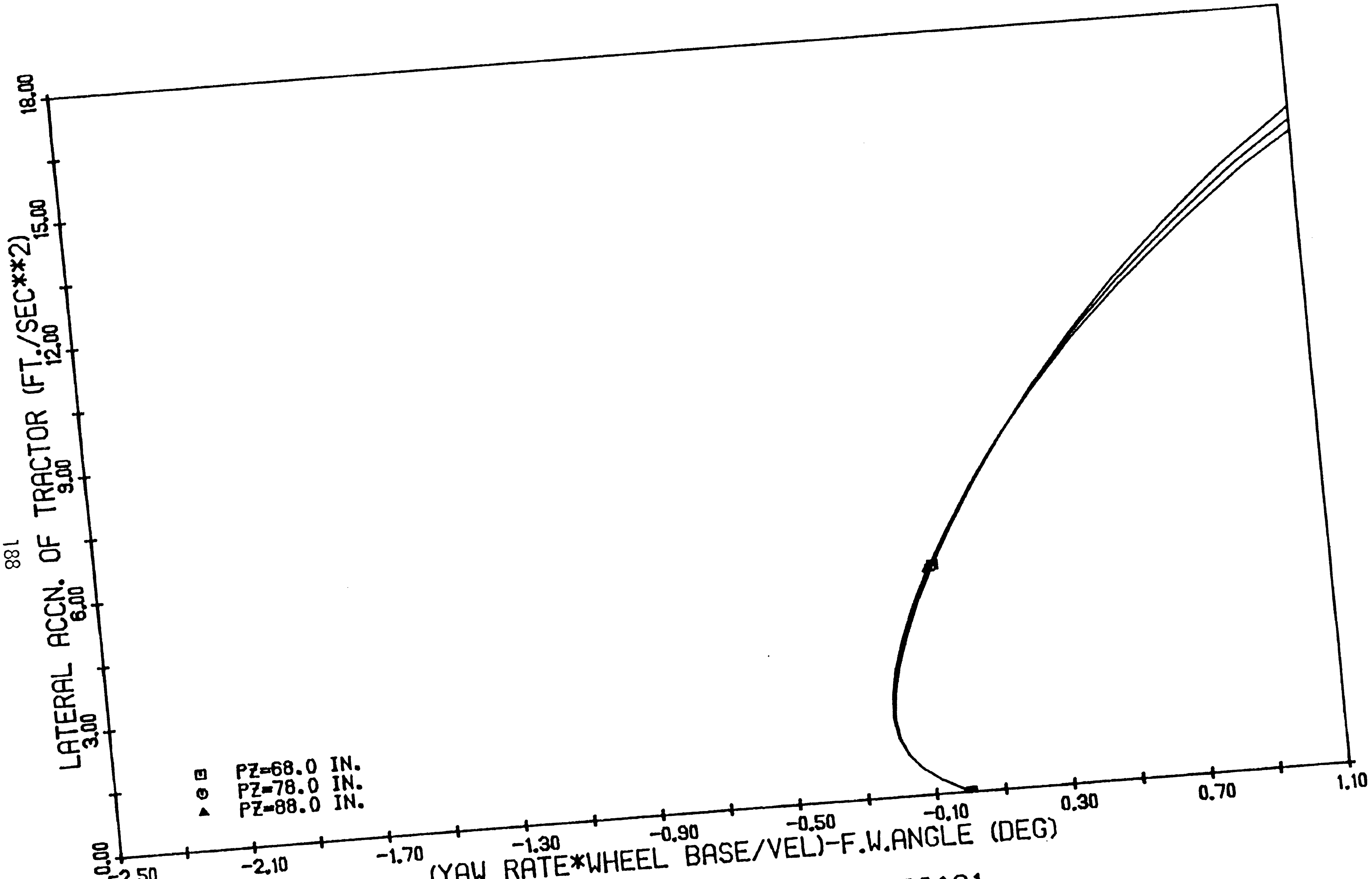
140 IN.WHEEL BASE TRACTOR,RIB TIRES,RUN # 70,71&72



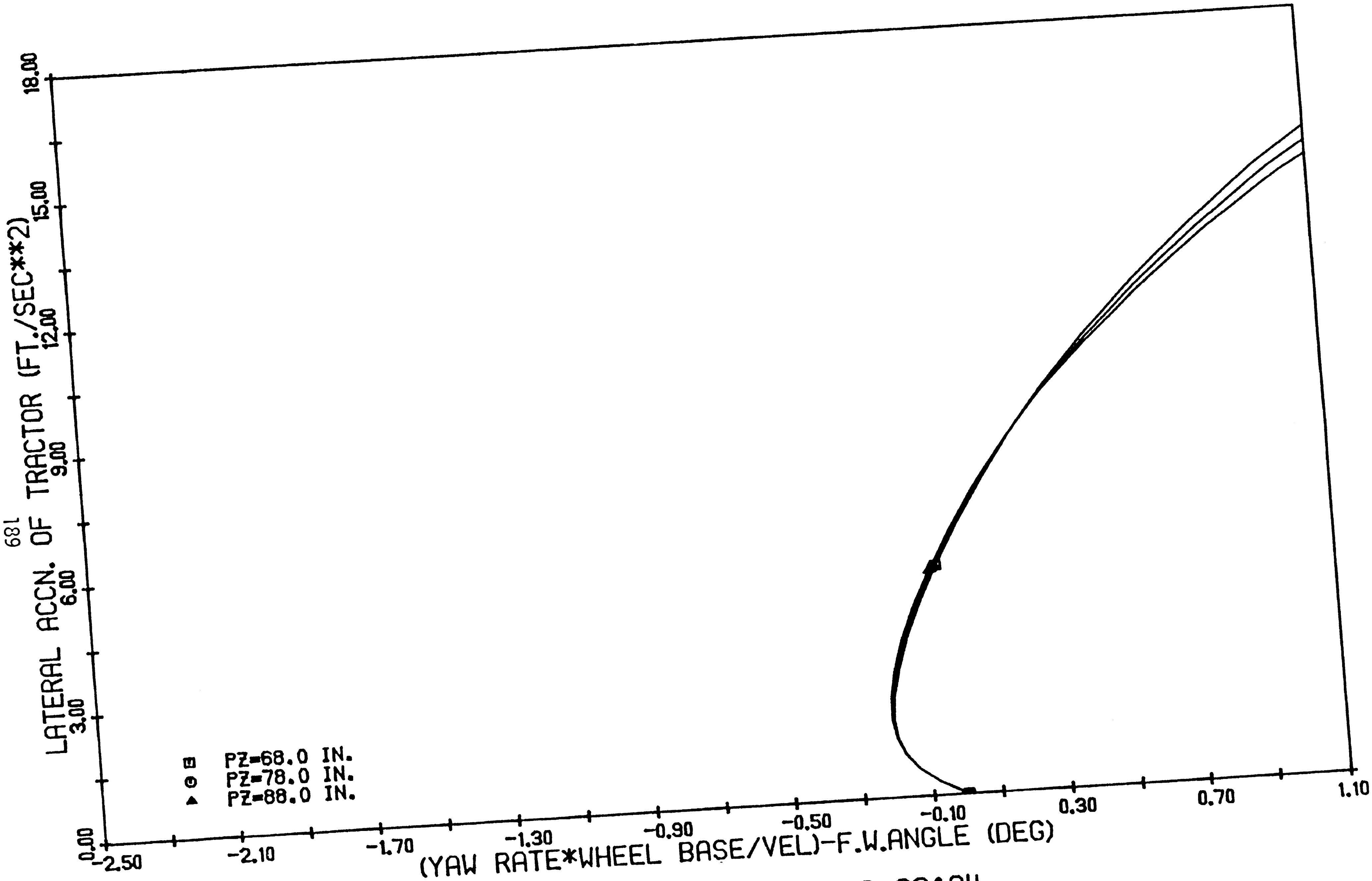
140 IN.WHEEL BASE TRACTOR,LUG TIRES,RUN # 73,74&75



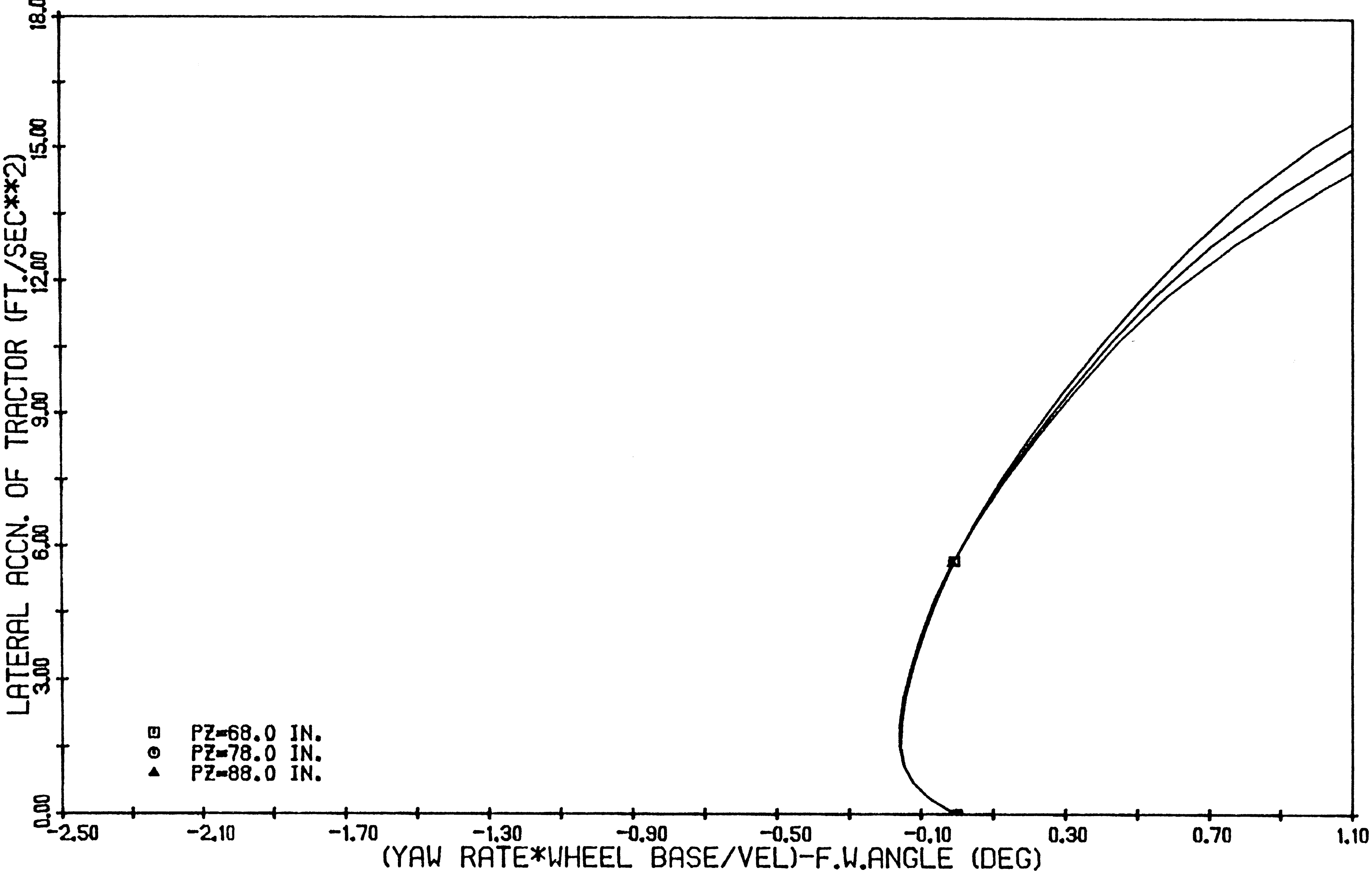
140 IN.WHEEL BASE TRACTOR,LUG TIRES,RUN # 76,77&78



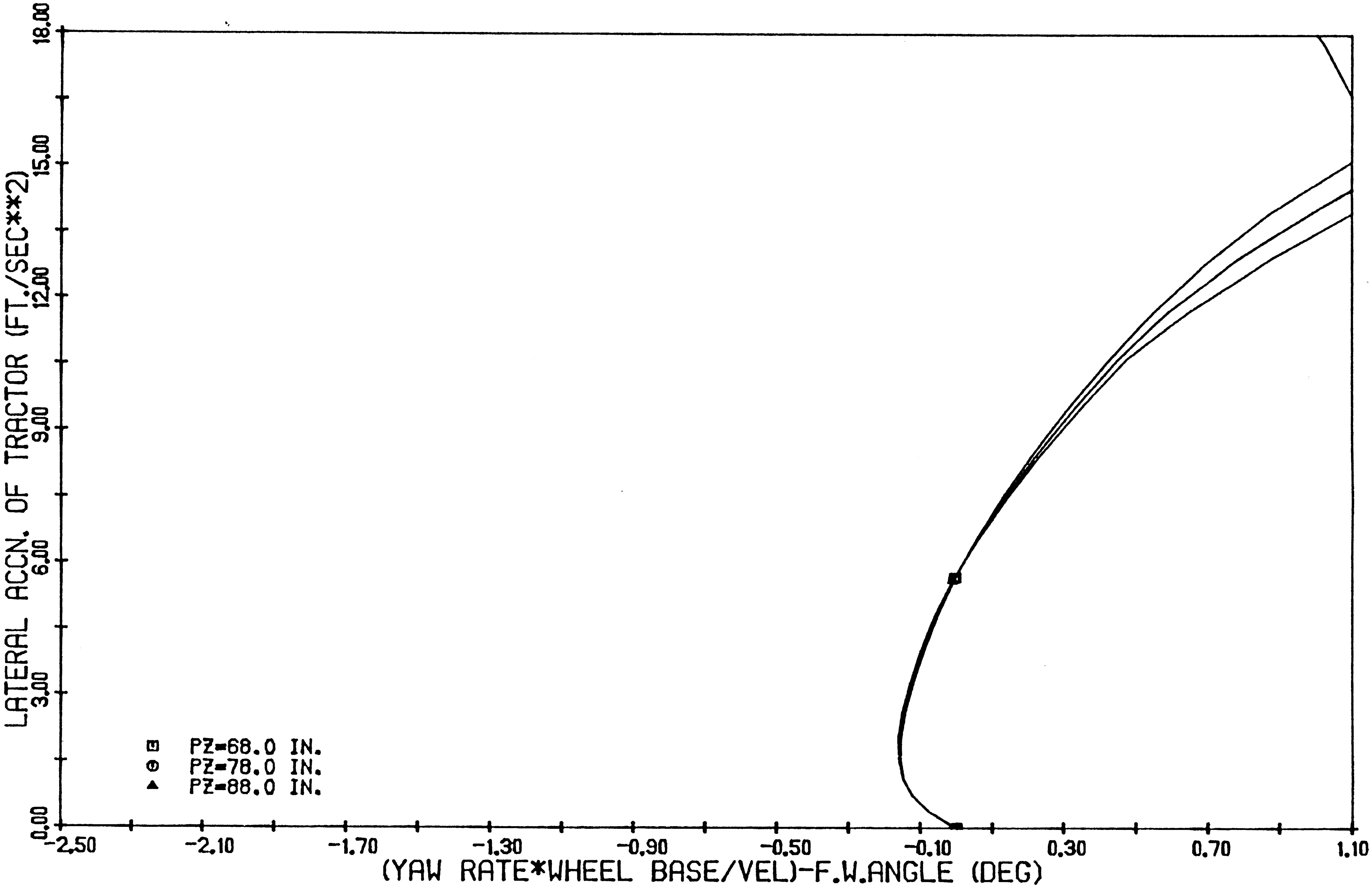
140 IN.WHEEL BASE TRACTOR,LUG TIRES,RUN # 79,80&81



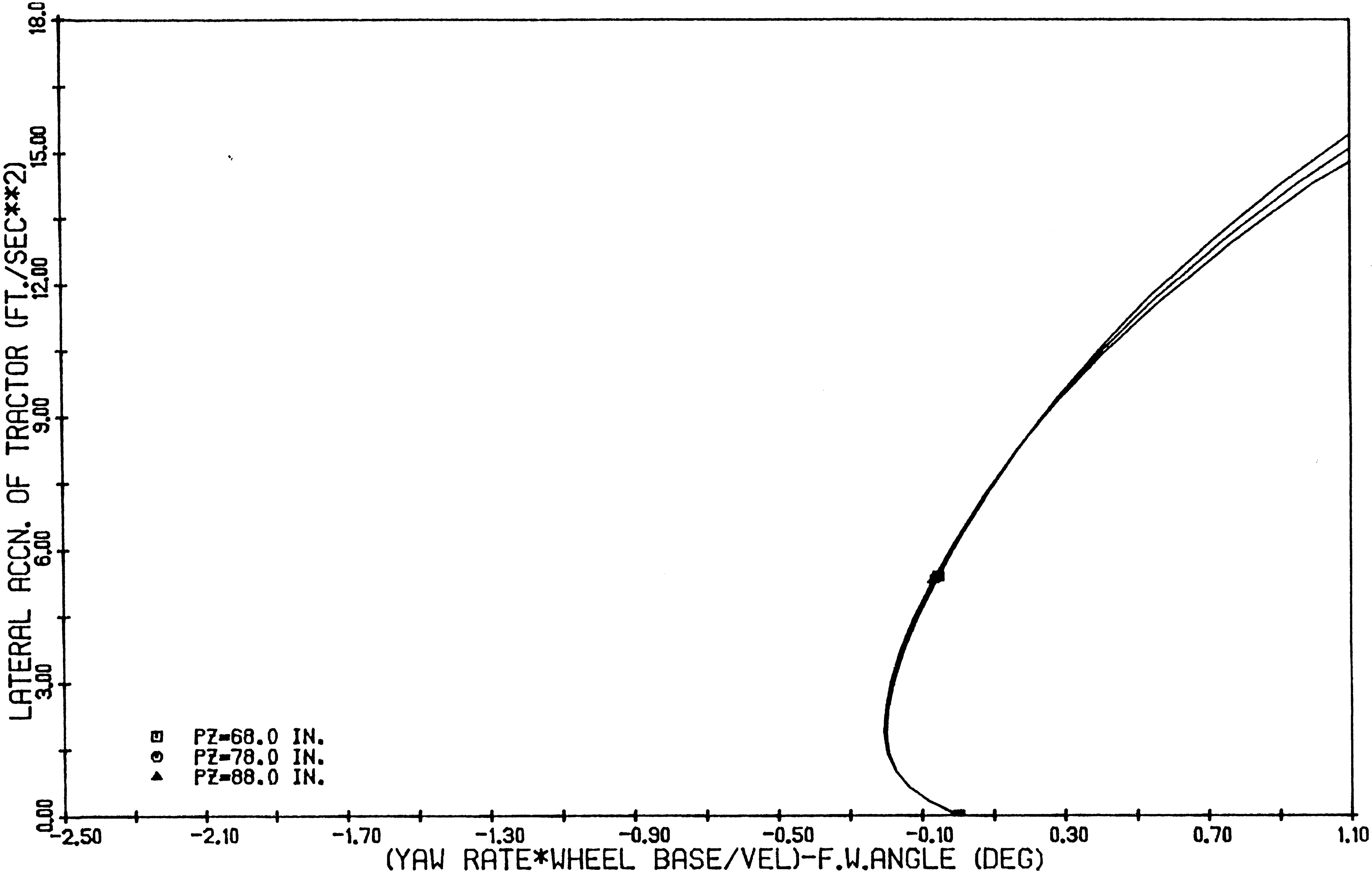
140 IN.WHEEL BASE TRACTOR,LUG TIRES,RUN # 82,83&84



140 IN. WHEEL BASE TRACTOR, LUG TIRES, RUN # 85, 86&87



140 IN.WHEEL BASE TRACTOR,LUG TIRES,RUN # 88,89&90



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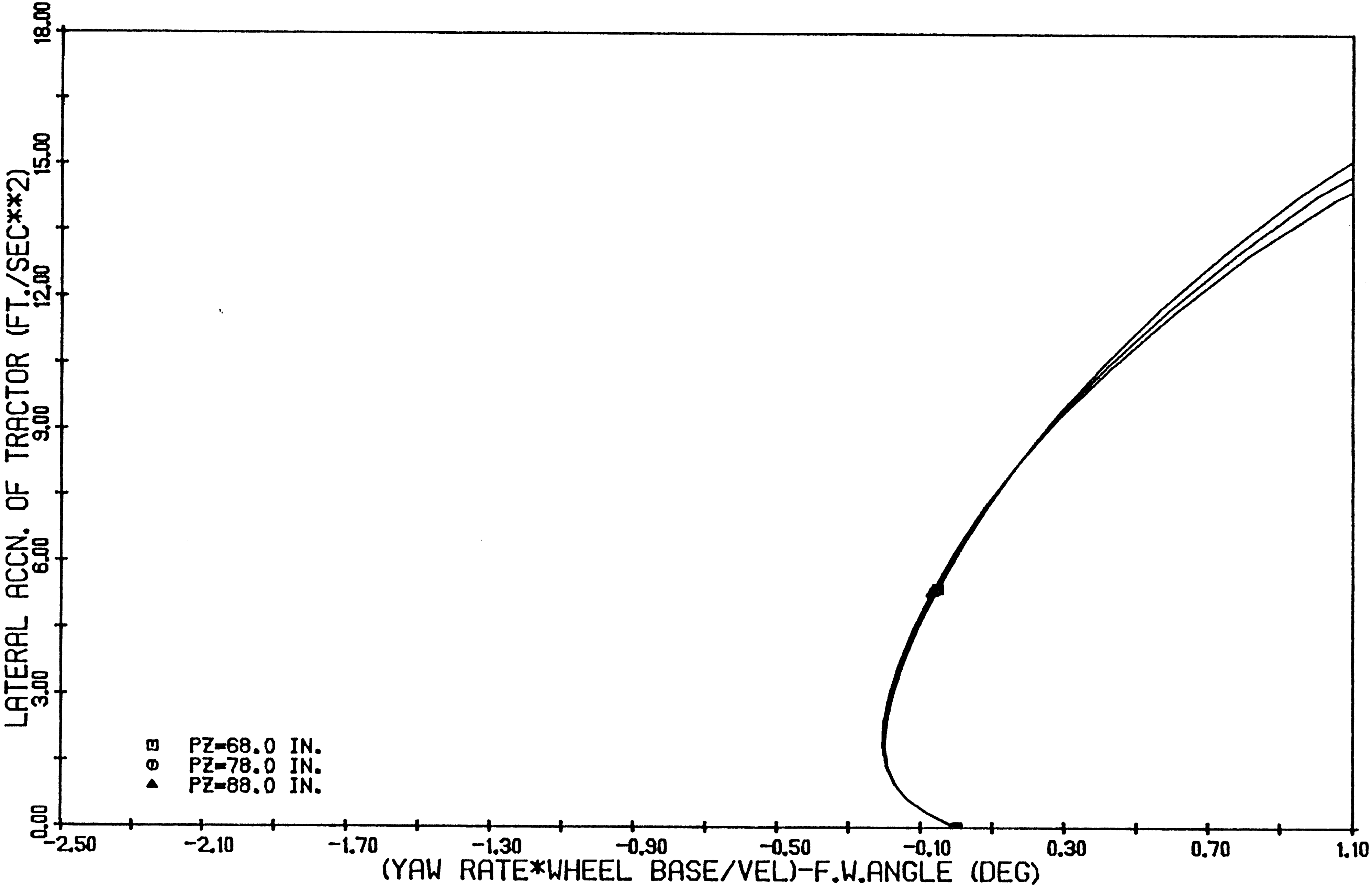
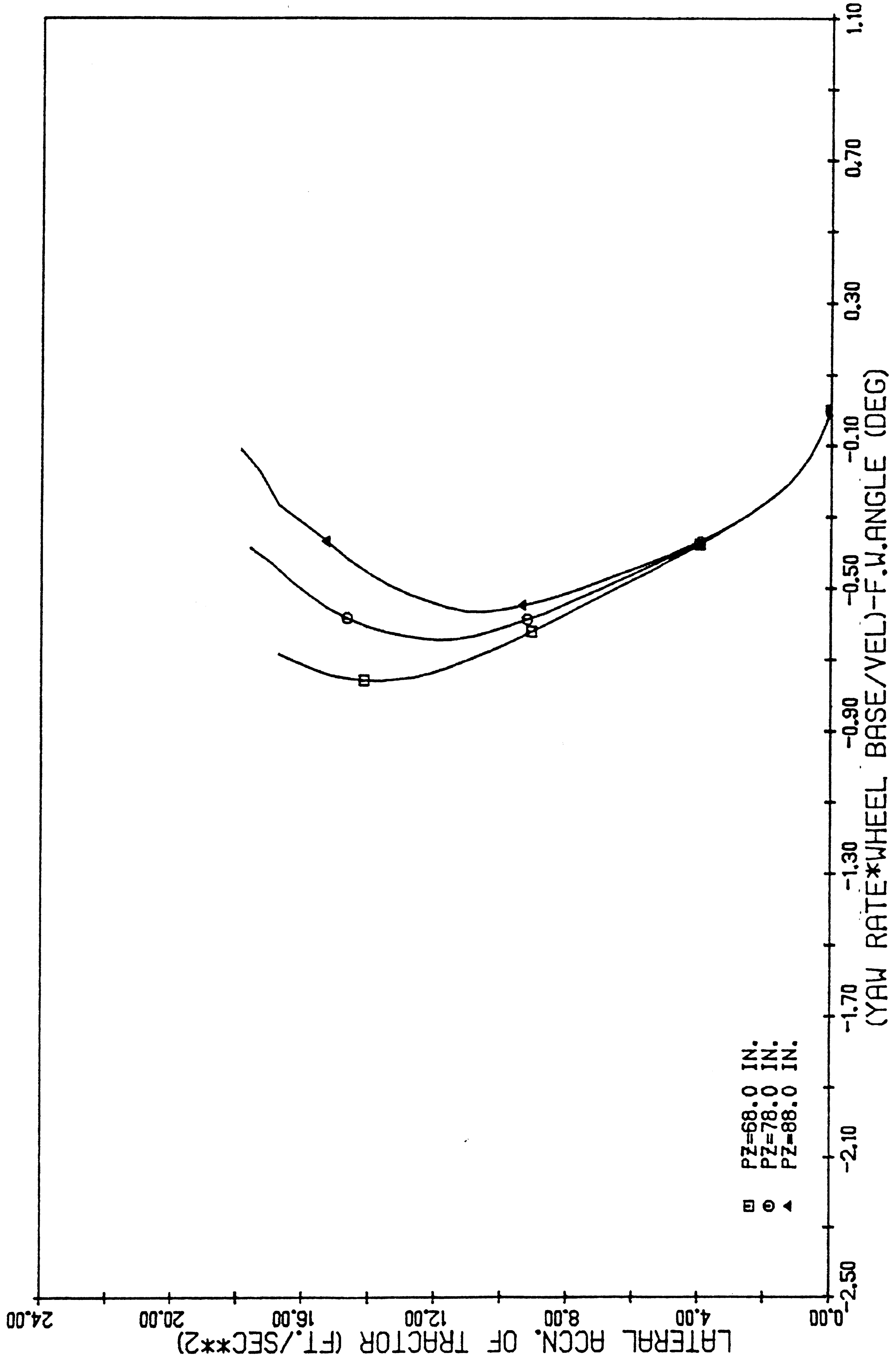
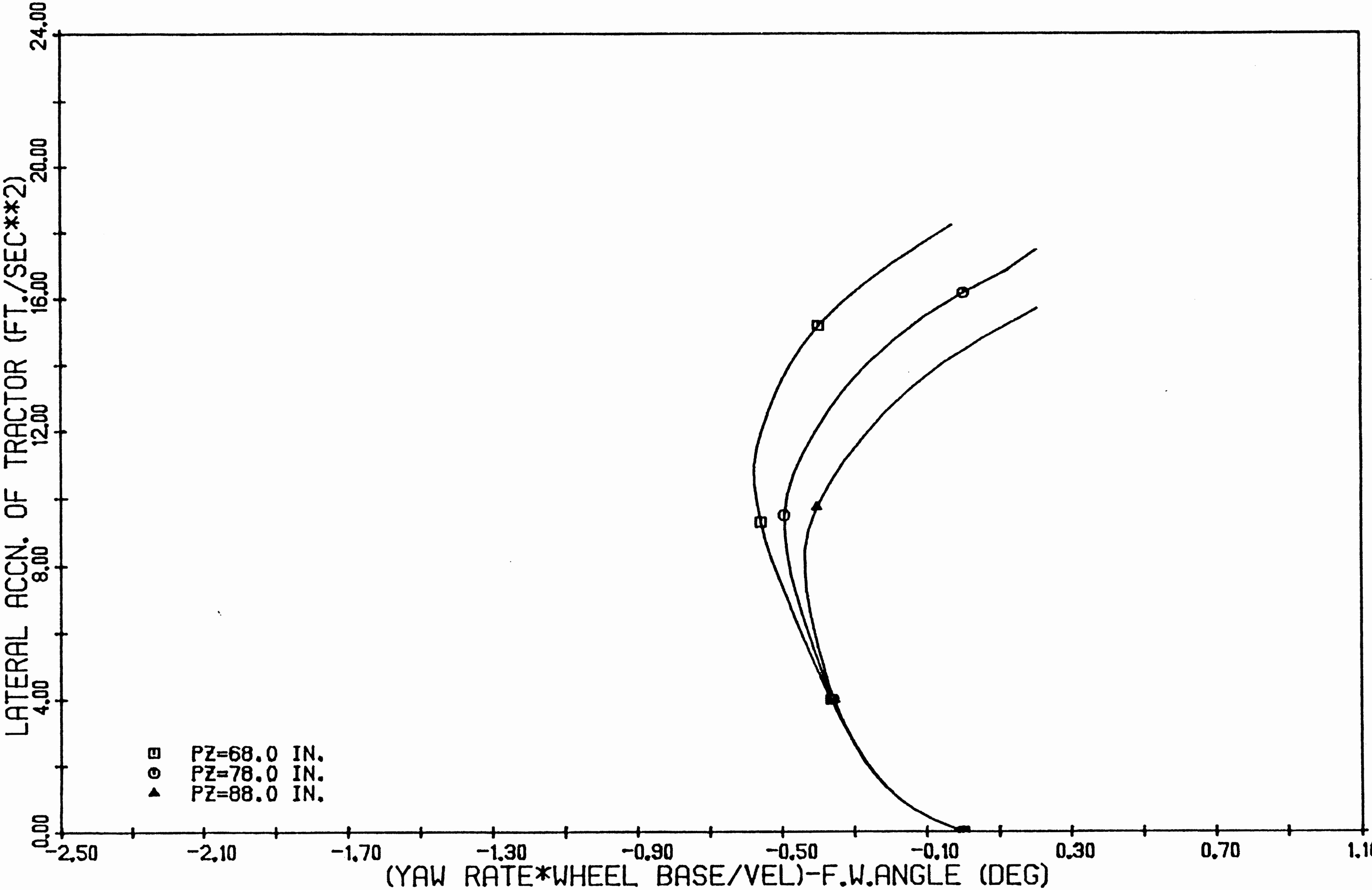


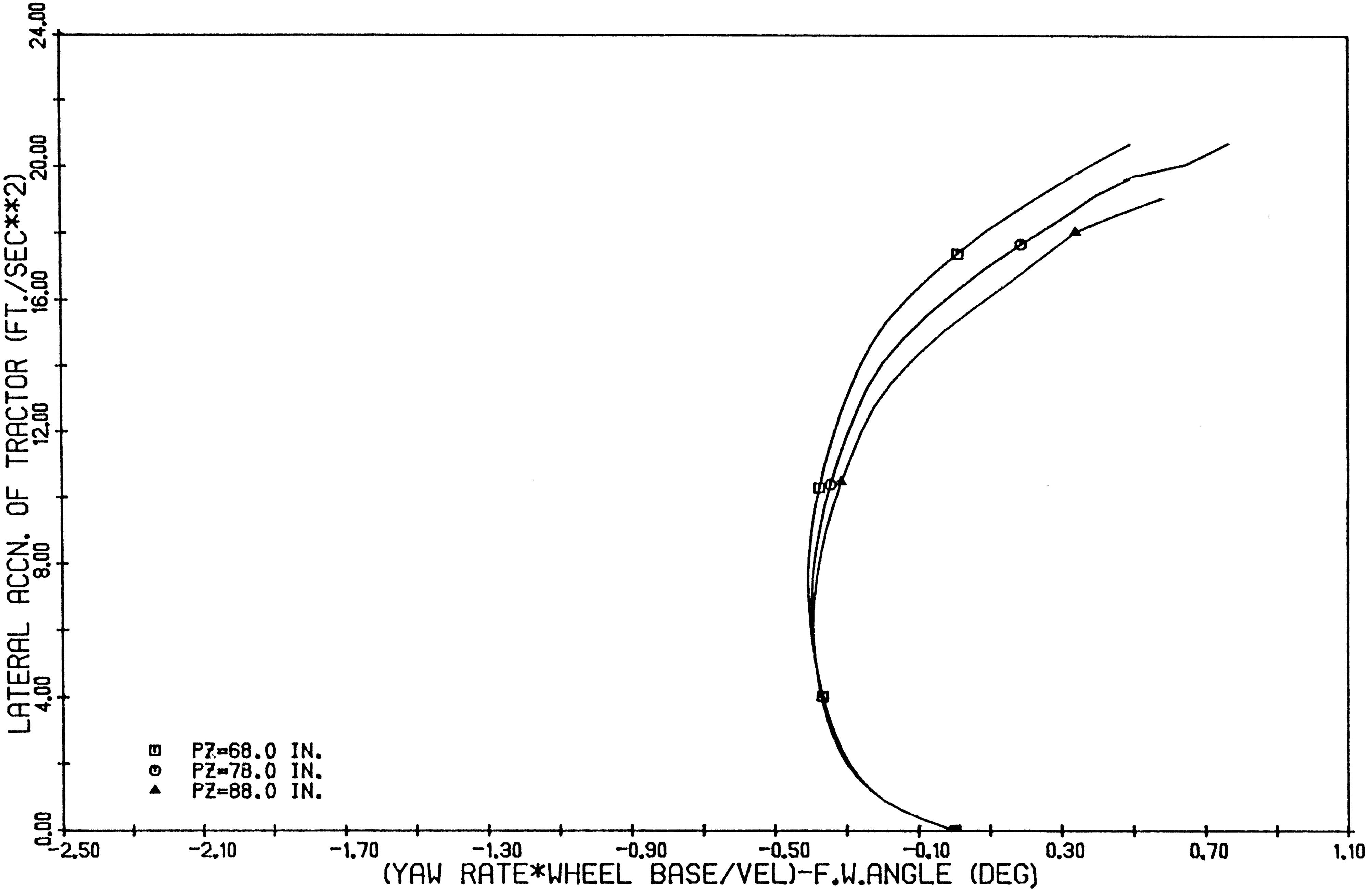
140 IN.WHEEL BASE TRACTOR,LUG TIRES,RUN # 94,95&96



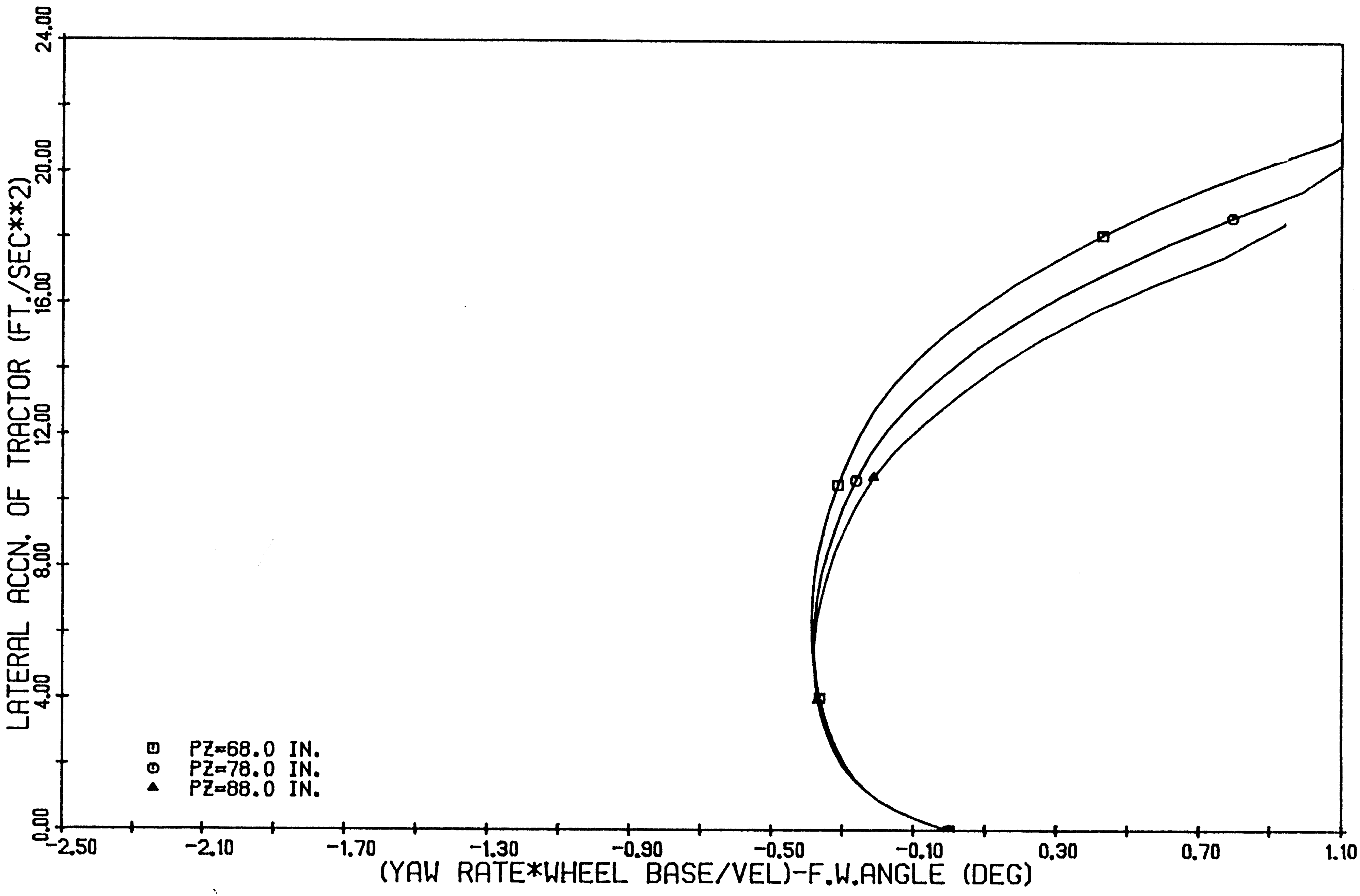
145 IN.WHEEL BASE TRACTOR,RIB TIRES,RUN # 97,98&99



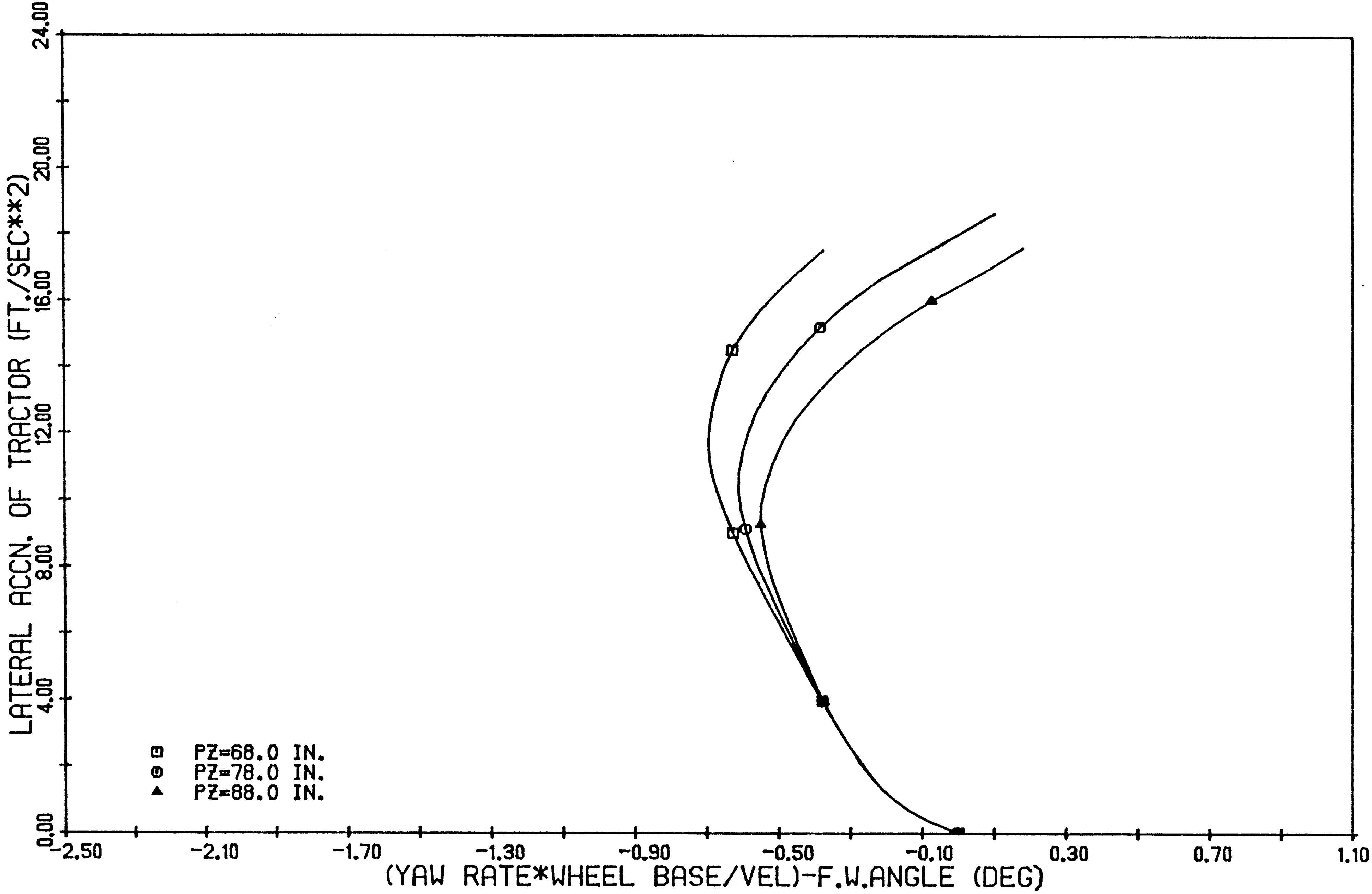
145 IN. WHEEL BASE TRACTOR, RIB TIRES, RUN # 100, 101&102



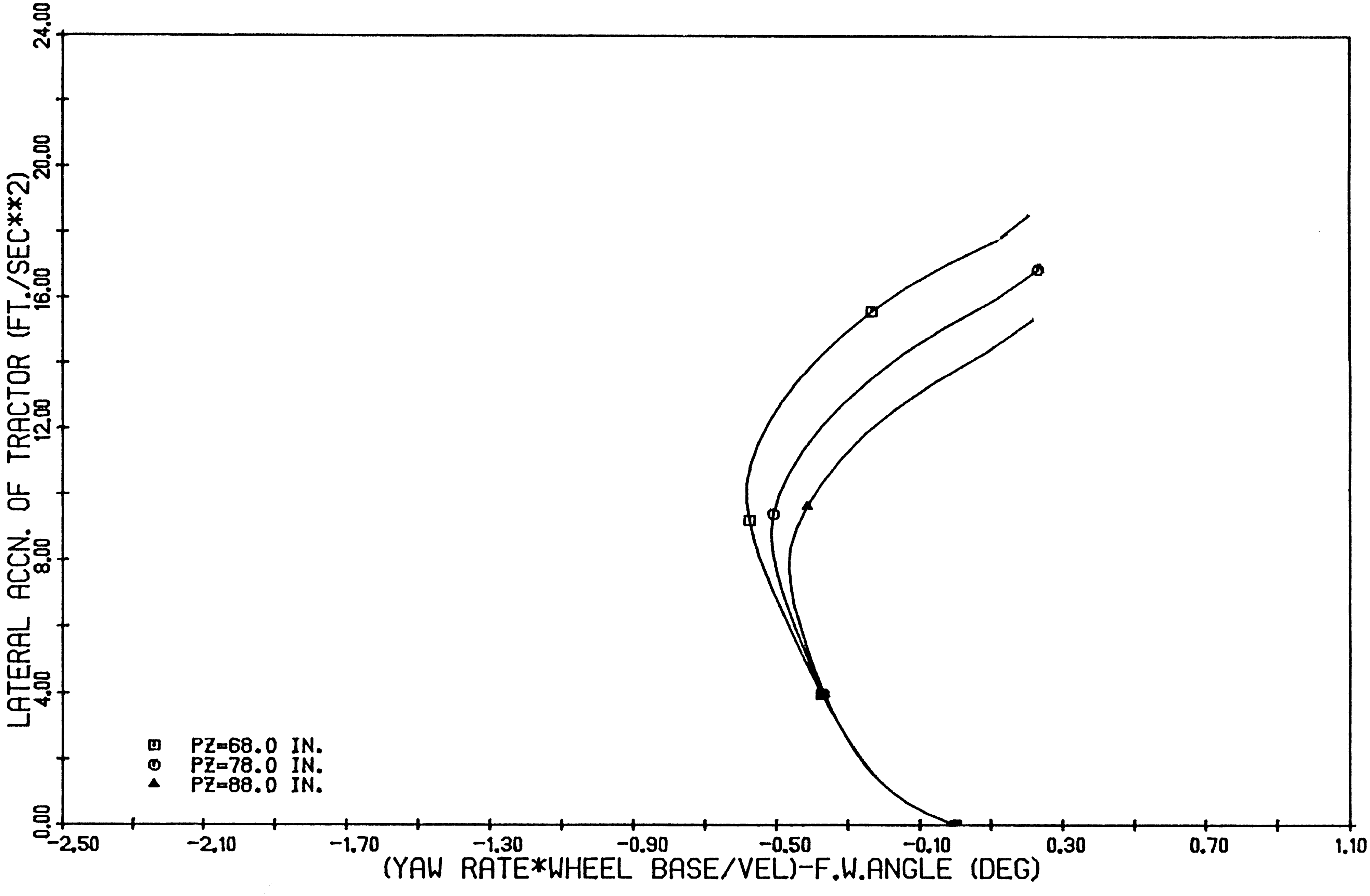
145 IN. WHEEL BASE TRACTOR, RIB TIRES, RUN # 103, 104&105



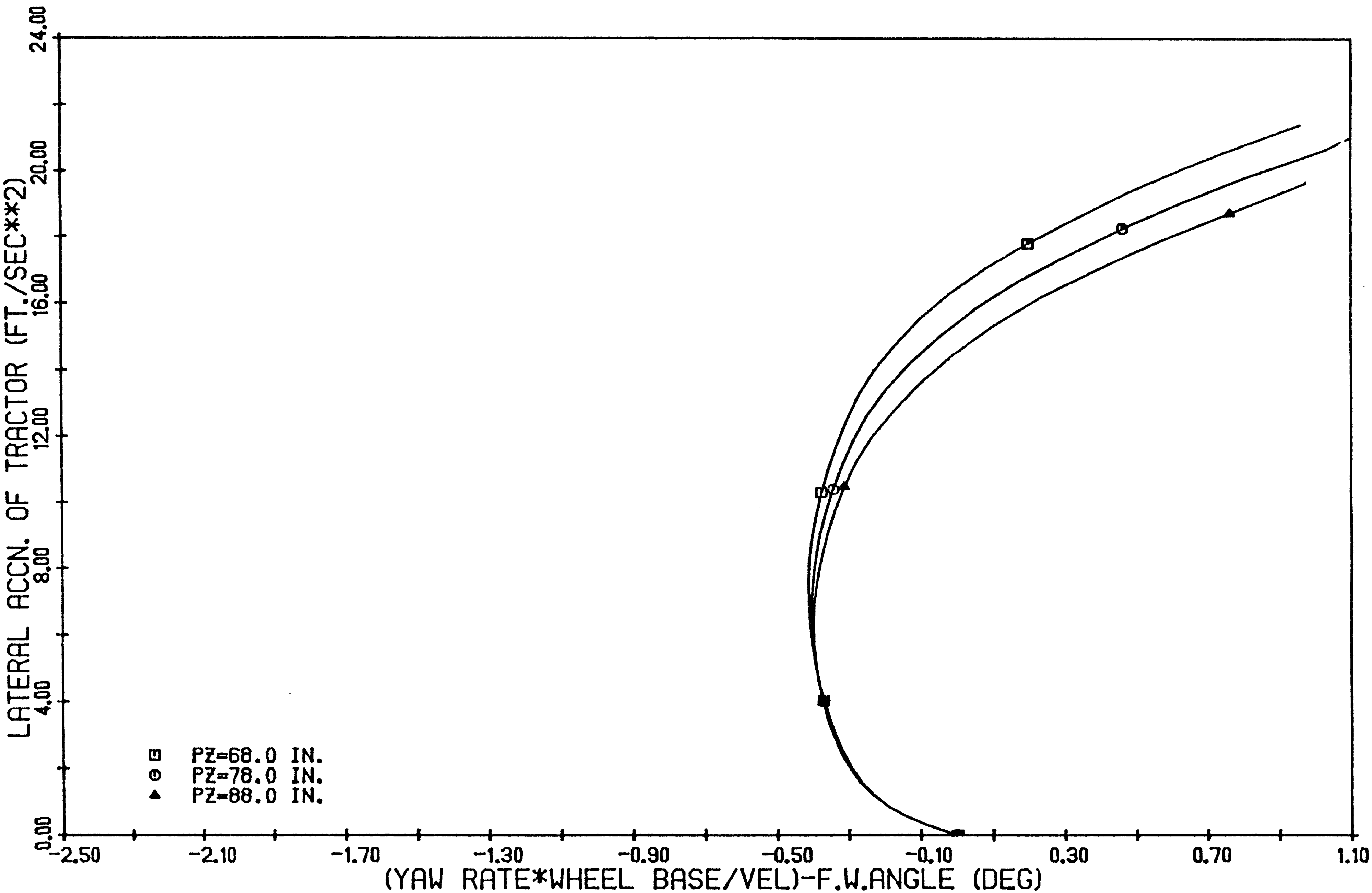
145 IN. WHEEL BASE TRACTOR, RIB TIRES, RUN # 106, 107&108



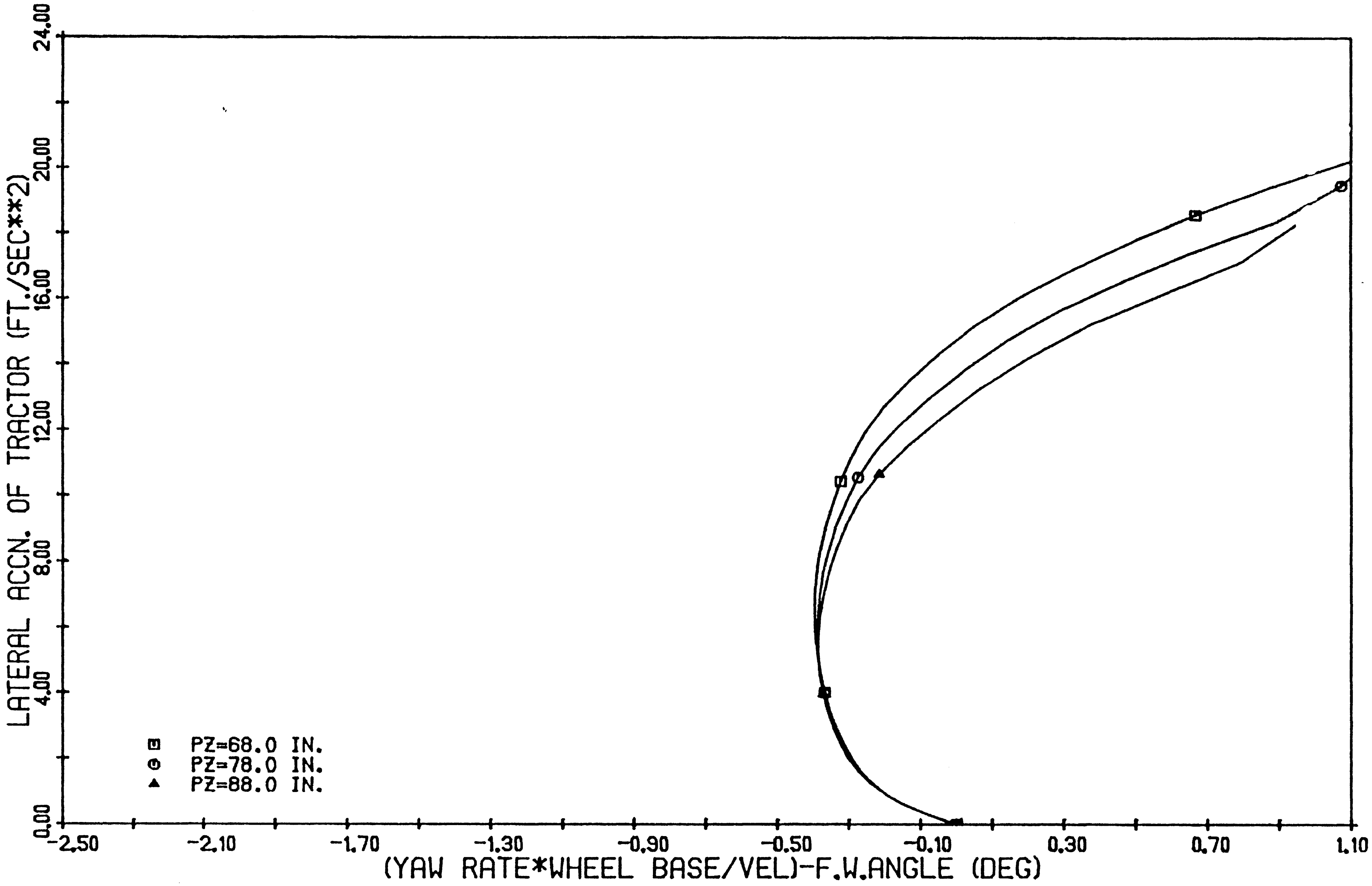
145 IN. WHEEL BASE TRACTOR, RIB TIRES, RUN # 109, 110&111



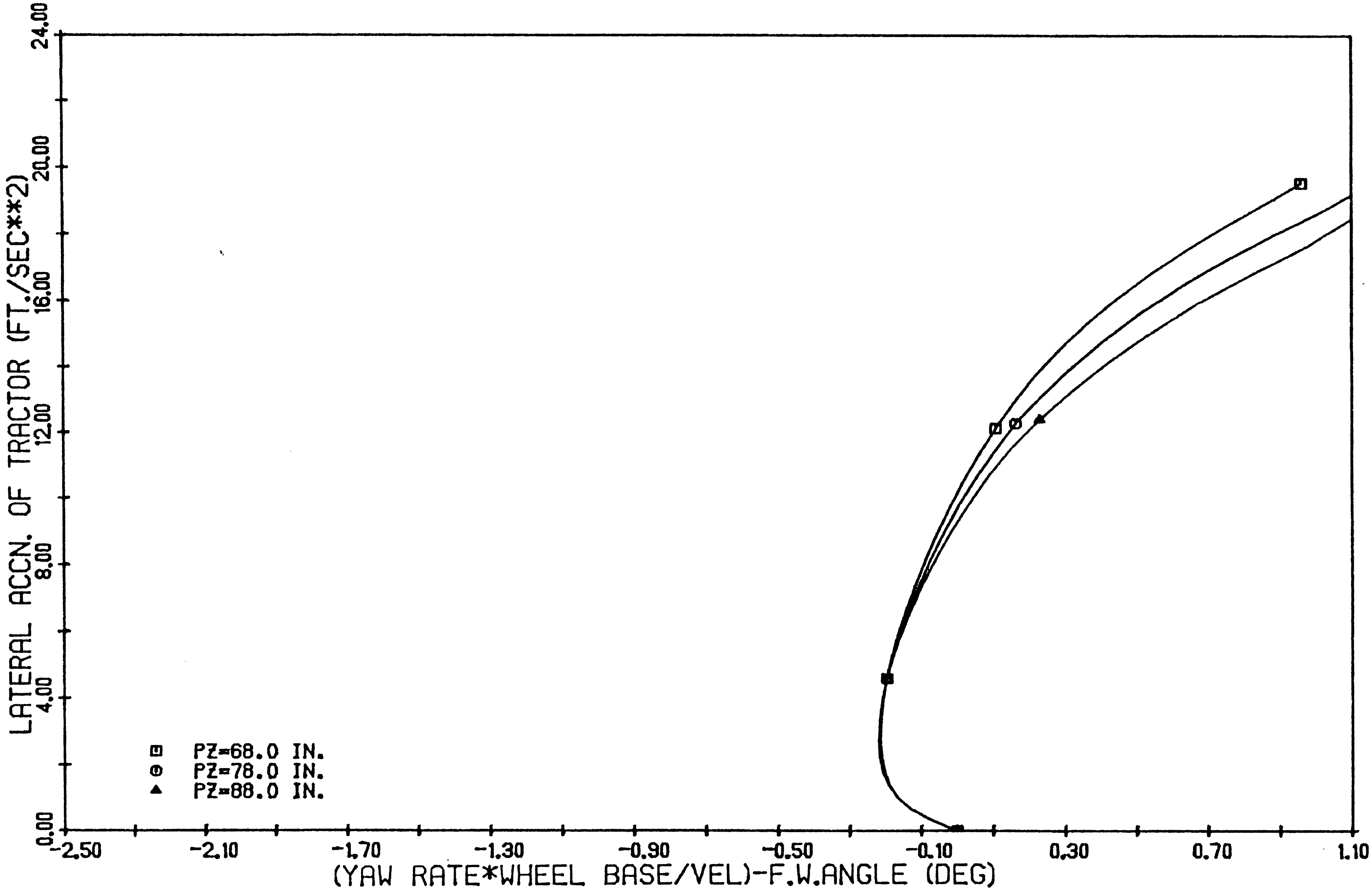
145 IN. WHEEL BASE TRACTOR, RIB TIRES, RUN # 112, 113&114



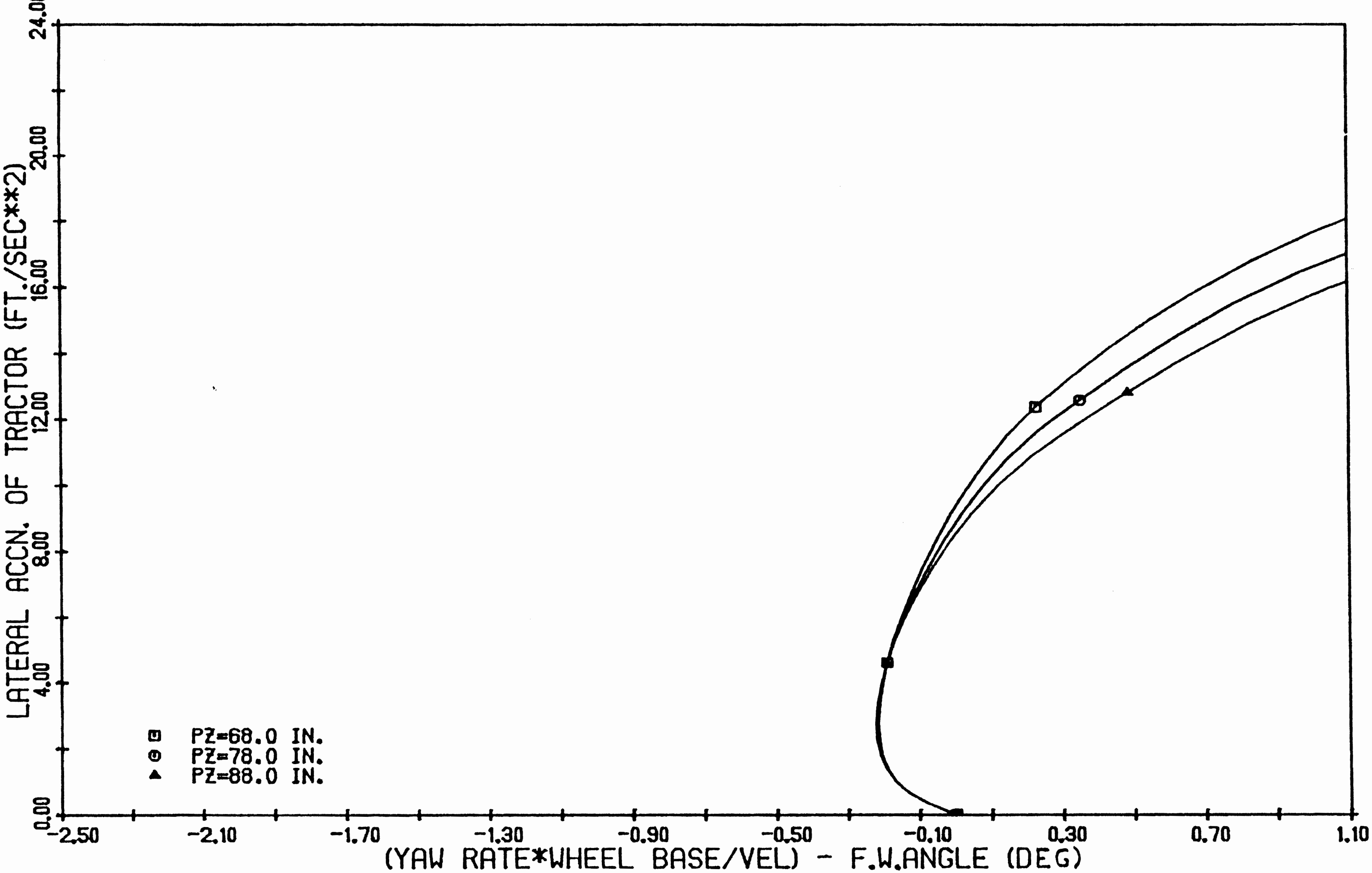
145 IN. WHEEL BASE TRACTOR, RIB TIRES, RUN # 115, 116&117



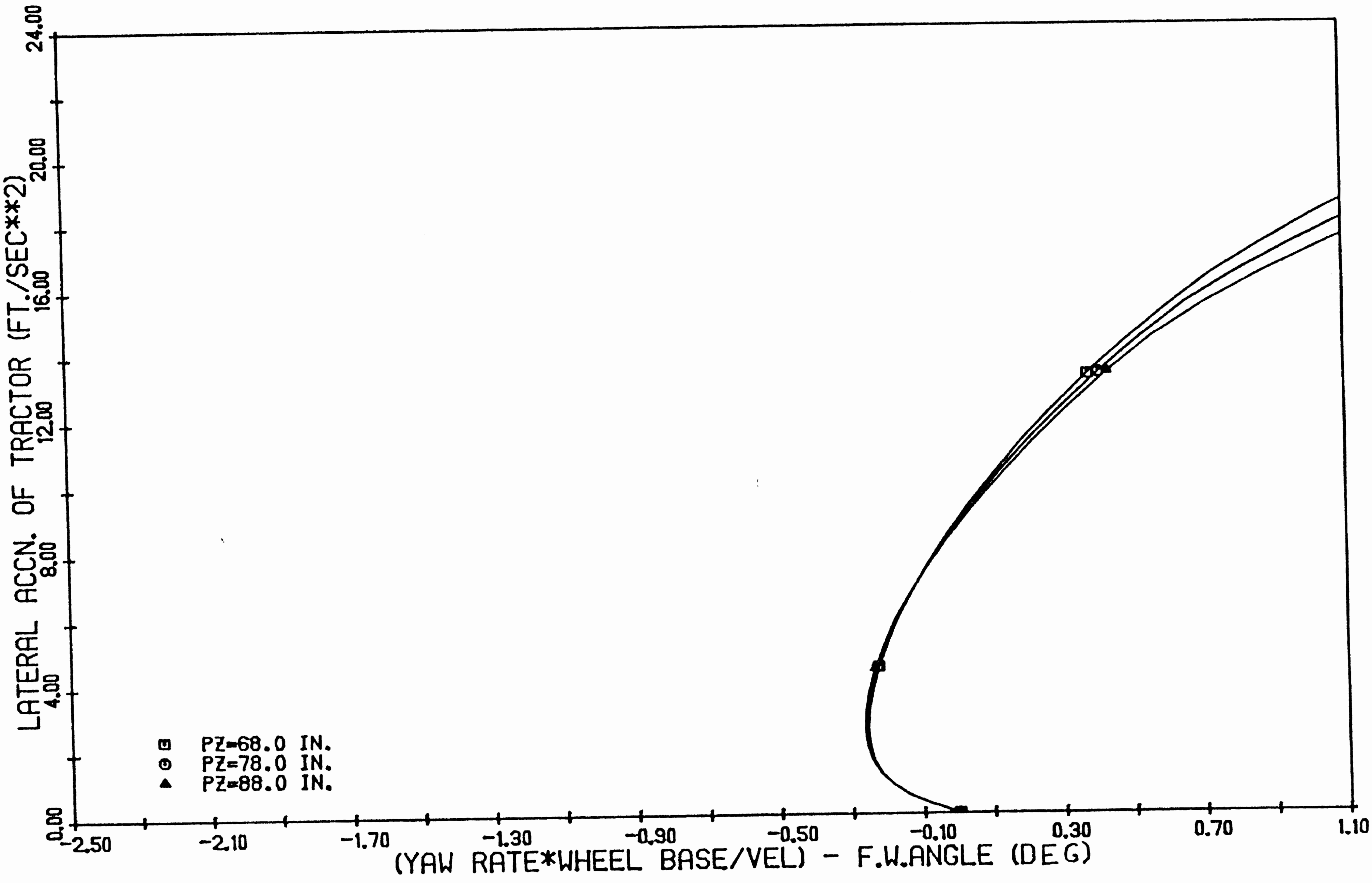
145 IN.WHEEL BASE TRACTOR, RIB TIRES, RUN # 118, 119&120



145 IN.WHEEL BASE TRACTOR,LUG TIRES,RUN # 121,122&123



145 IN. WHEEL BASE TRACTOR, LUG TIRES, RUN # 124, 125&126



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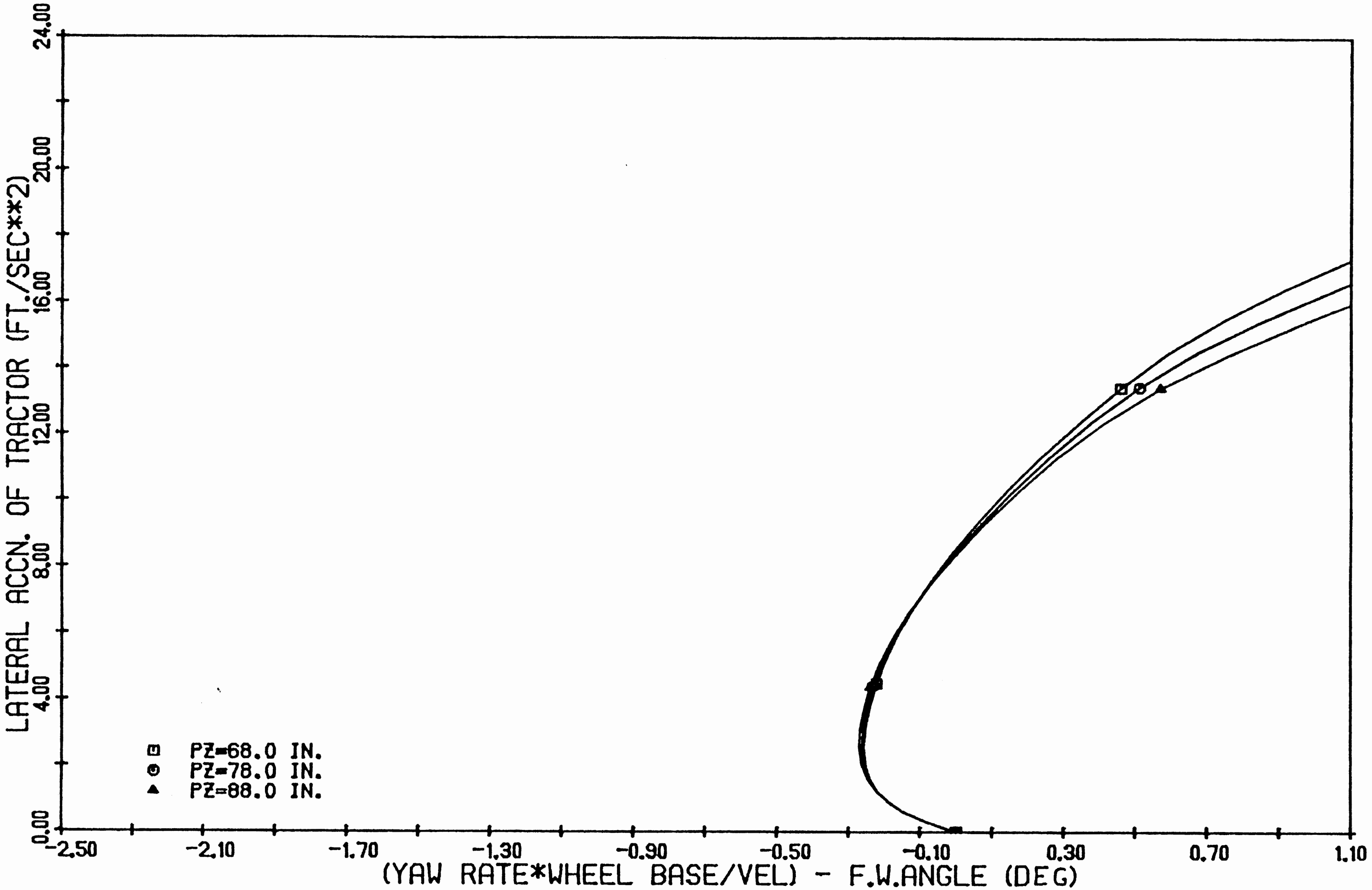

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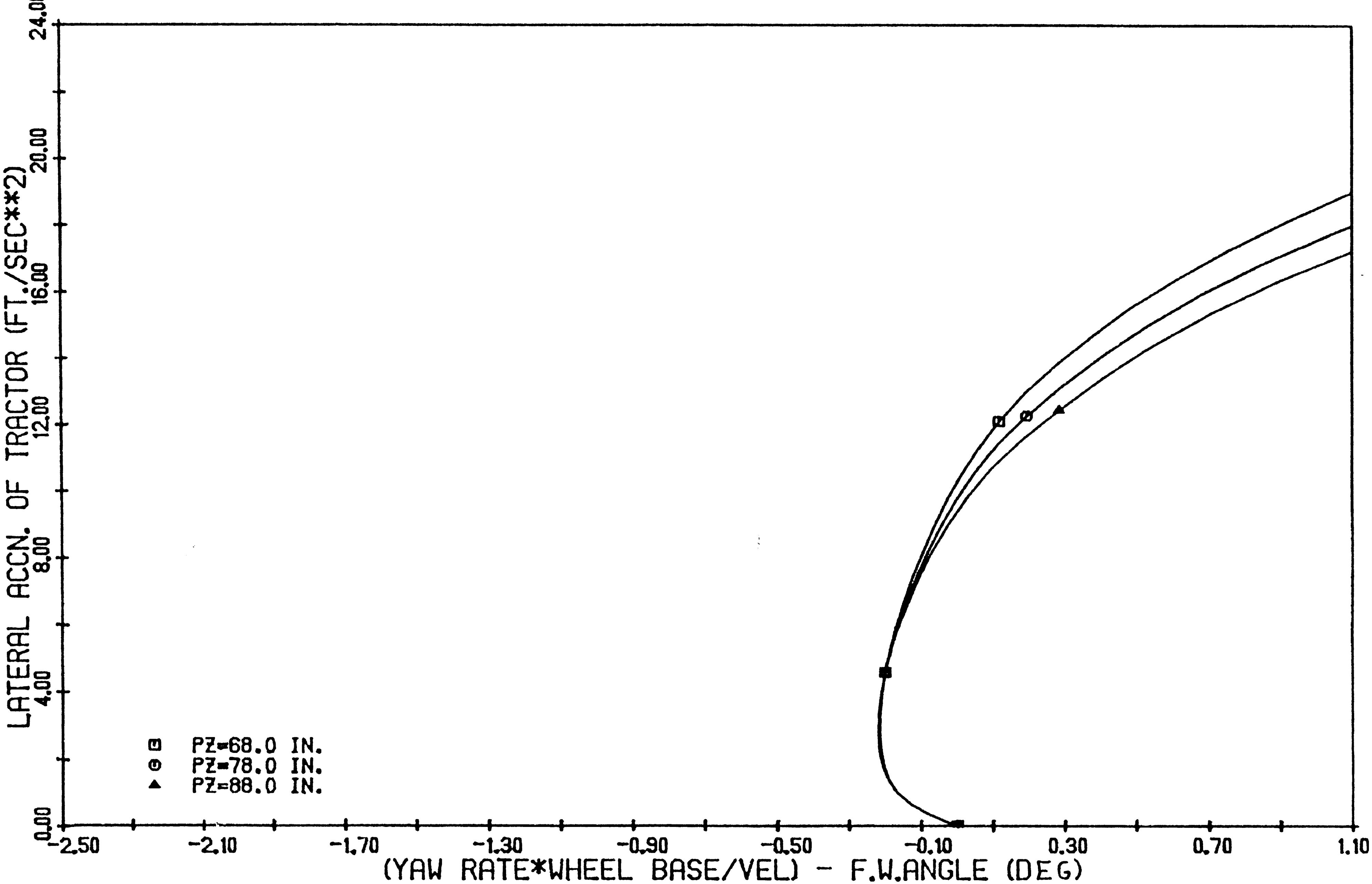

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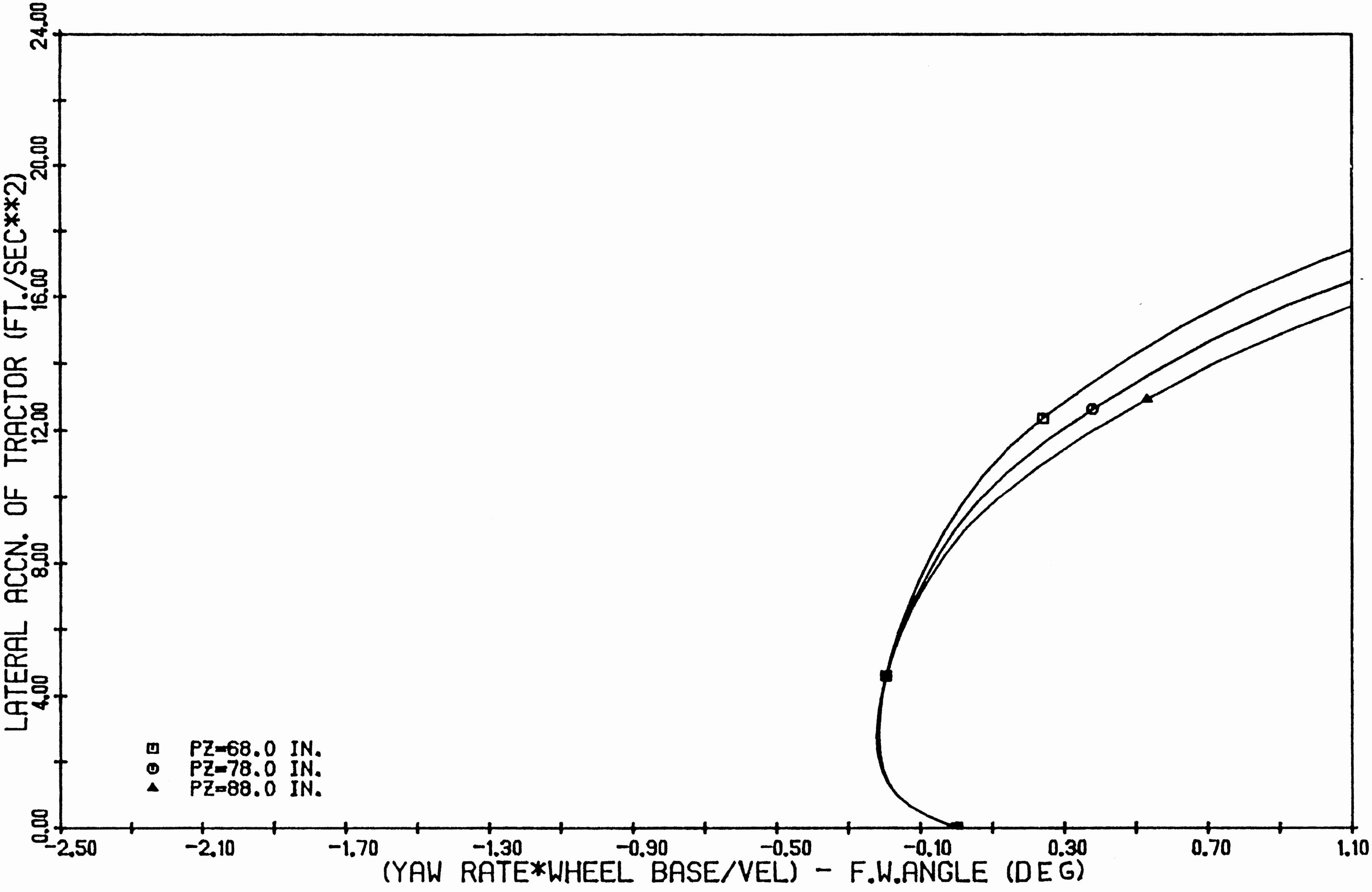

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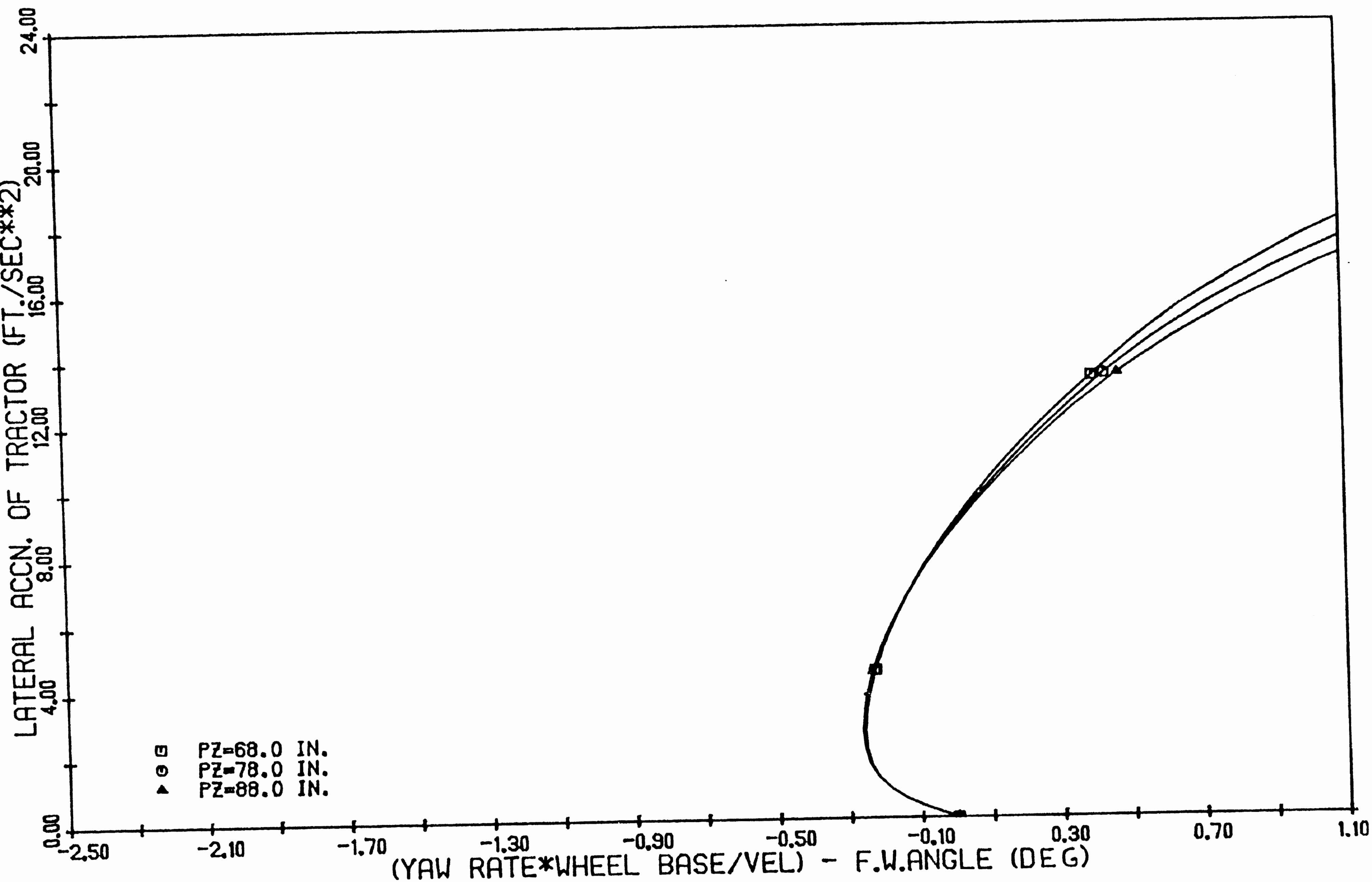

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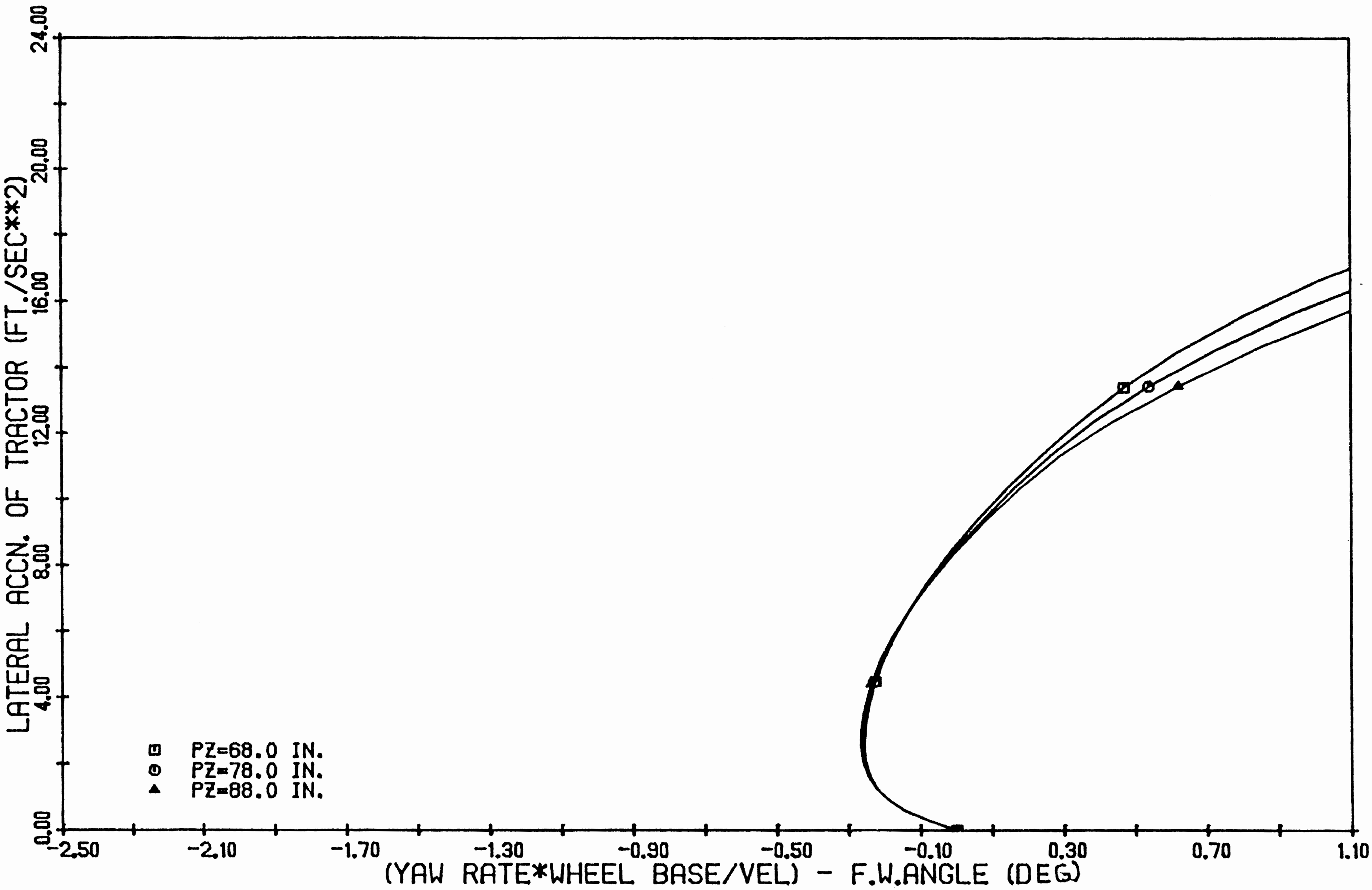

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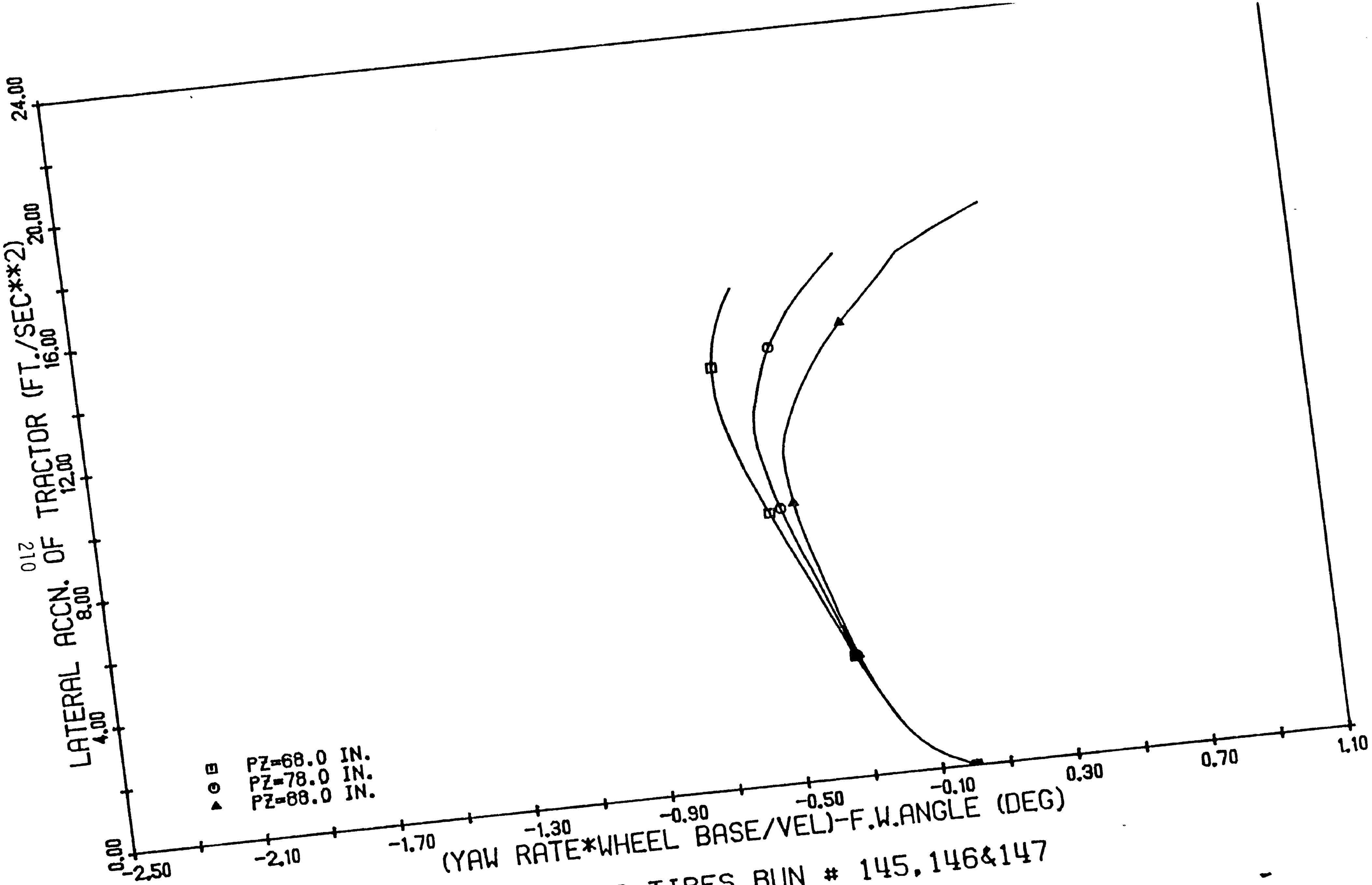

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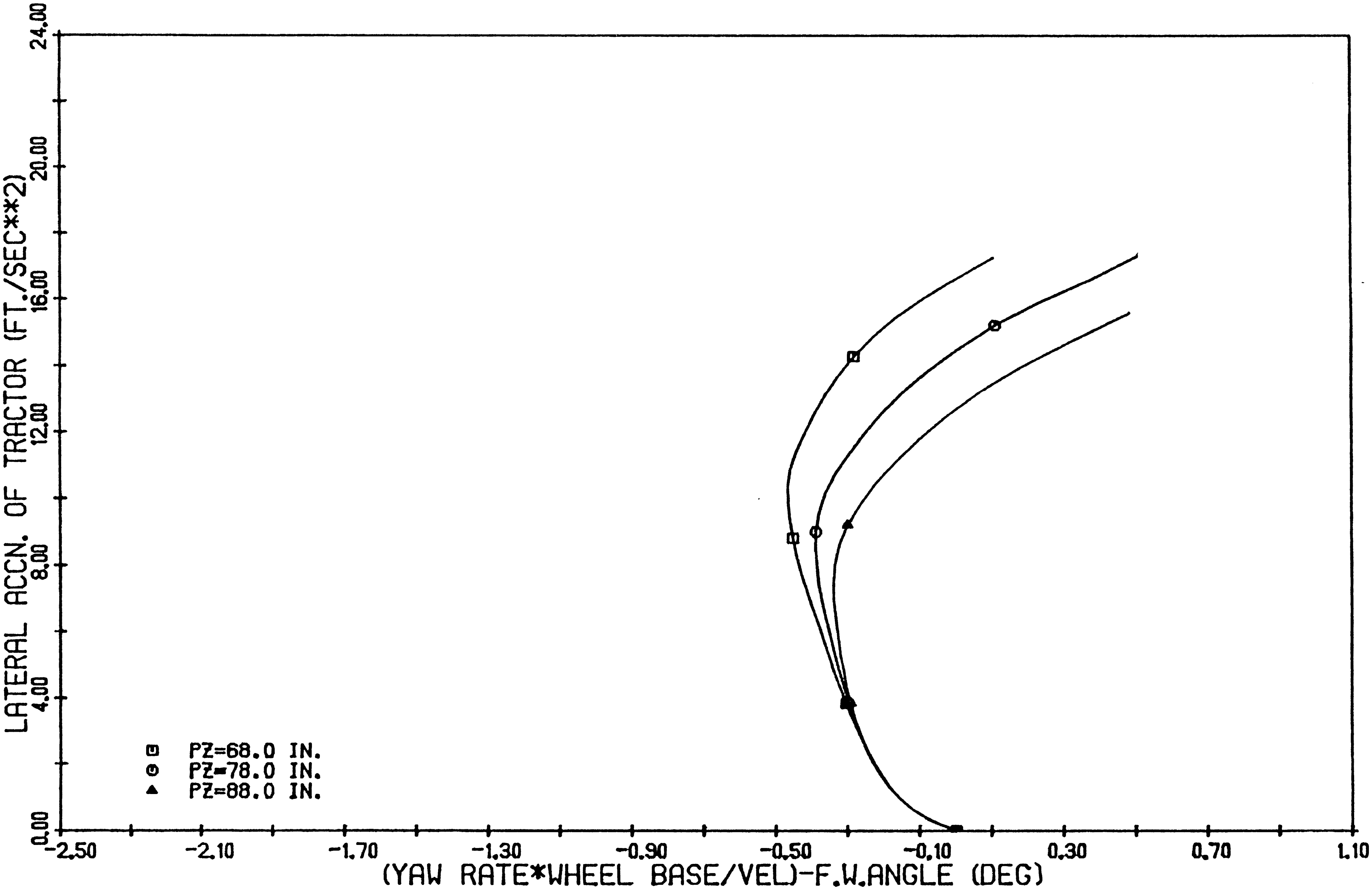

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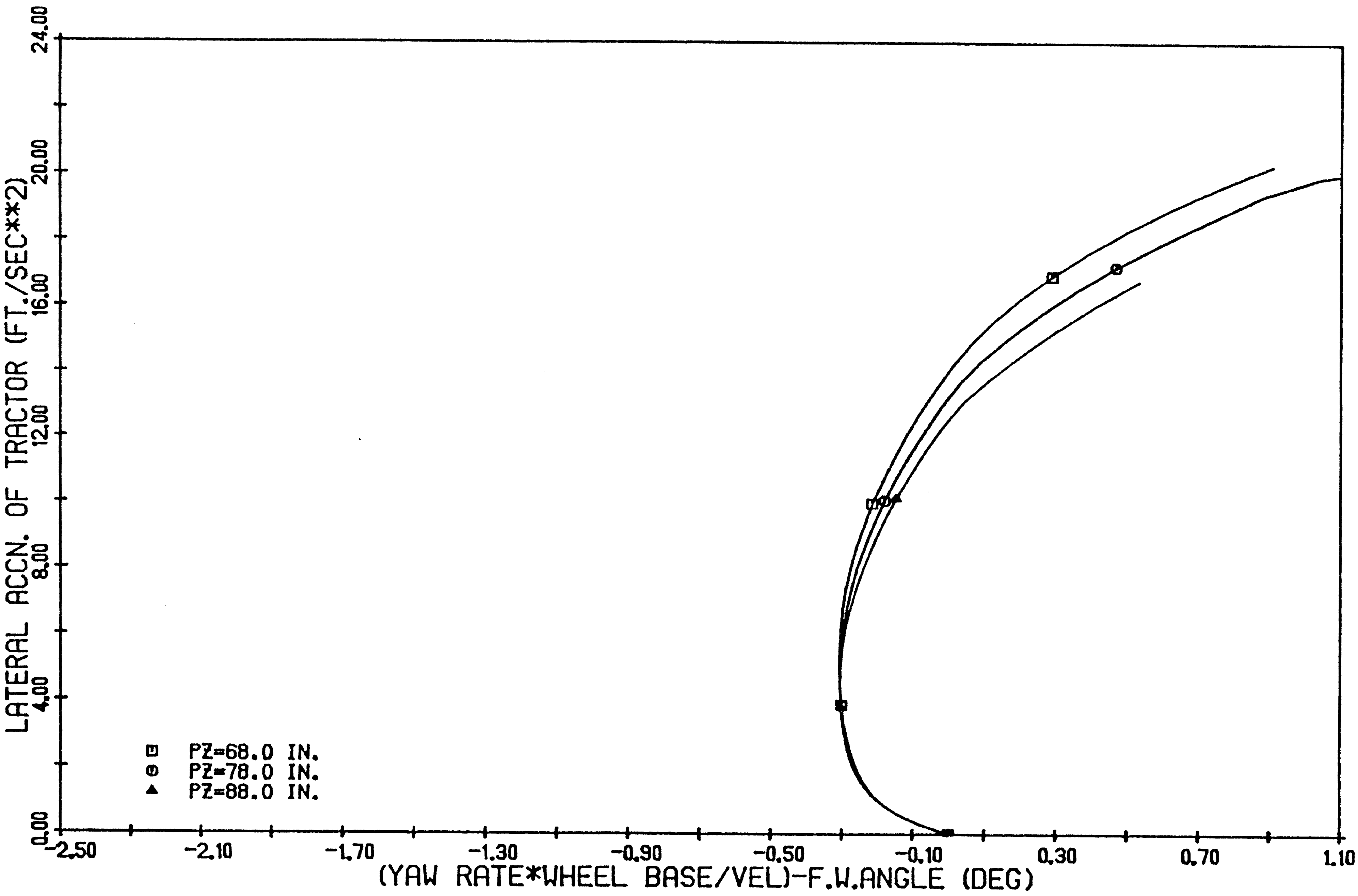
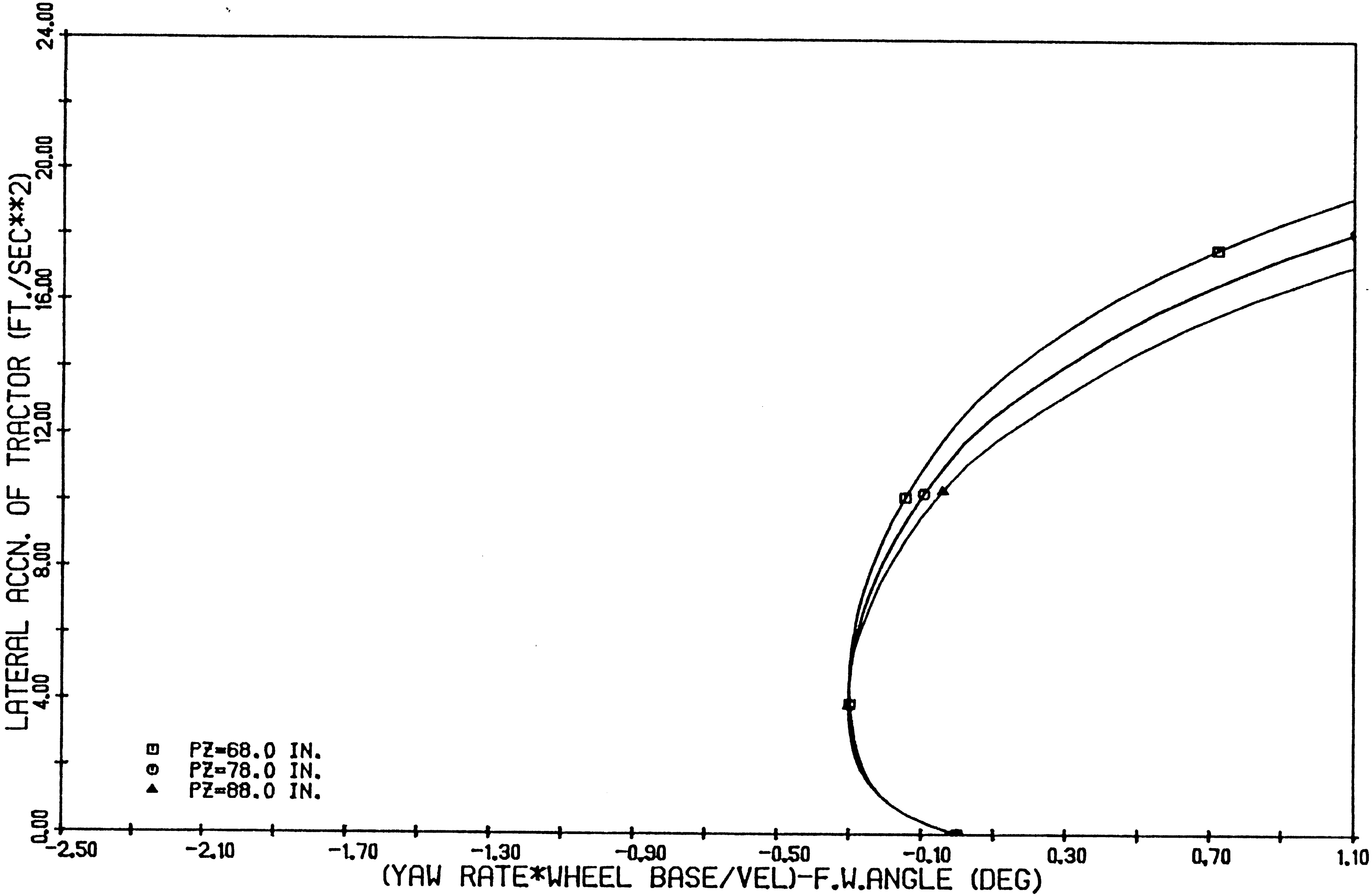
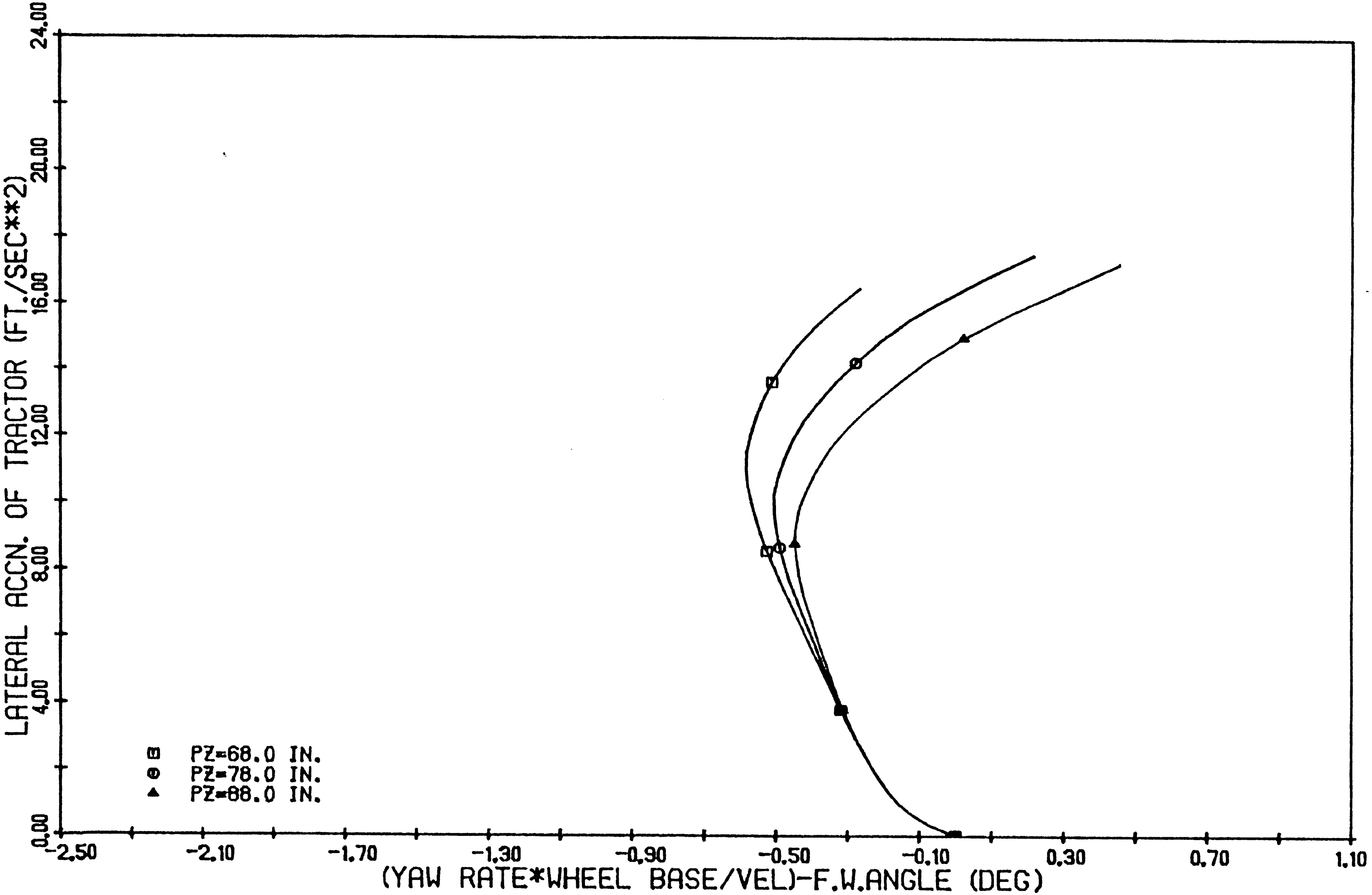


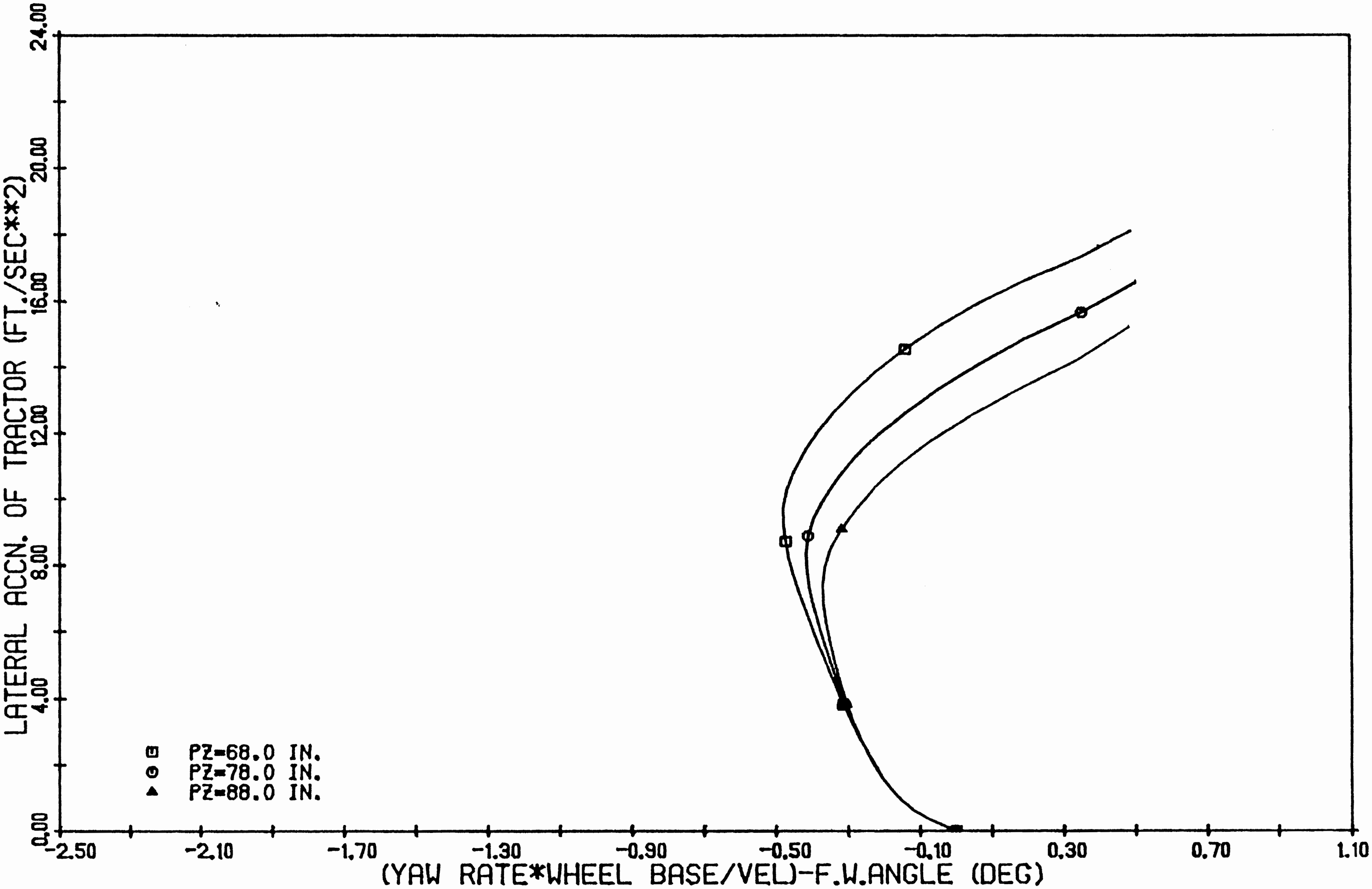
165 IN.WHEEL BASE TRACTOR,RIB TIRES,RUN # 151,152&153



165 IN. WHEEL BASE TRACTOR, RIB TIRES, RUN # 154, 155&156



165 IN.WHEEL BASE TRACTOR,RIB TIRES,RUN # 157,158&159



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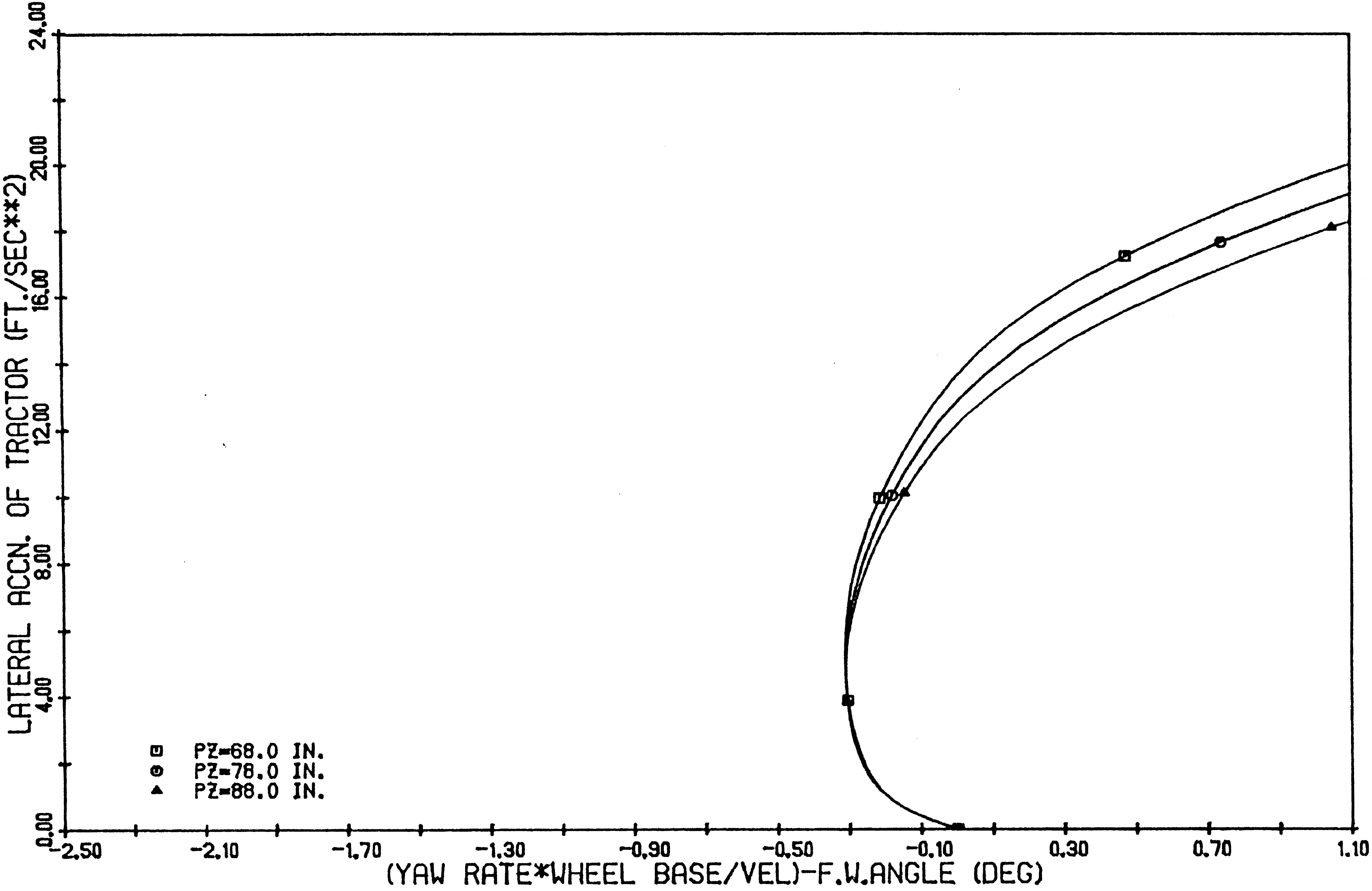

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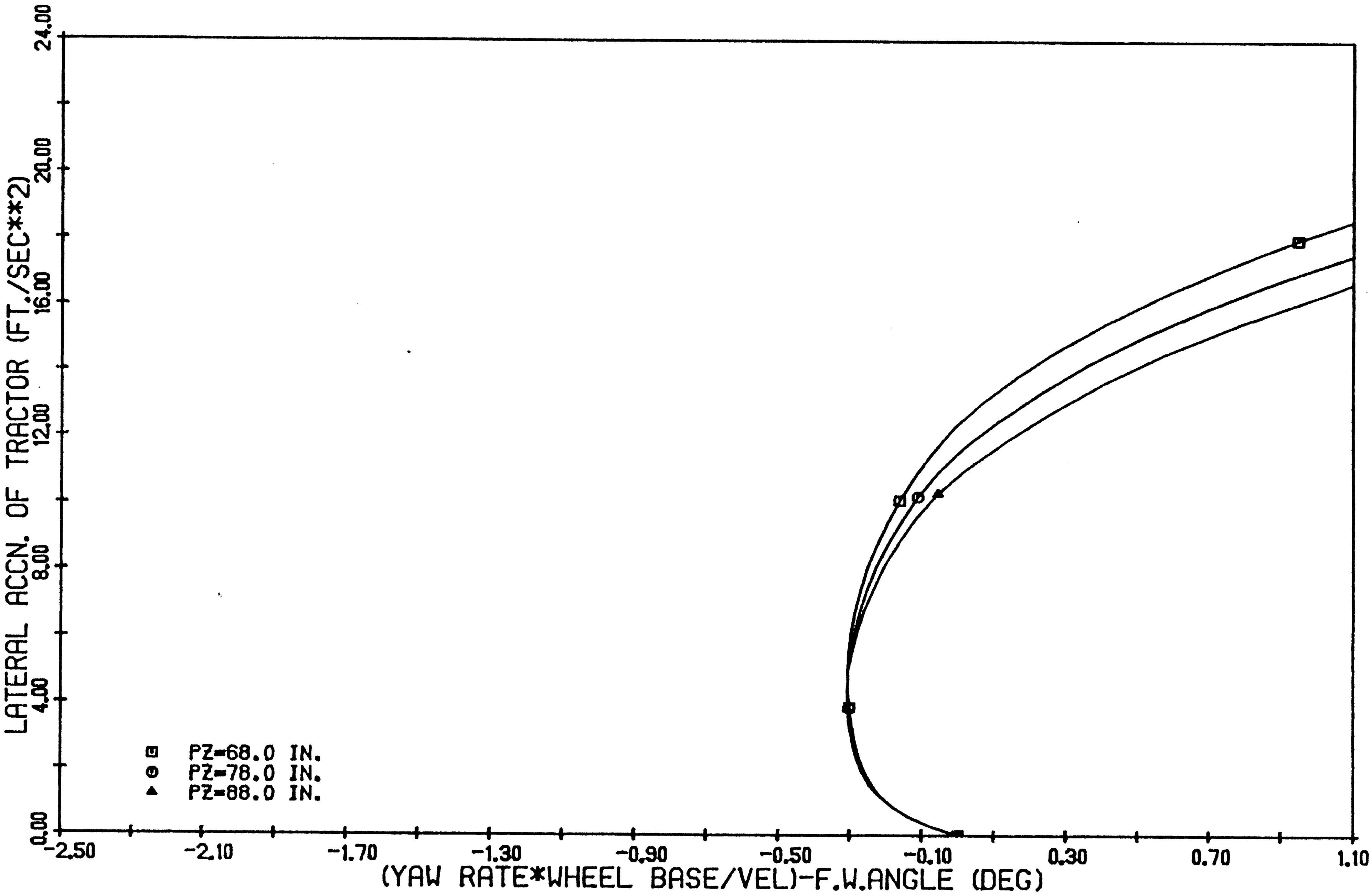

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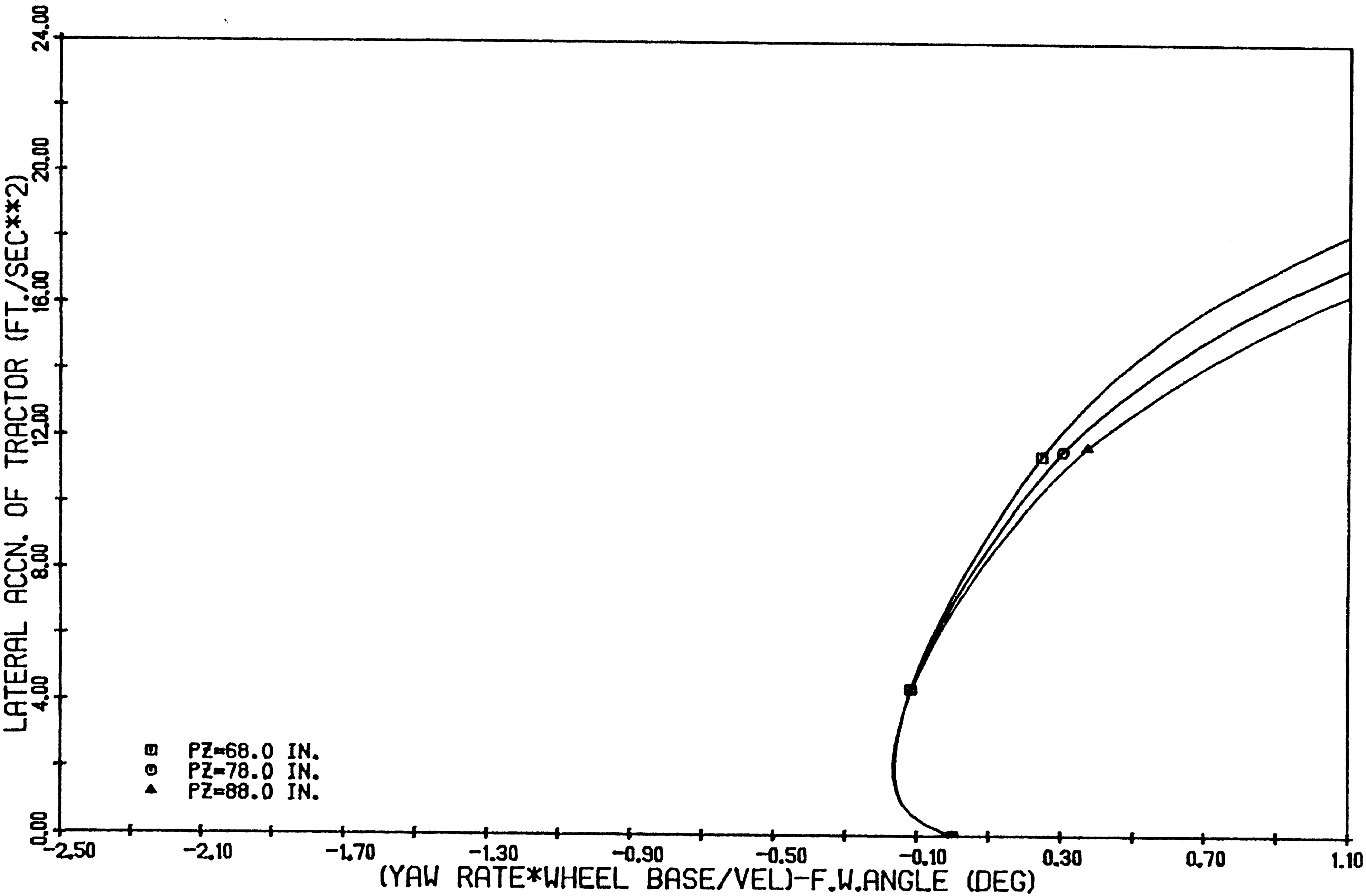

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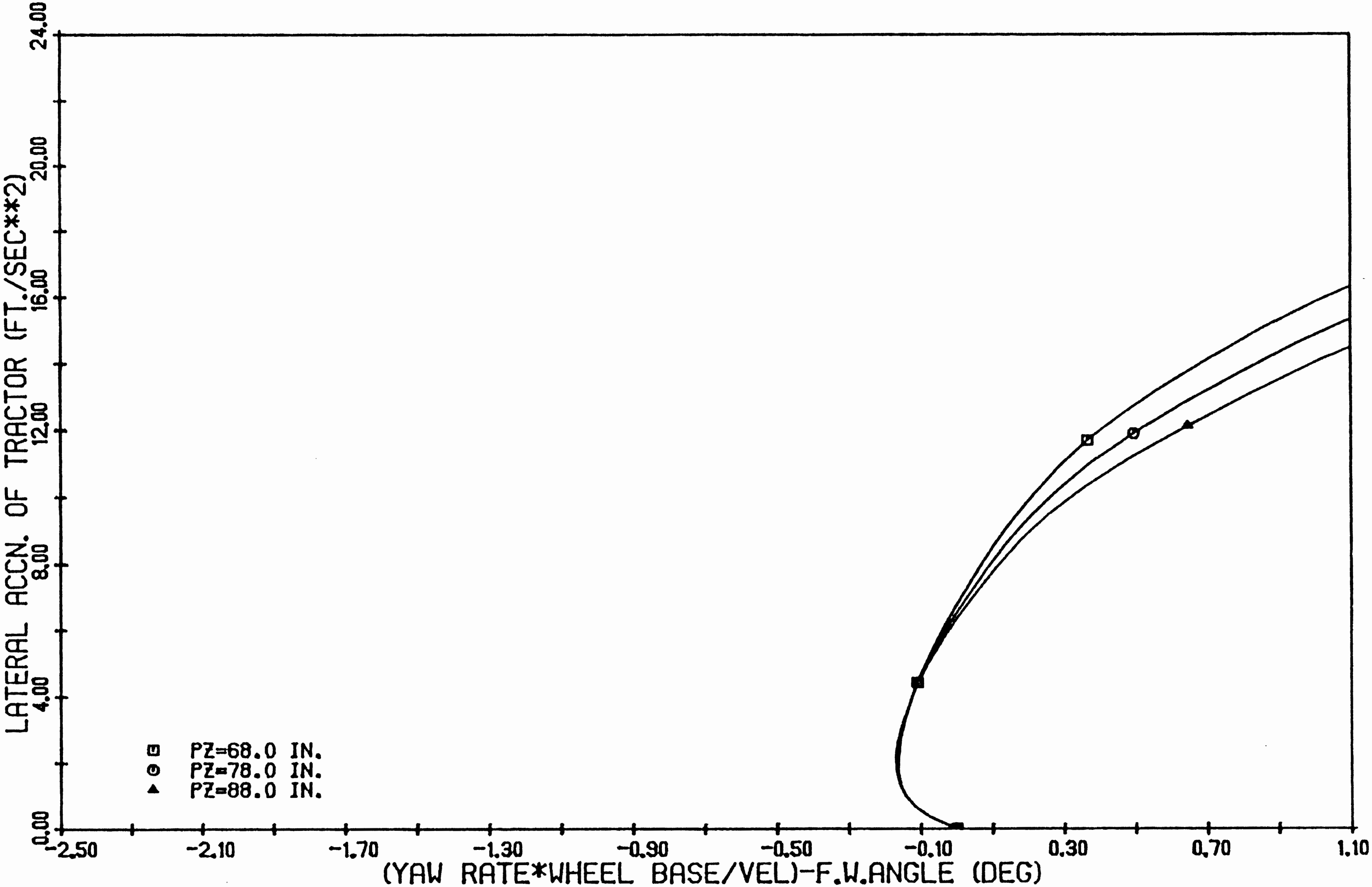

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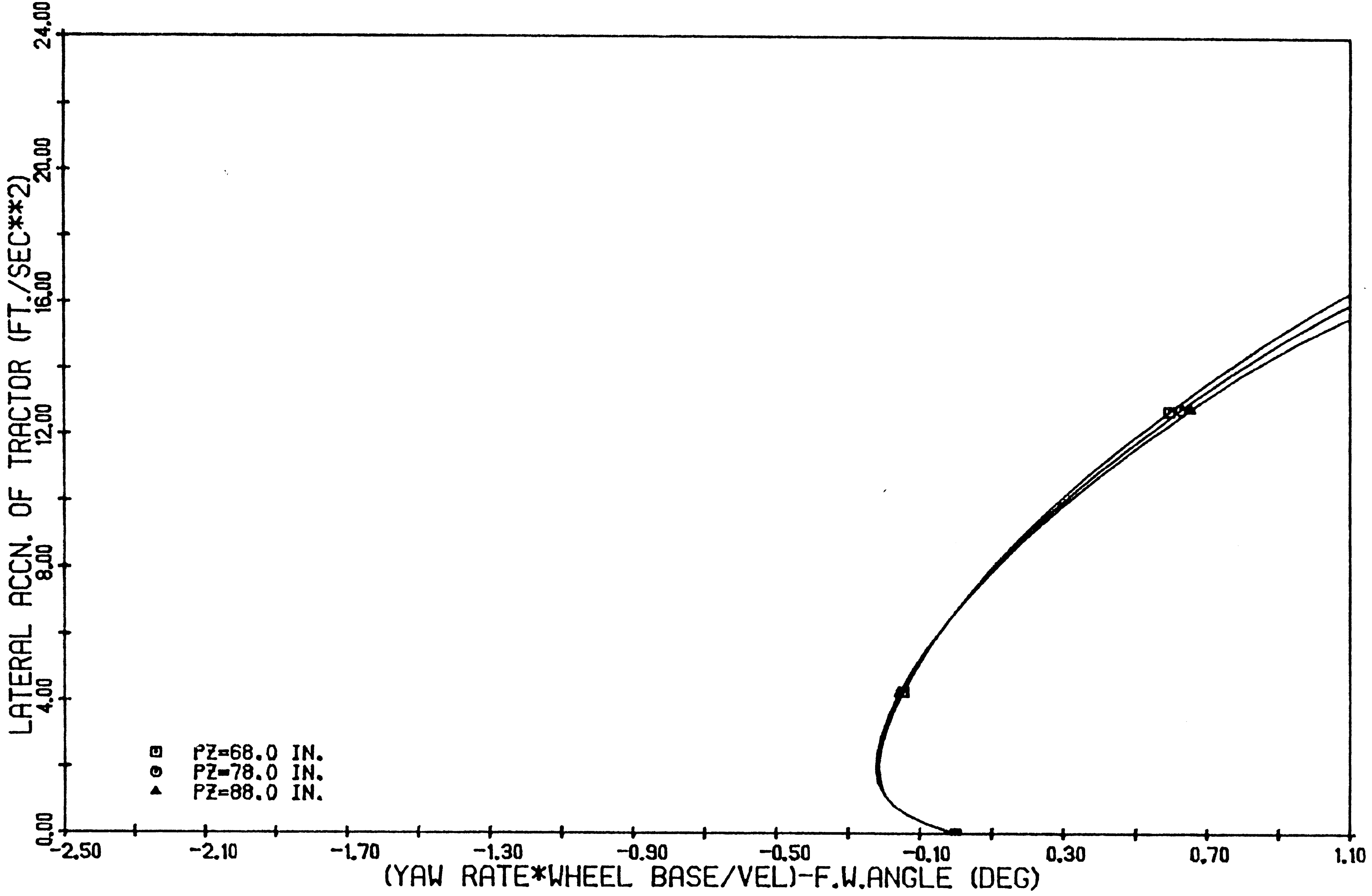

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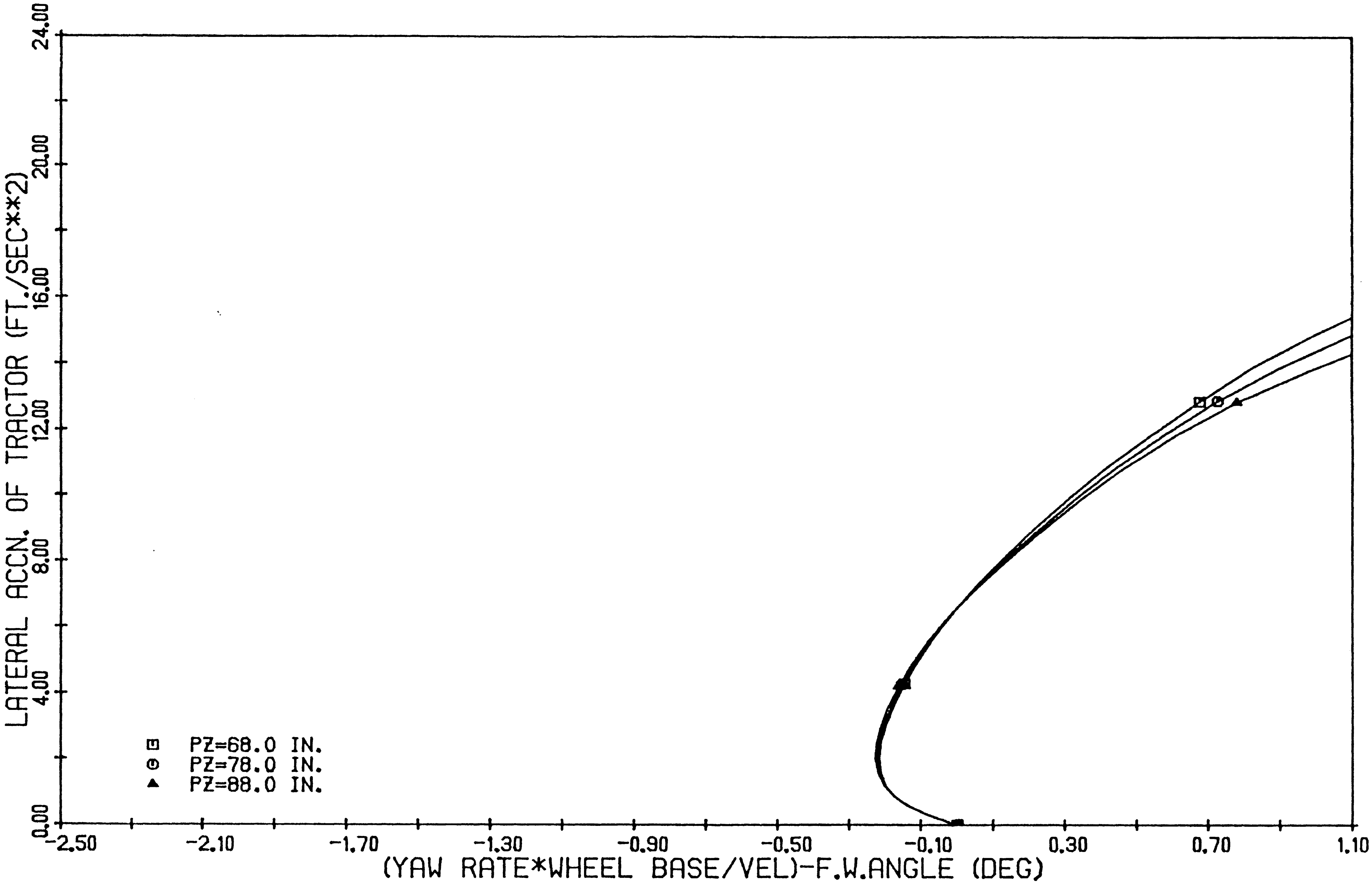

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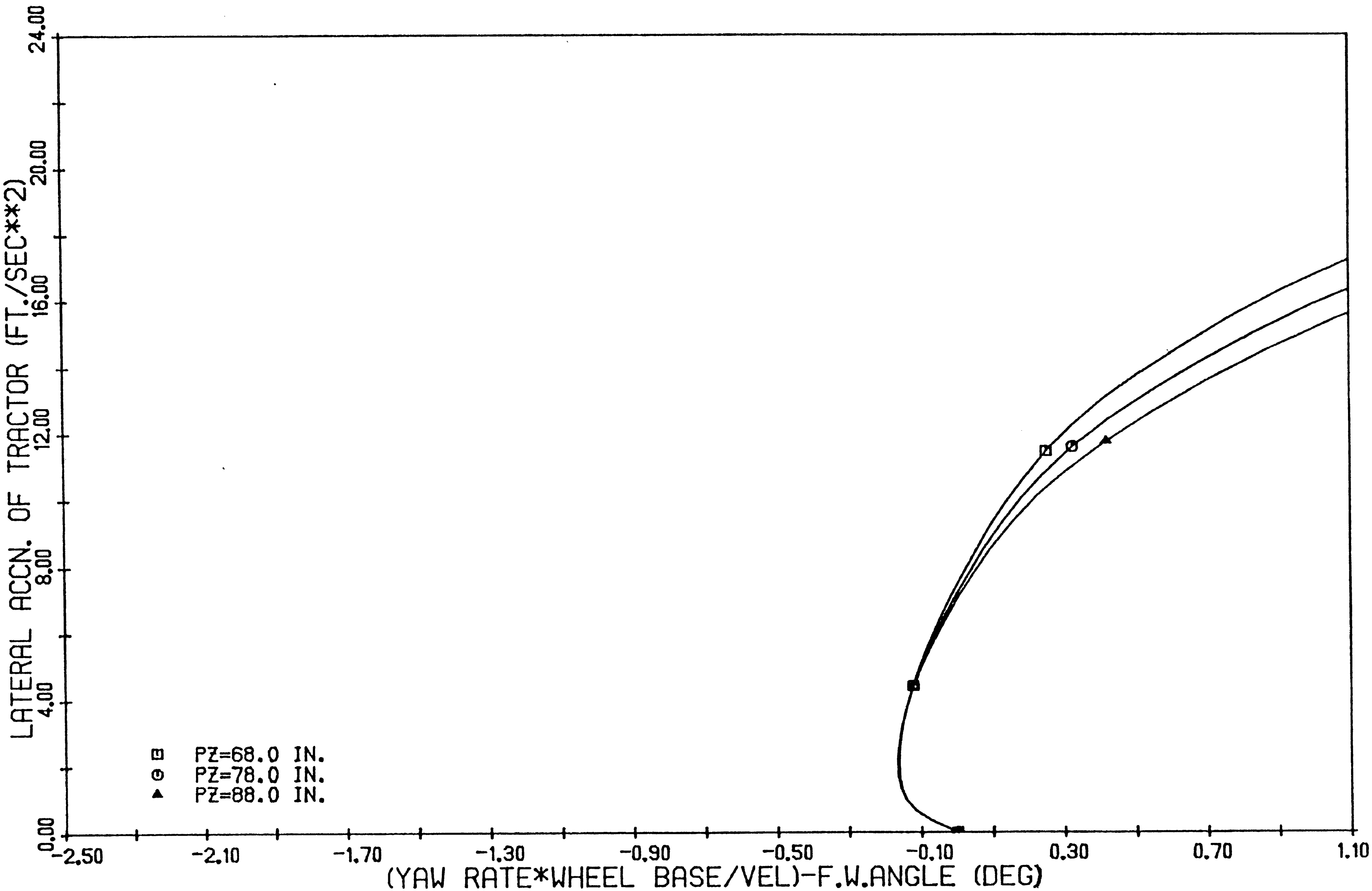

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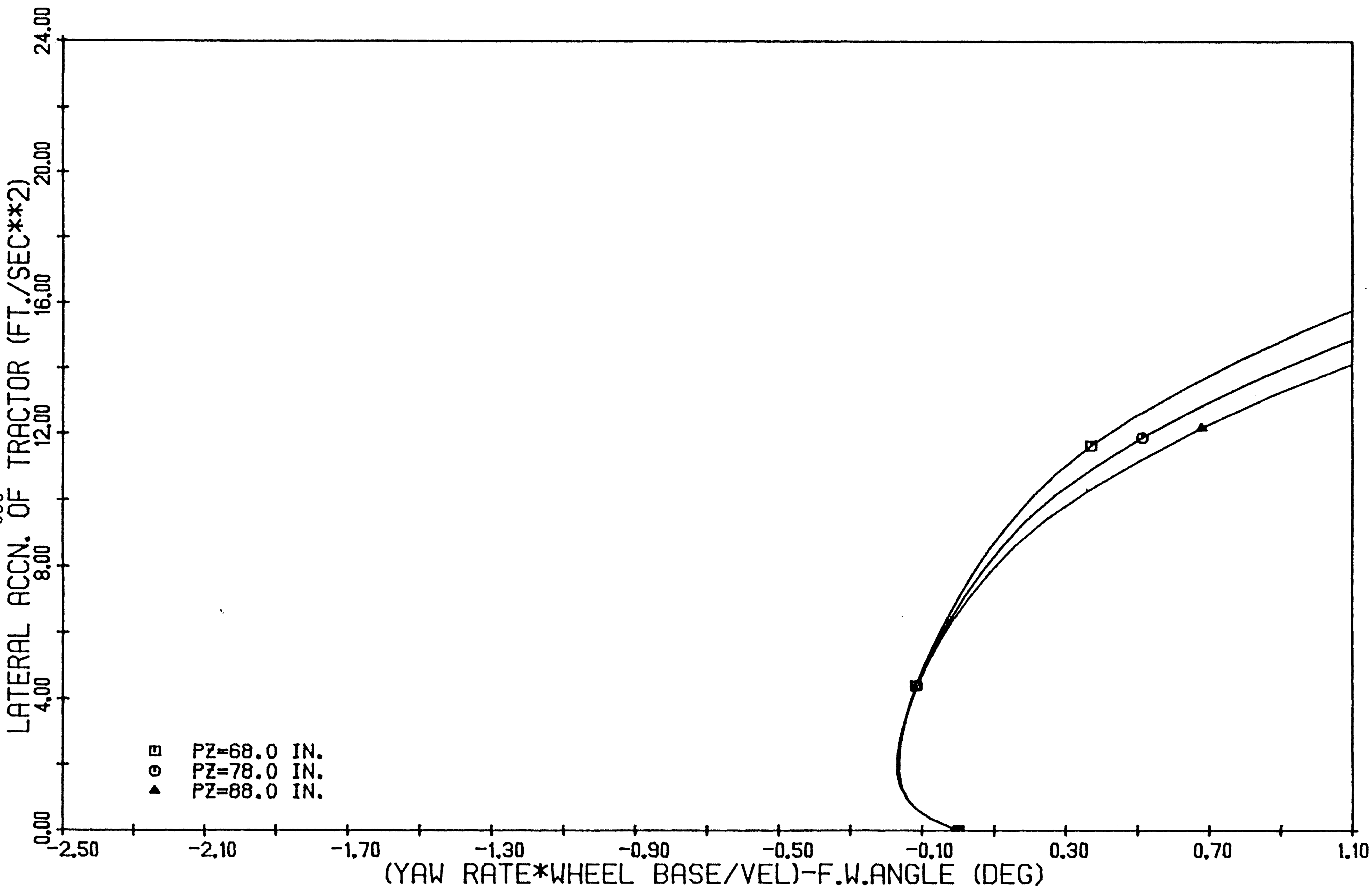

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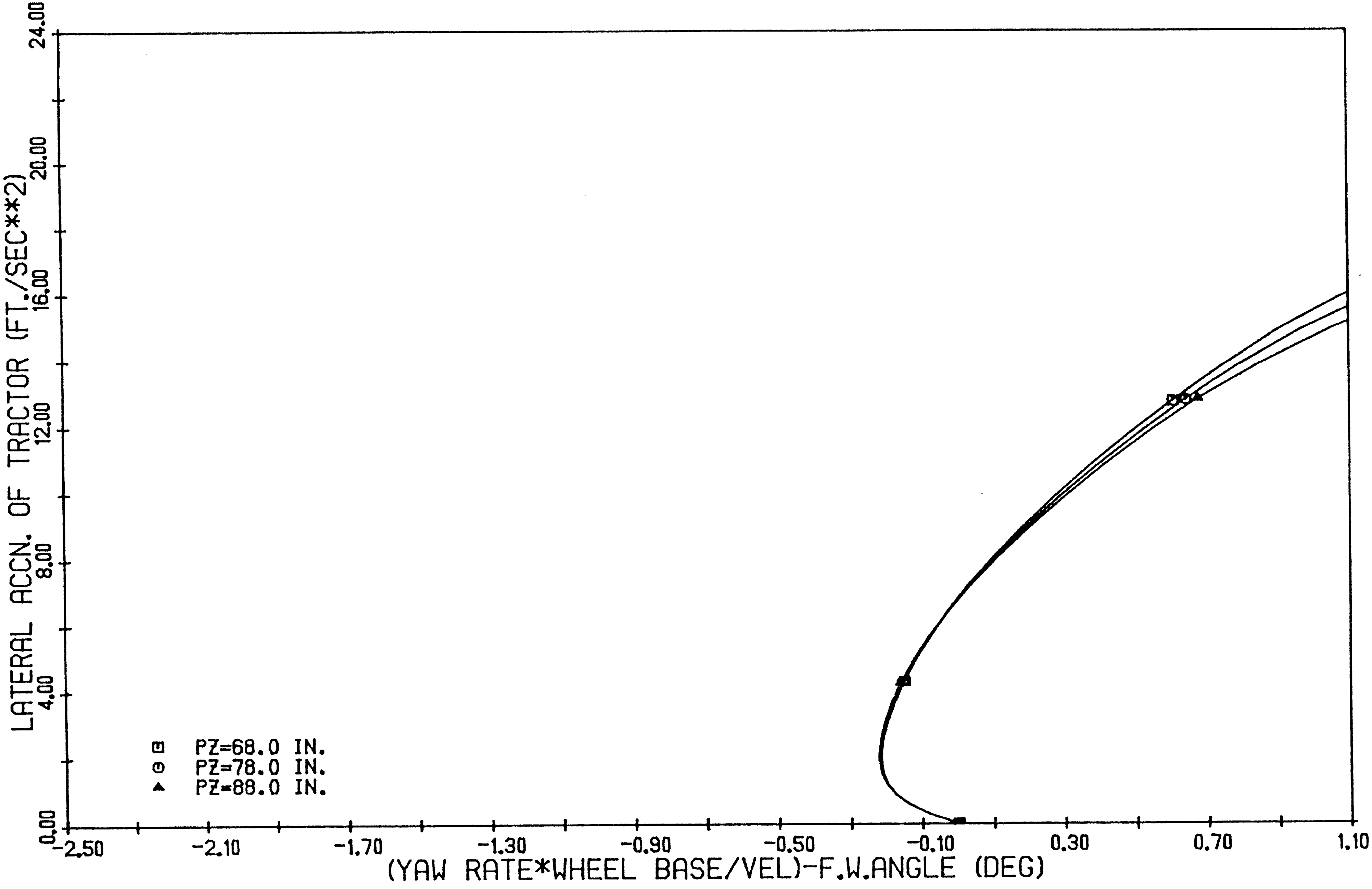

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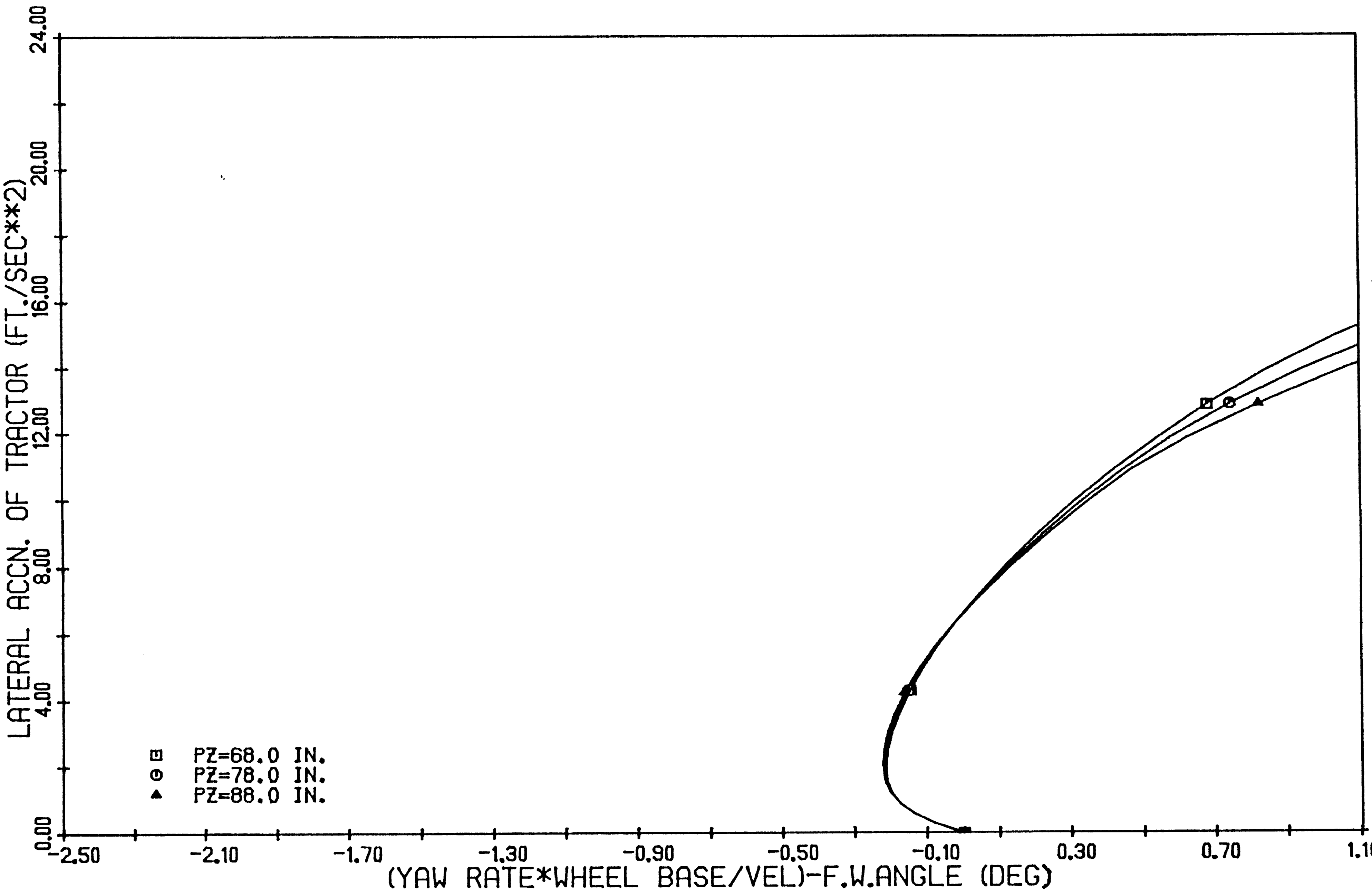
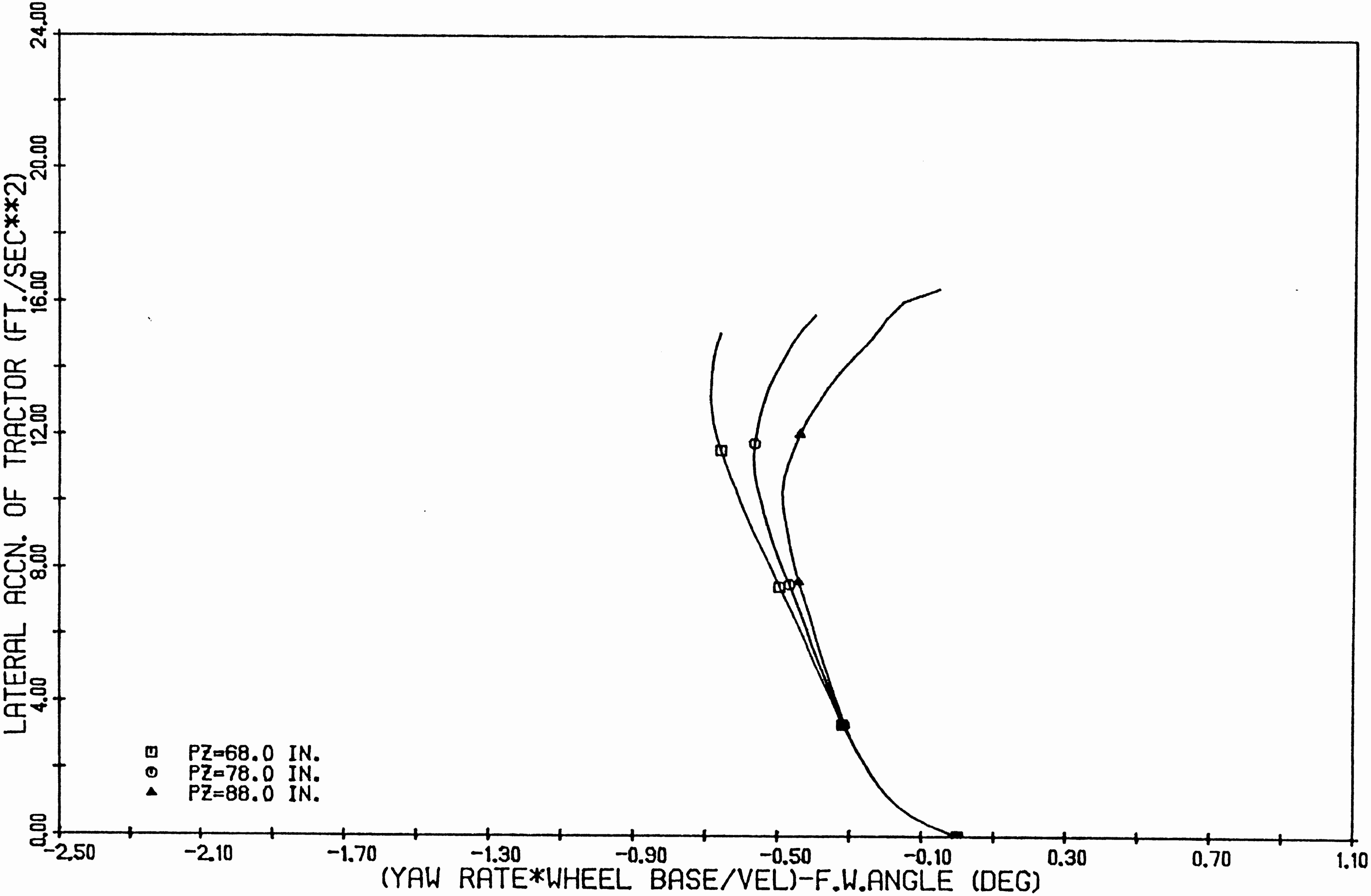
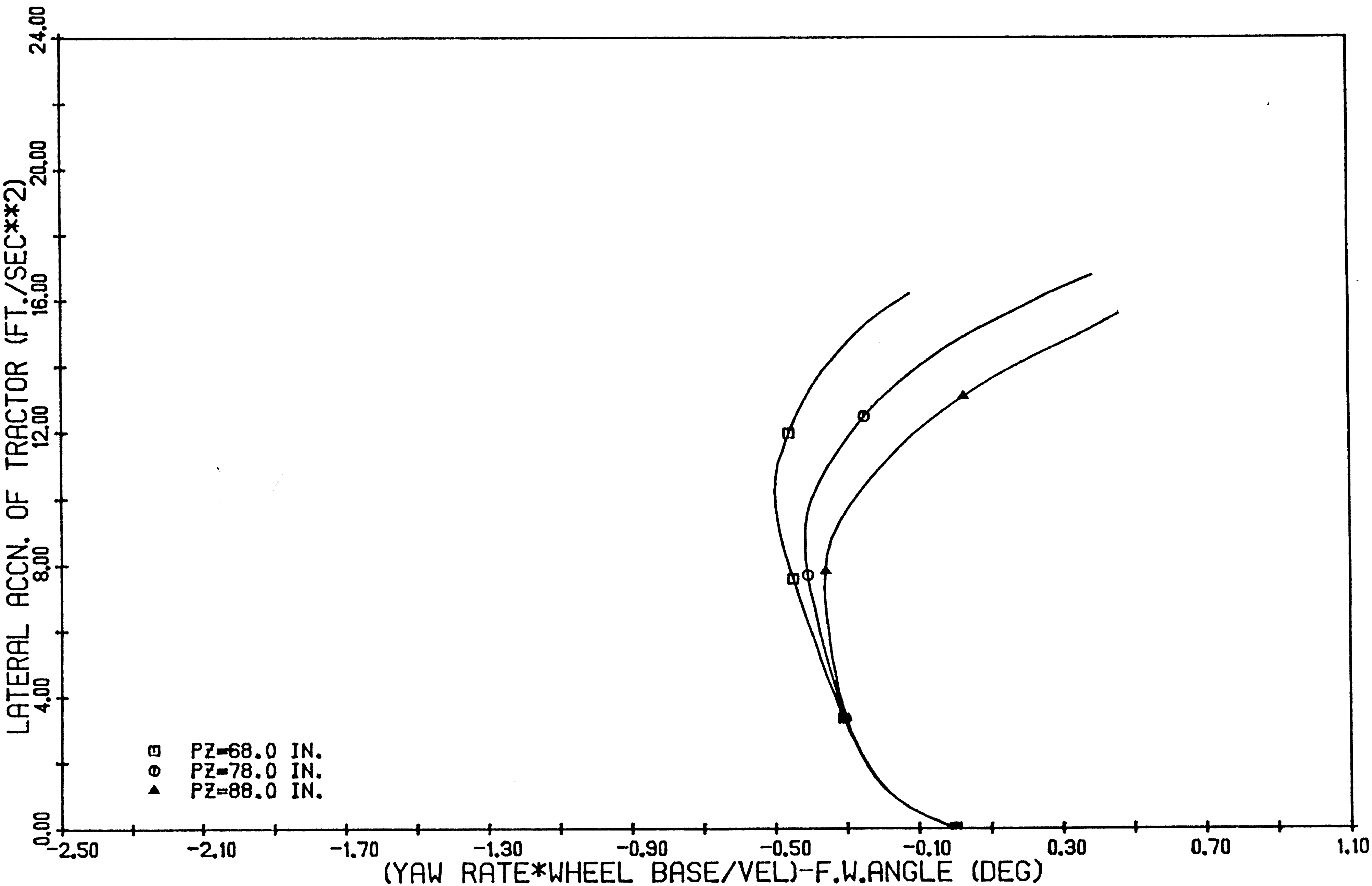


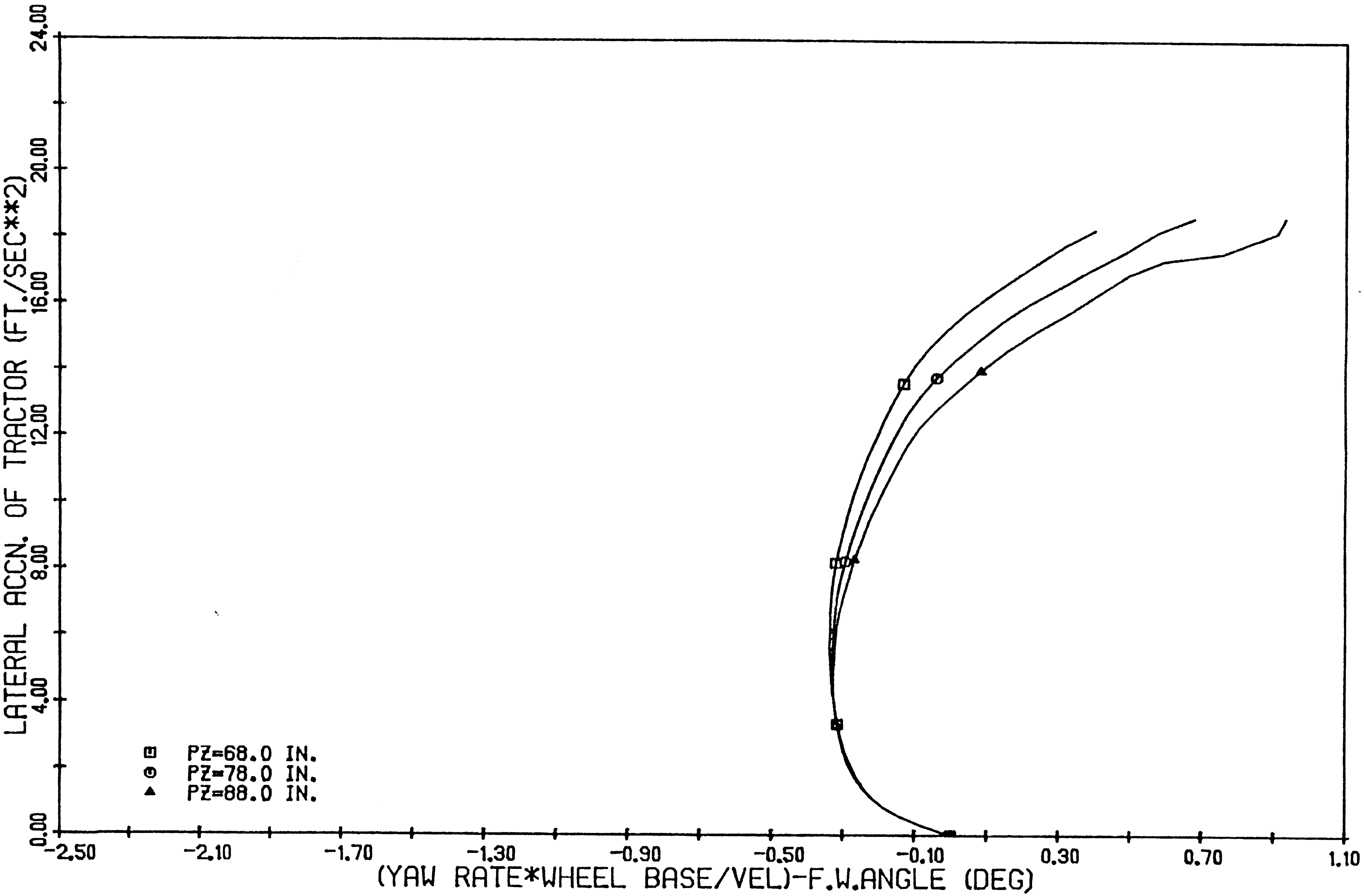
165 IN. WHEEL BASE TRACTOR, LUG TIRES, RUN # 190, 191&192



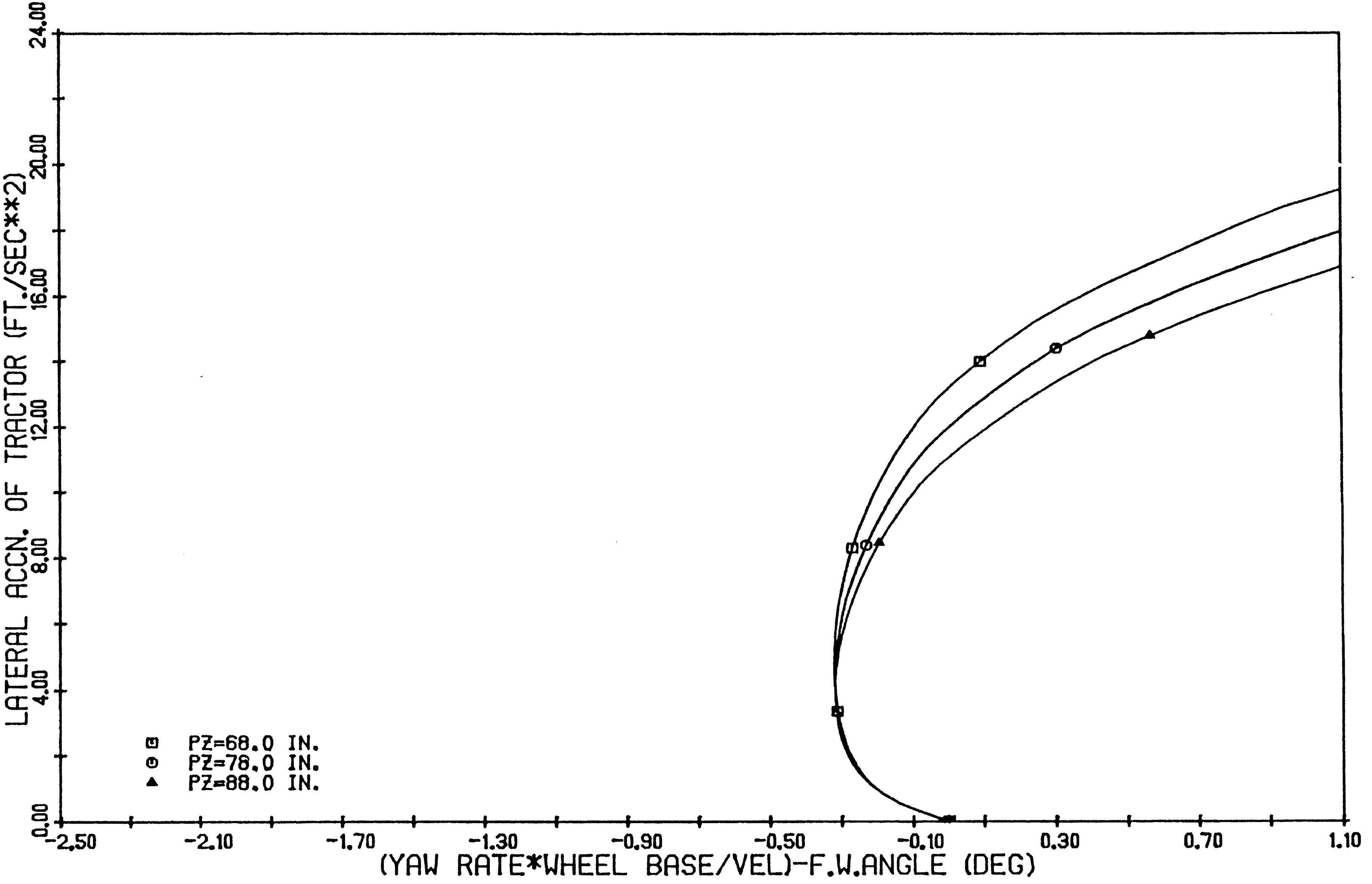
200 IN.WHEEL BASE TRACTOR,RIB TIRES,RUN # 193,194&195



200 IN.WHEEL BASE TRACTOR,RIB TIRES,RUN # 196,197&198



200 IN. WHEEL BASE TRACTOR, RIB TIRES, RUN # 199, 200&201



229

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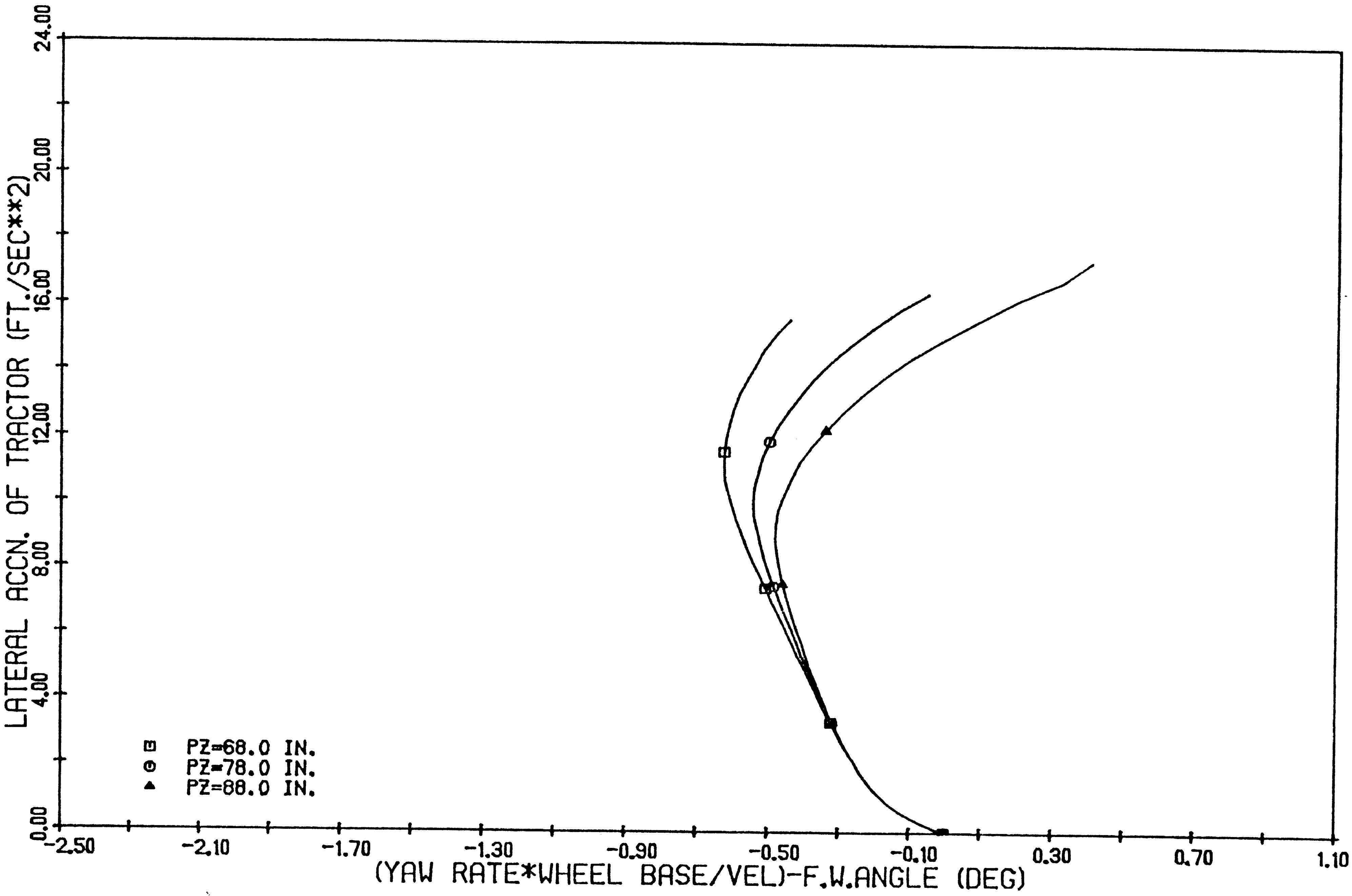

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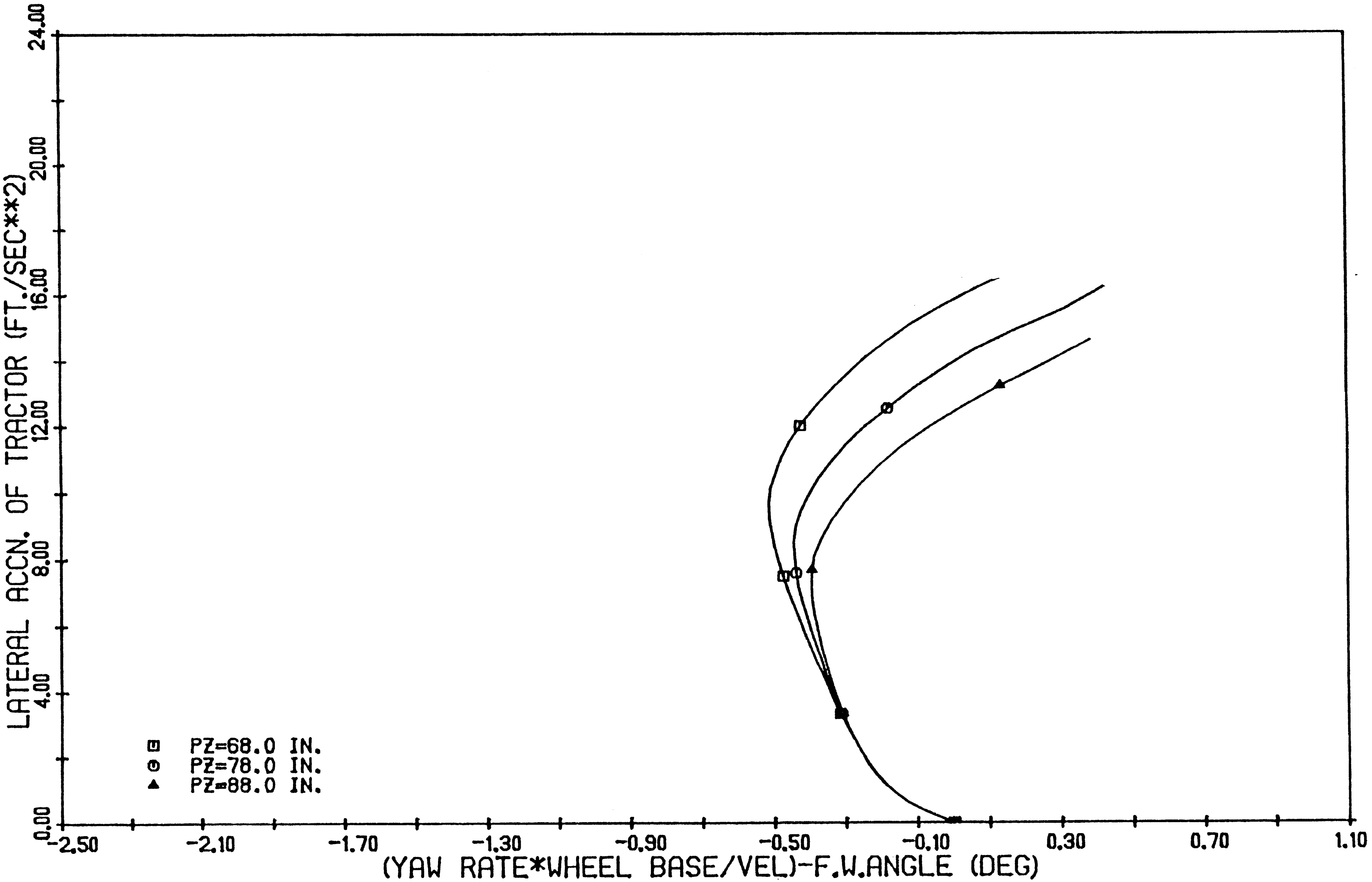

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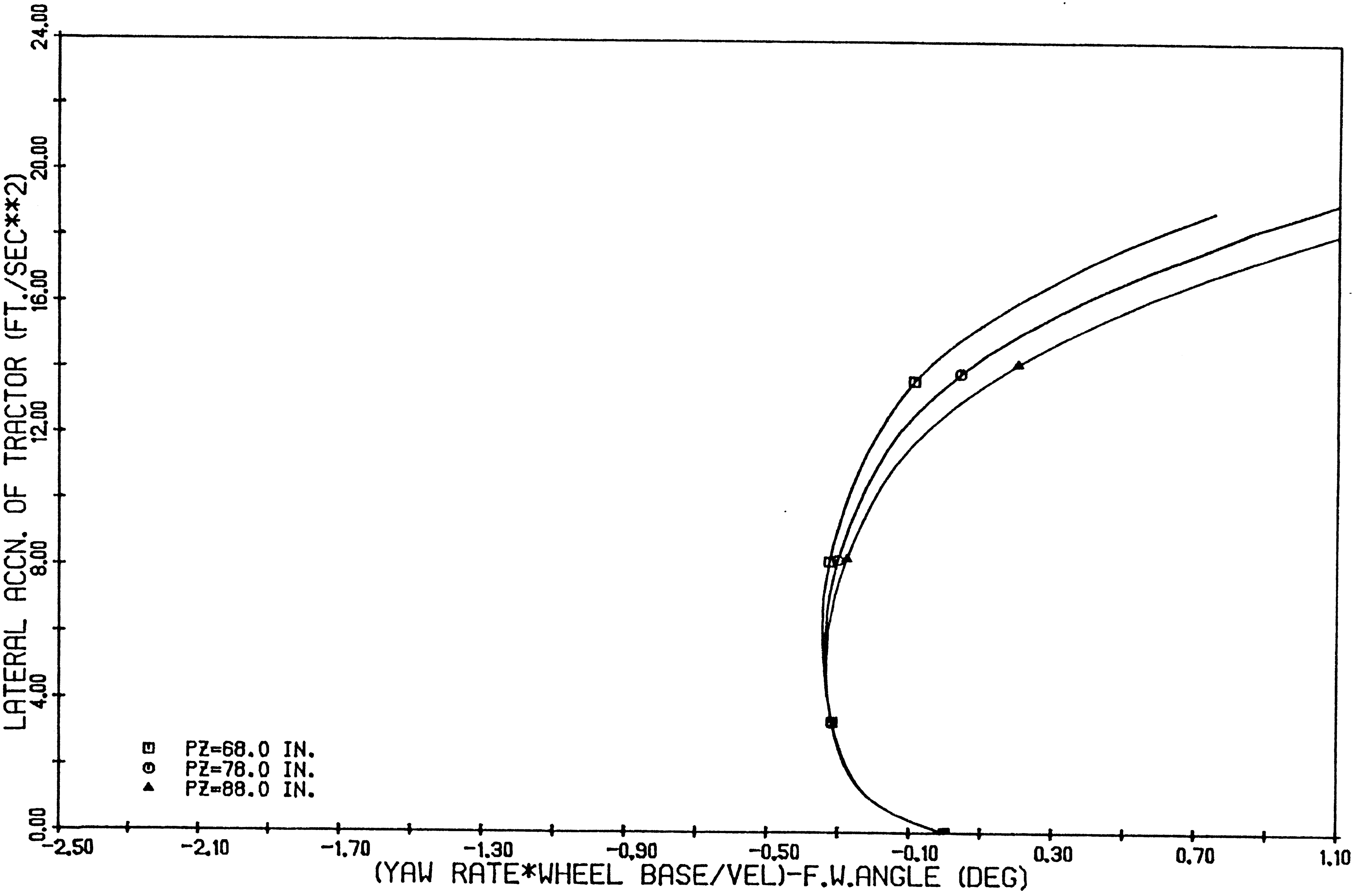

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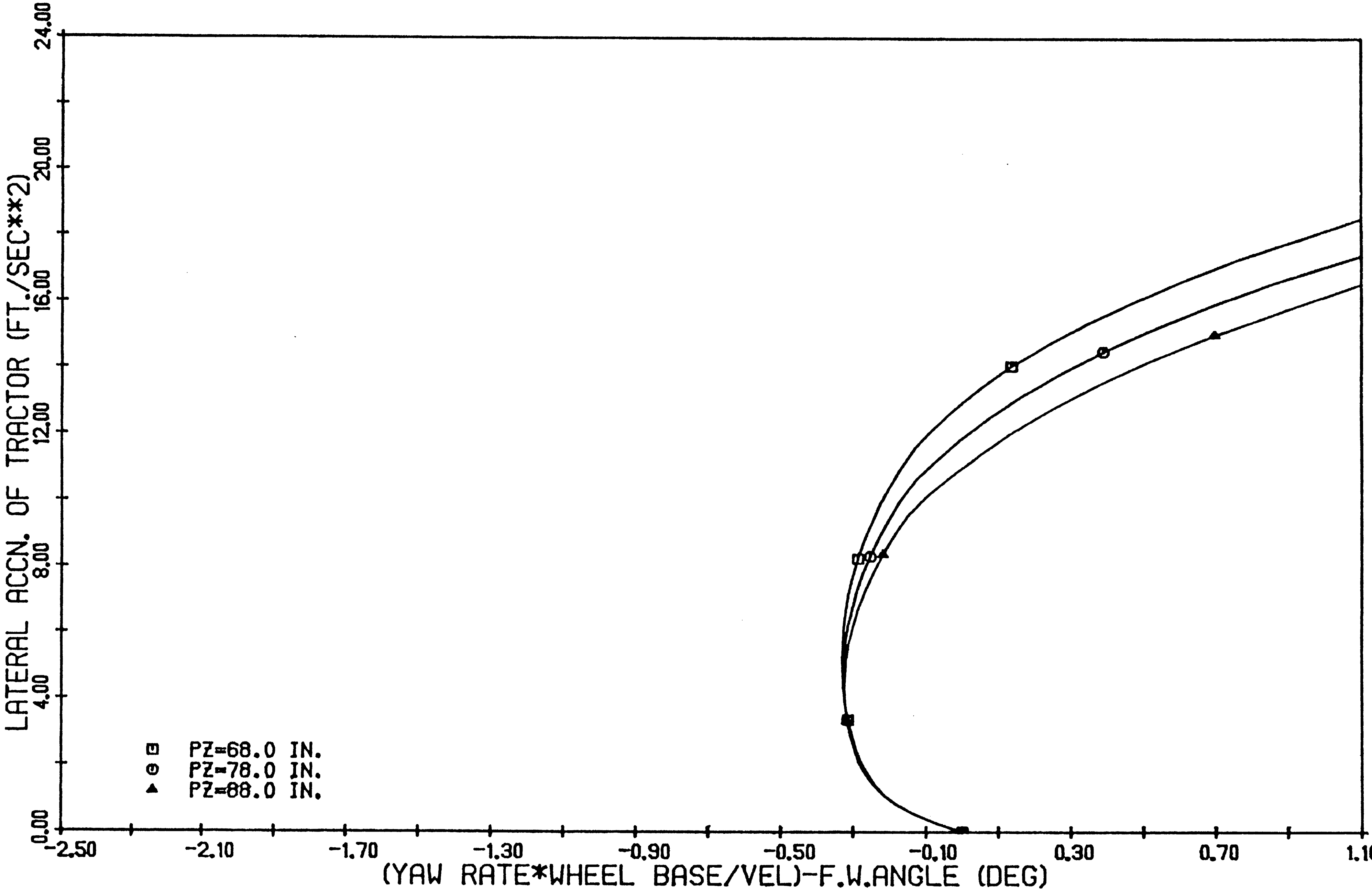

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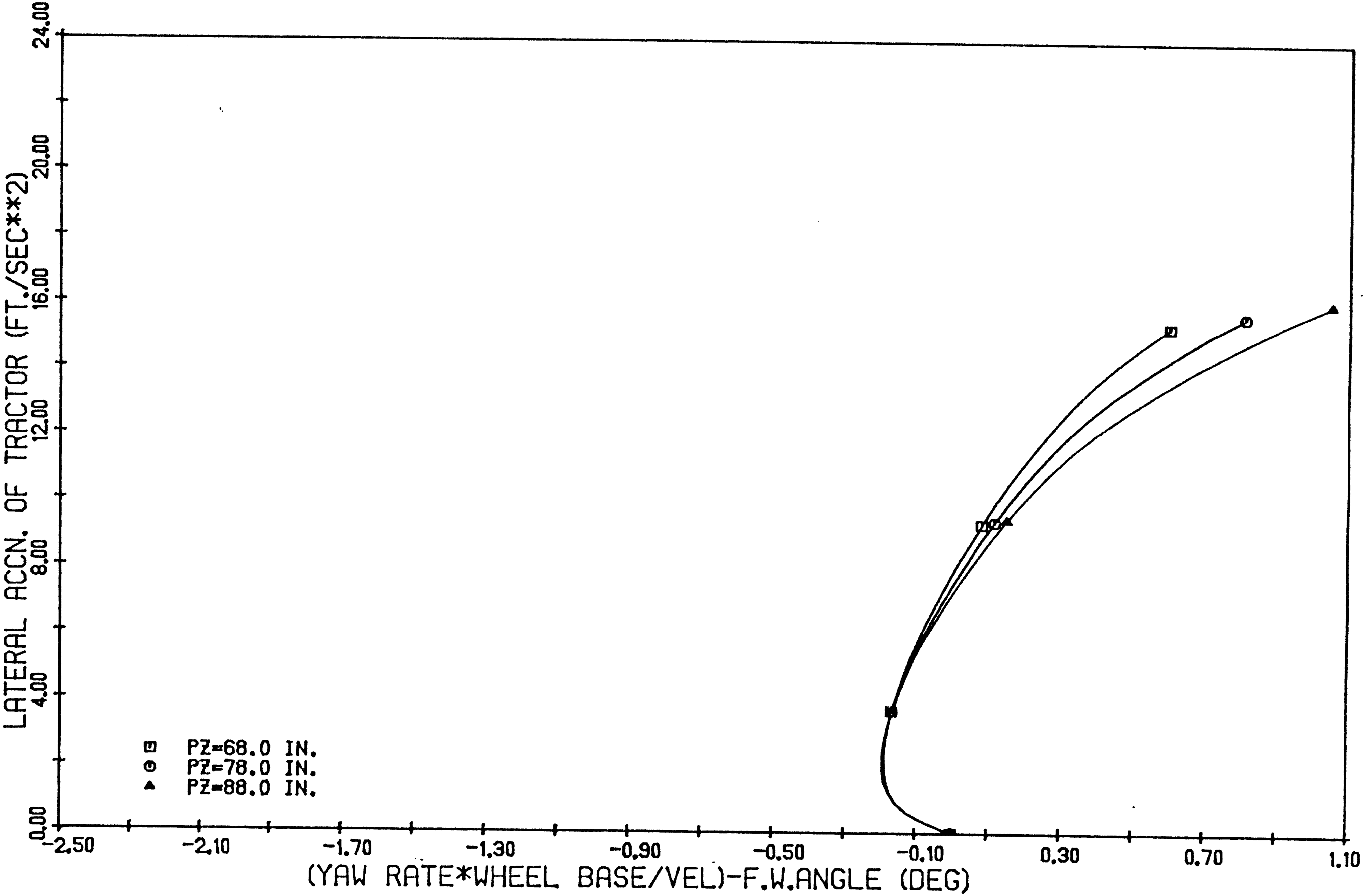

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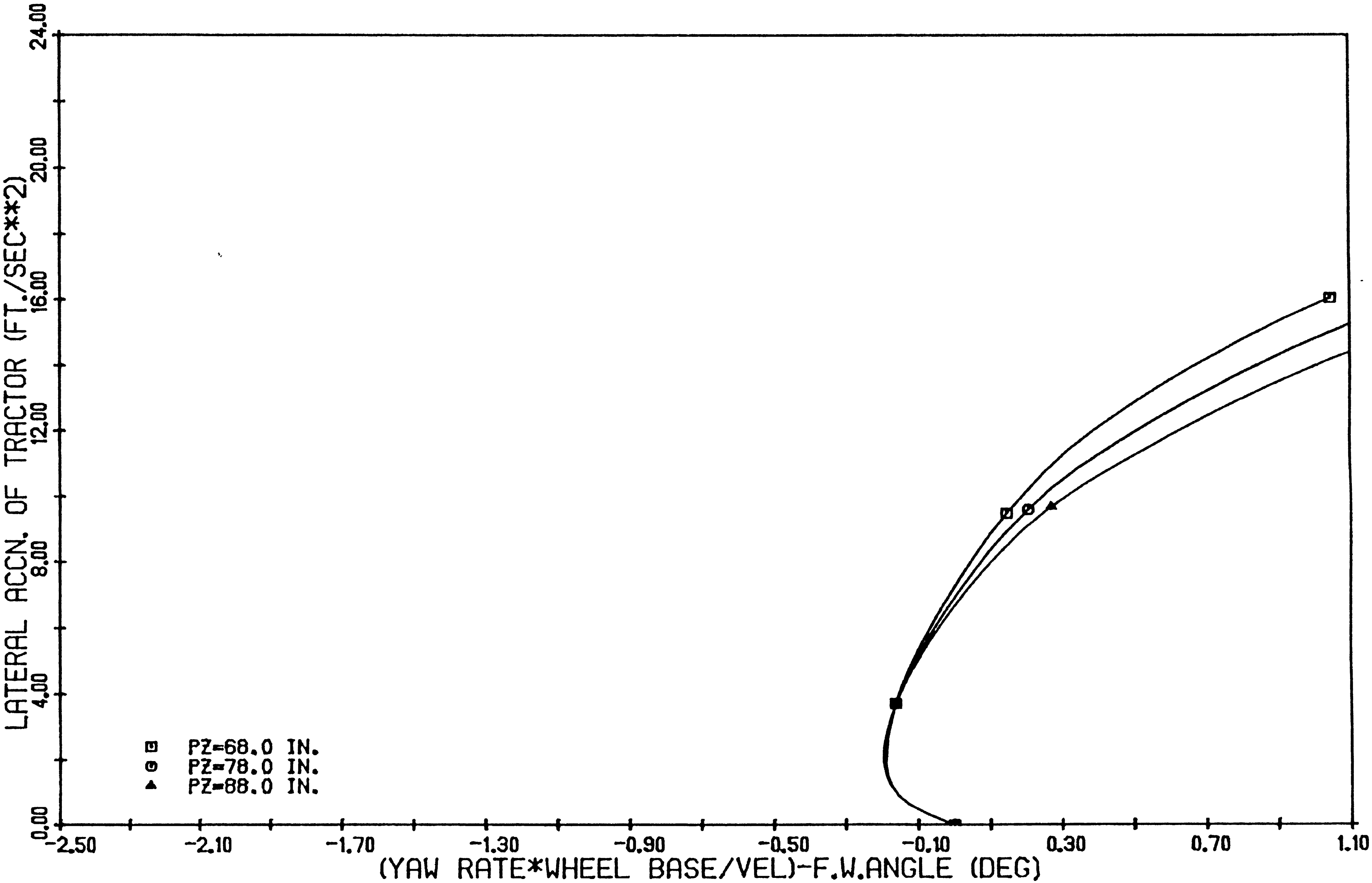

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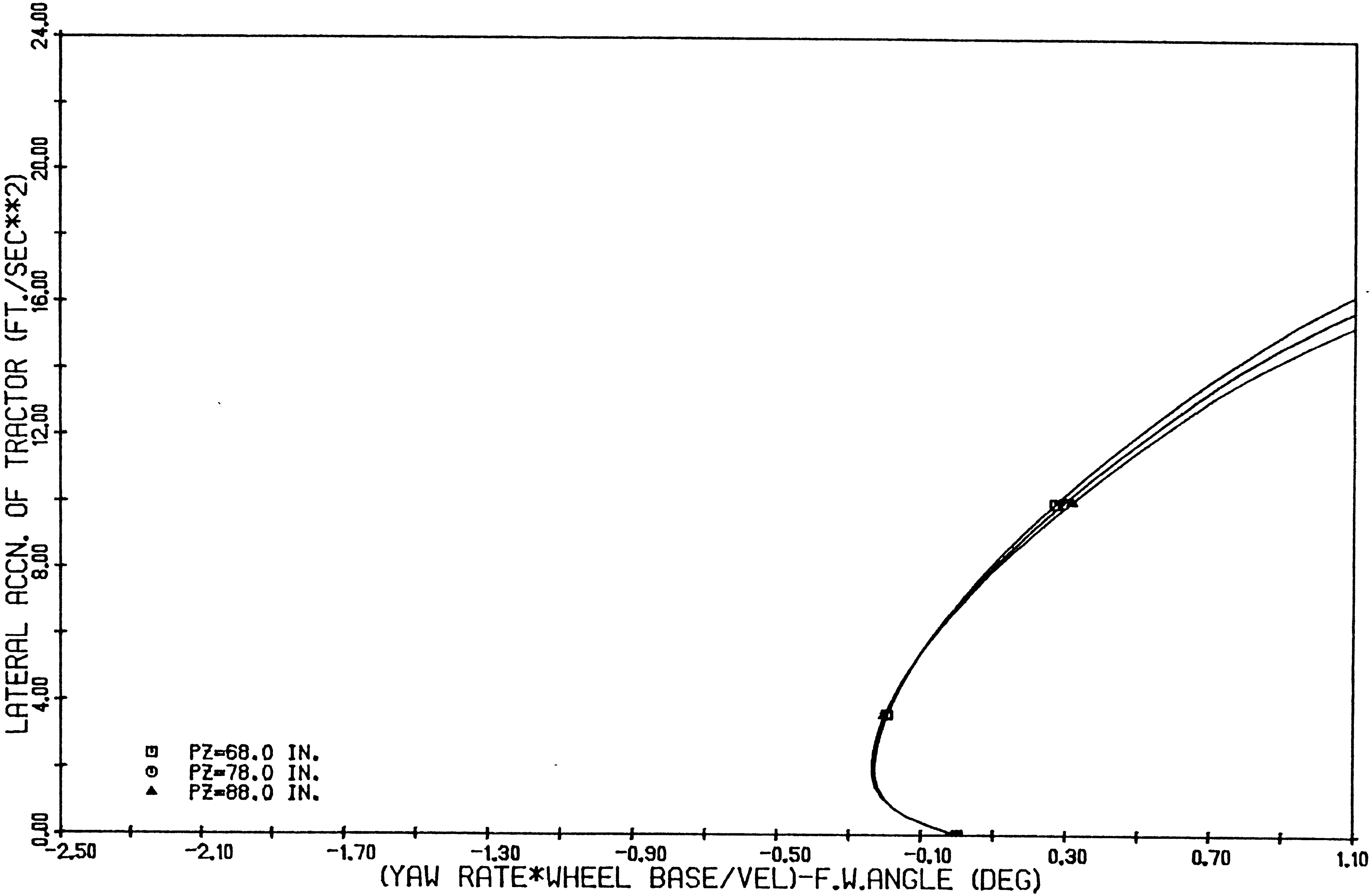

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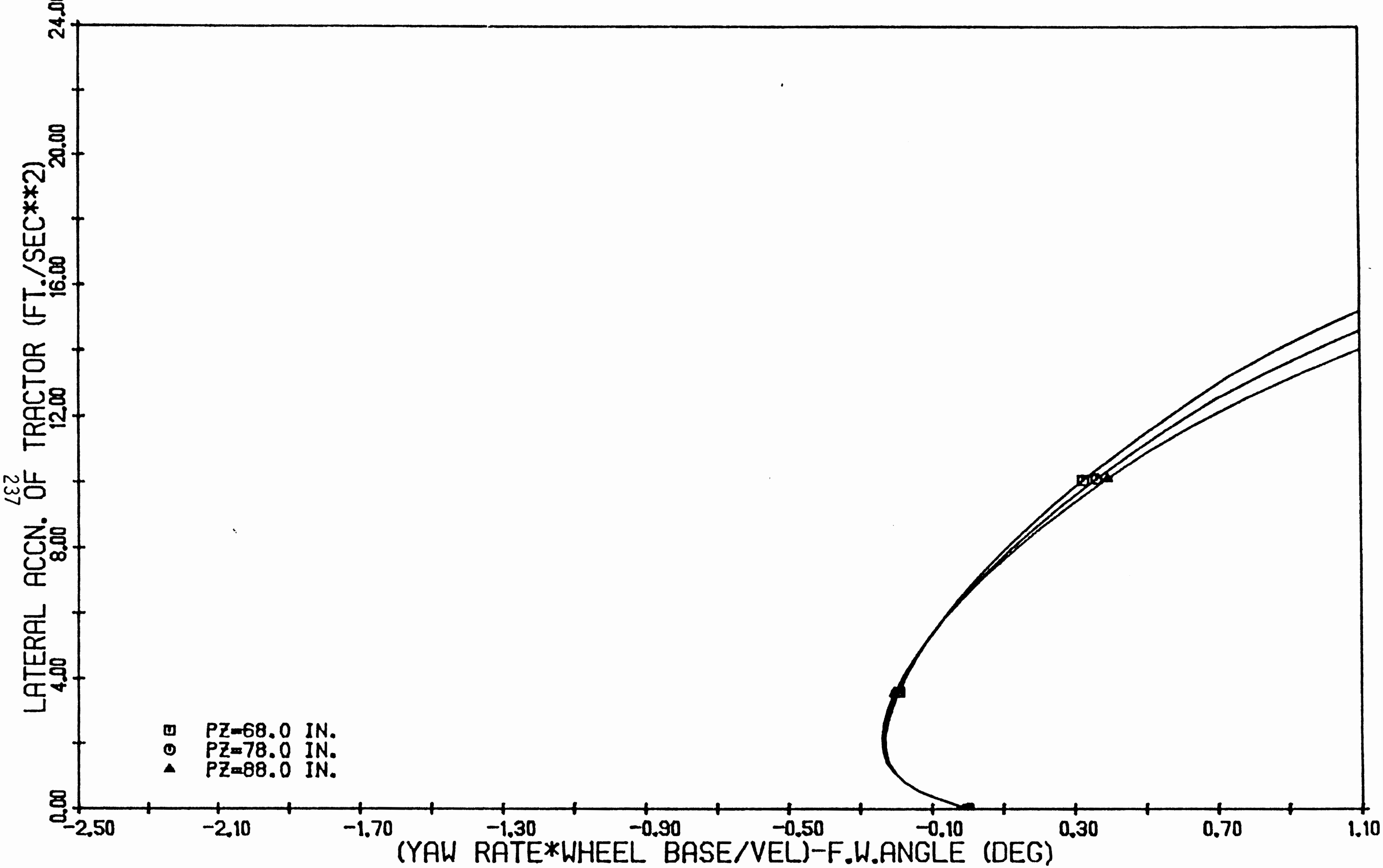

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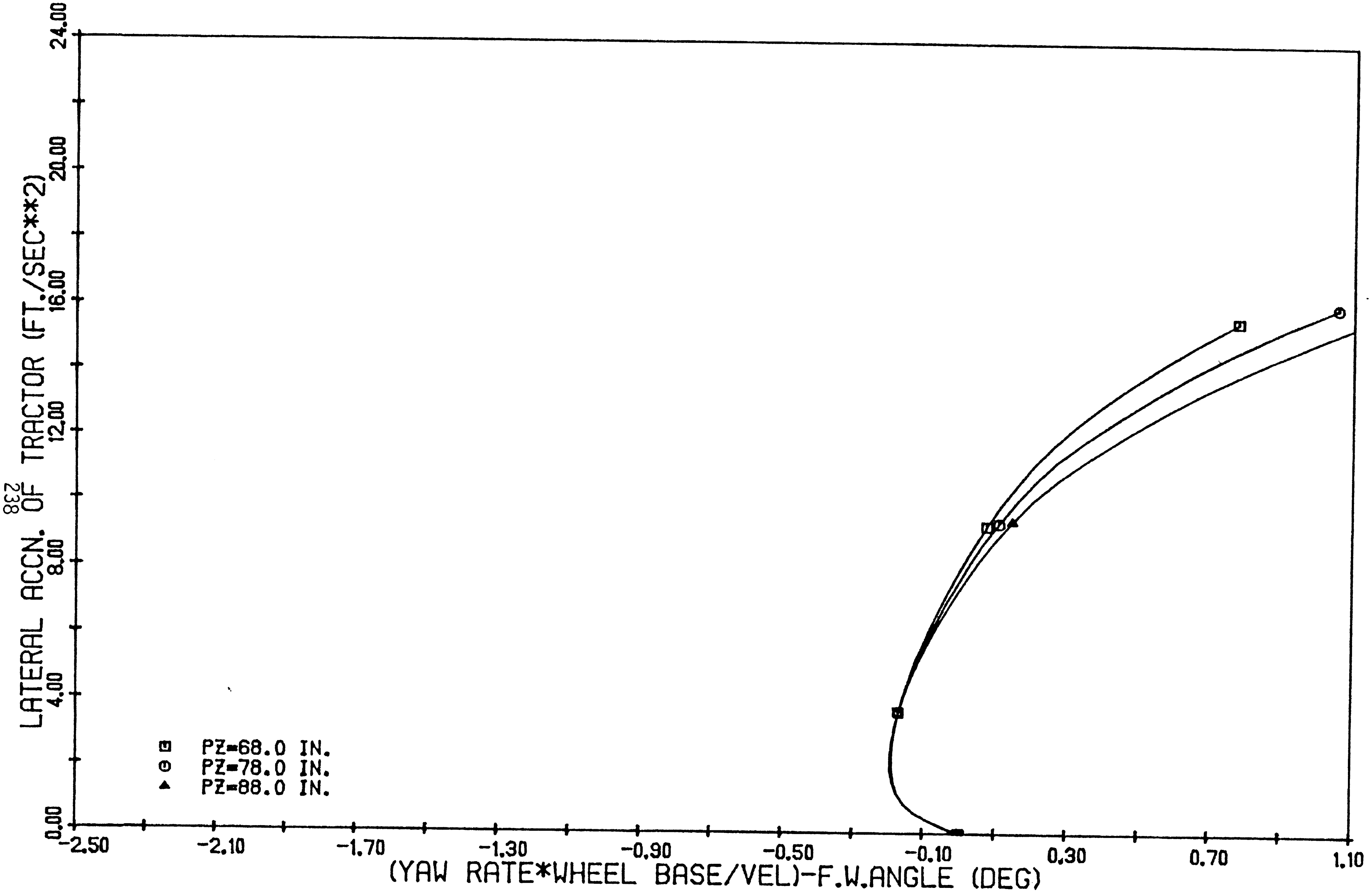
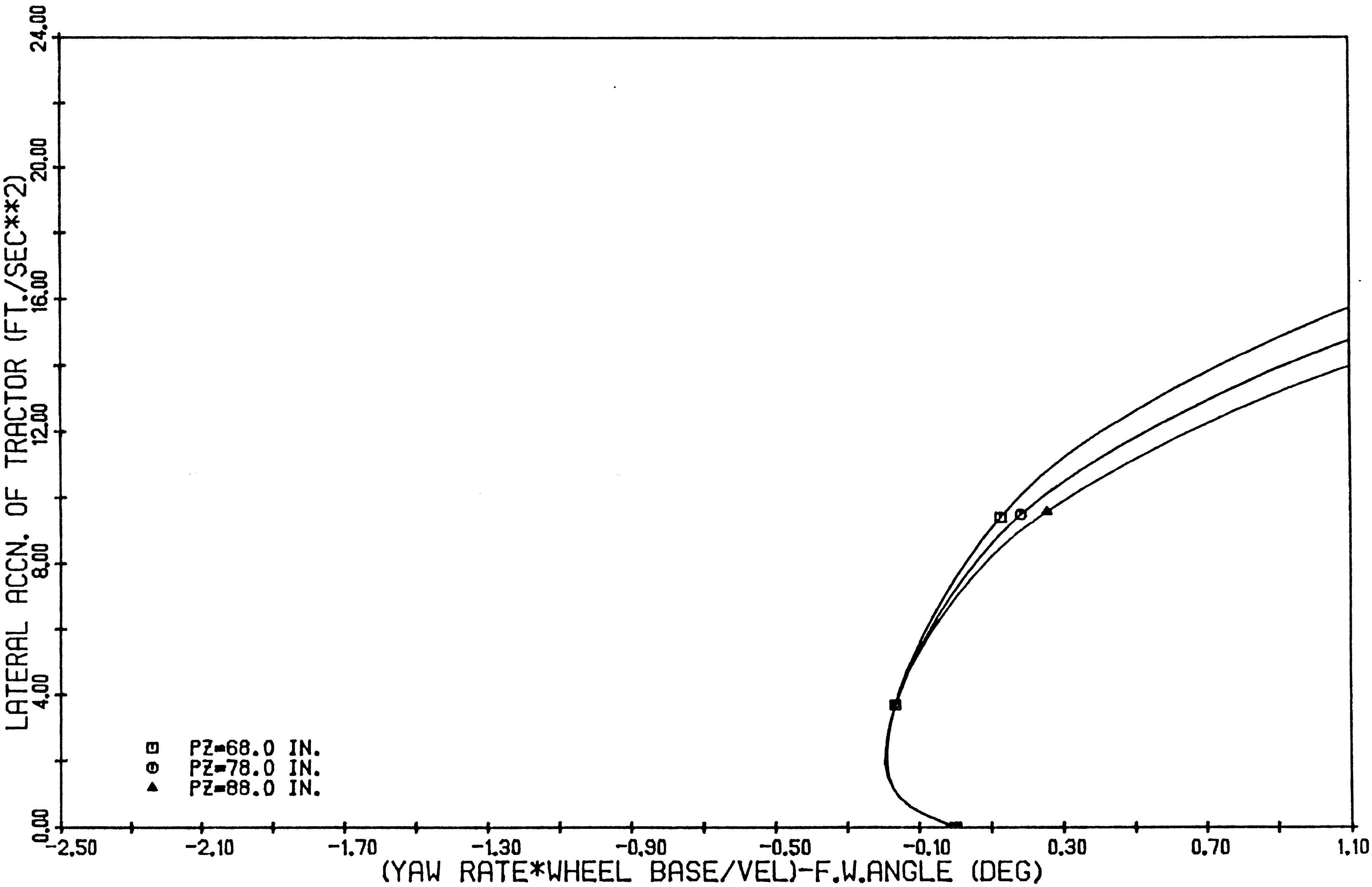


200 IN. WHEEL BASE TRACTOR, LUG TIRES, RUN # 229, 230&231



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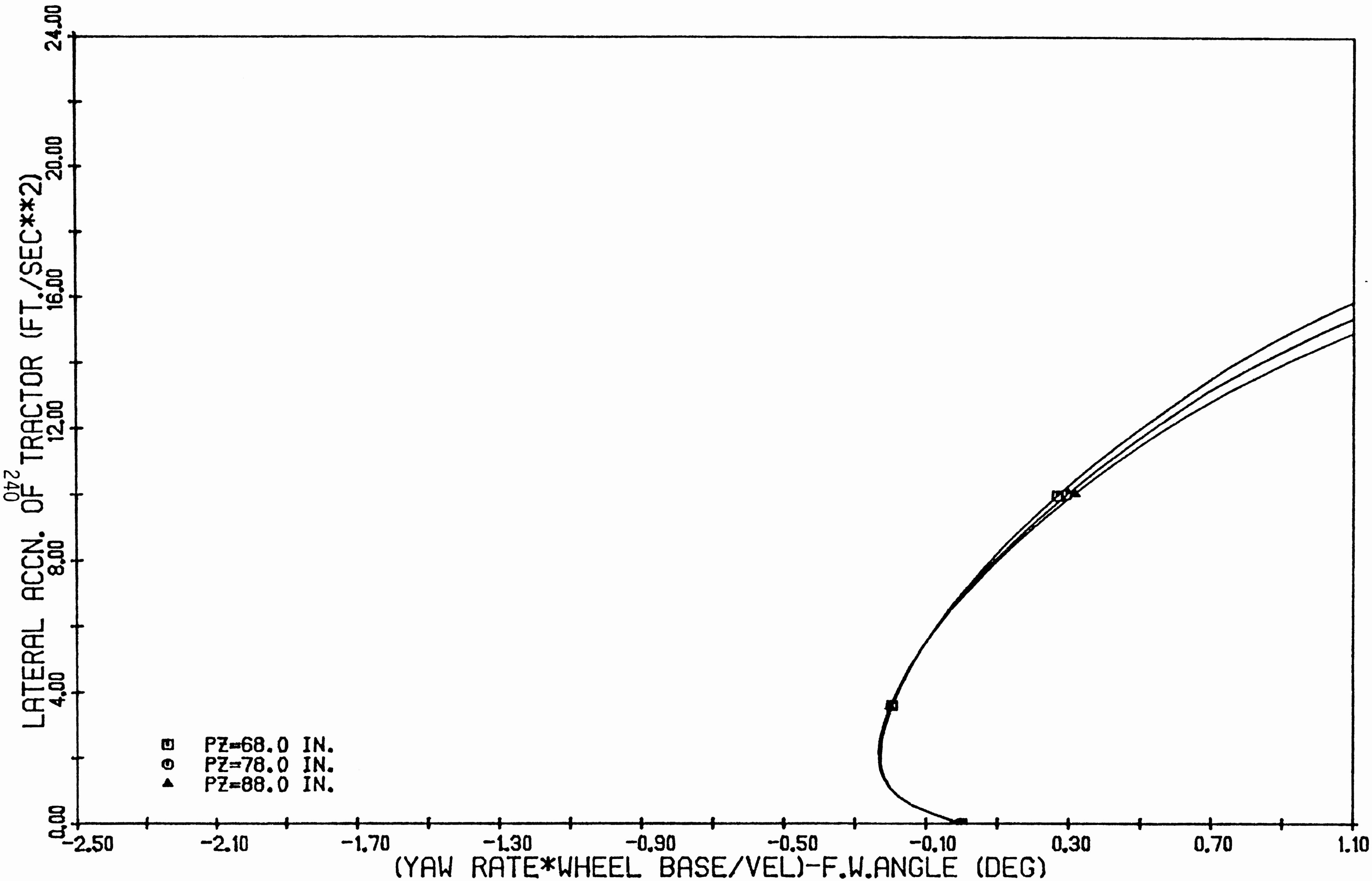

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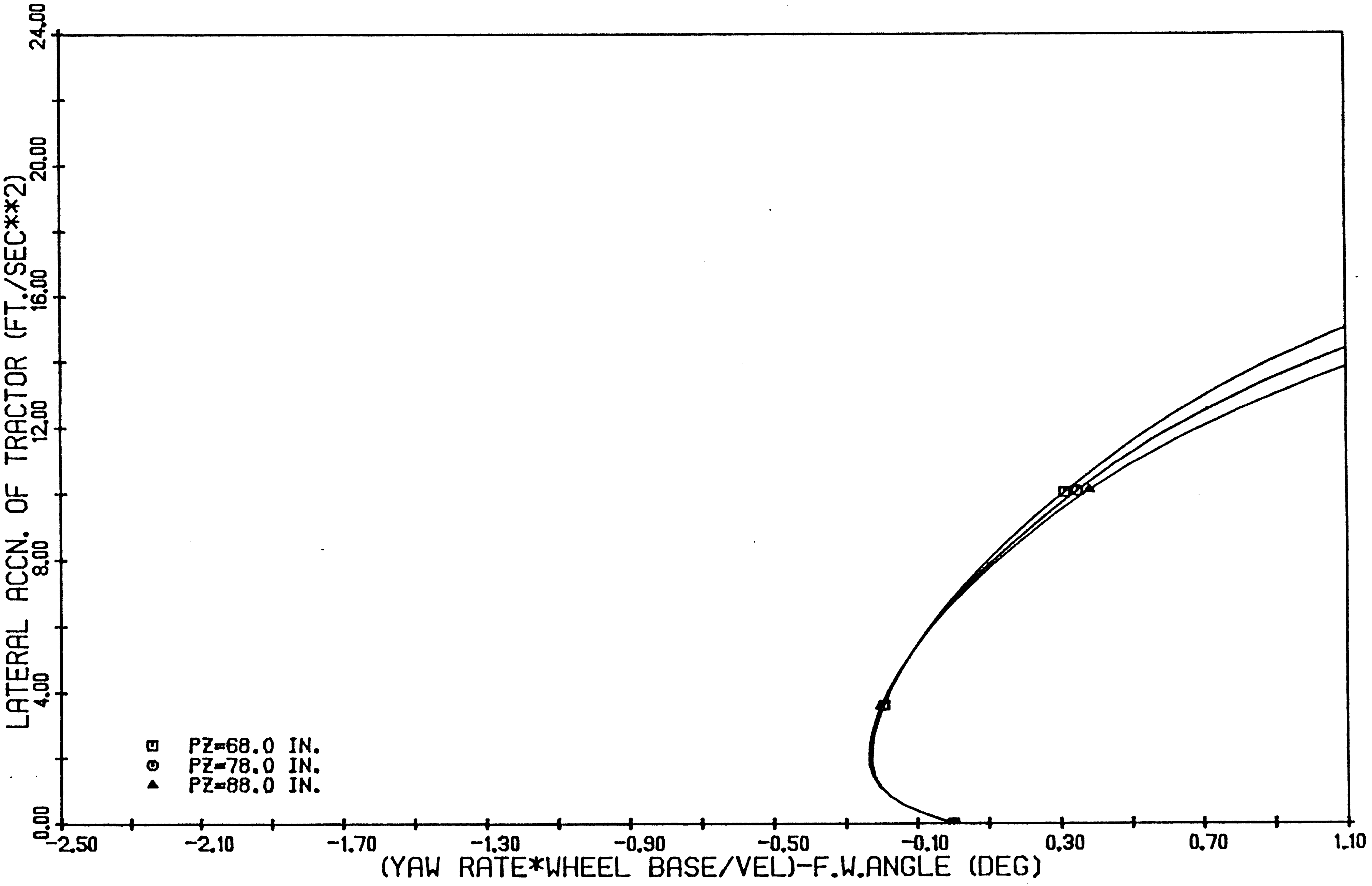


200 IN.WHEEL BASE TRACTOR,LUG TIRES,RUN # 238,239&240

APPENDIX VI

DETAILED MEASURES OF RIDE RESPONSE

This appendix contains a detailed discussion of the ride response of the various vehicle combinations tested, as well as a complete set of power spectral density plots for all tests. Section VI.1 contains a vehicle-by-vehicle discussion of dominant ride modes and the effects of surface and speed on the operator's vibrational environment. Additional power spectra are presented in VI.2 covering all other vehicle configurations and test conditions.

Test surfaces are referenced by site number. The site numbers are as follows:

1) I-94 East, Mile Markers 181-182
   smooth bituminous expressway
2) I-94 West, Mile Markers 75-74
   pockmarked concrete
3) US 23 South, Mile Markers 47-46
   aging concrete
4) M-14 East, east of US 23
   new concrete
5) Huron Parkway, Glacier Way to Geddes
   aging urban street

VI.1 Dominant Modes and Effects of Surface and Speed

In the following sections, cab vibrations are characterized by the power spectral densities of vertical and longitudinal vibrations of the operator's seat. These measures are augmented by power spectra and phase relationships of the three frame-mounted accelerometer signals to deduce the modes of vibration that account for vibrations of the seat. These pieces of information provide a description of the vehicle's ride response in terms of the dominant ride modes and the vibrational environment of the operator.

Each vehicle is treated separately with a discussion of the ride modes followed by a summary of the effects of differing surfaces and speeds on the cab vibrations.

VI.1.1 Cab-Over-Engine Tractor, Bobtail. Dominant modes were identified by examining the power spectral densities and phase relationships between the three frame-mounted accelerometer signals. Peaks in the spectral density occur at frequencies where a resonance occurs or a large driving force is present. By examining the phase relationships and the relative amplitudes at the three frame locations, the mode shape can be estimated. PSD's from the frame-located accelerometers are shown in Figure VI.1 for the bobtail COE tractor traveling over site number 1 (smooth bituminous section of I-94) at 55 mph. Phase angles of the midframe and rear frame signals relative to the front location are shown in Figure VI.2. All three locations show significant peaks at approximately 7.5, 15, and 22.5 Hz. These peaks correspond to the first-, second- and third-order wheel rotation. Tire radial force variations are a major vibratory input on this surface which has only small irregularities exciting the suspension. Two other peaks appear below 7.5 Hz at 3.0-3.5 and 5.0-5.5 Hz, the magnitudes of these peaks vary from location to location, providing an initial indication of mode shape. The 3.0-3.5 Hz mode has nearly constant amplitude from front to rear with the center and rear signals lagging the front signal by less than 90°. This is a "bouncing" mode and the phase lag is due to the spacing between the front and rear axles which causes disturbances to be encountered by the rear axle at a time delay relative to the front axle, thus slightly distorting the mode shape. At 5.0-5.5 Hz the power content increases from front to rear and both the center and rear signals are approximately 180° out of phase with the front. This frequency corresponds to a "pitching" motion with the node located between the front axle and the frame midpoint. Higher frequency components cannot be clearly attributed to any particular source, but in all likelihood power found in the 10-14 Hz range can be attributed to unsprung mass motions, axle hop, etc. Higher frequency motions are due to various component resonances, viz., exhaust stacks, fuel tanks, etc.

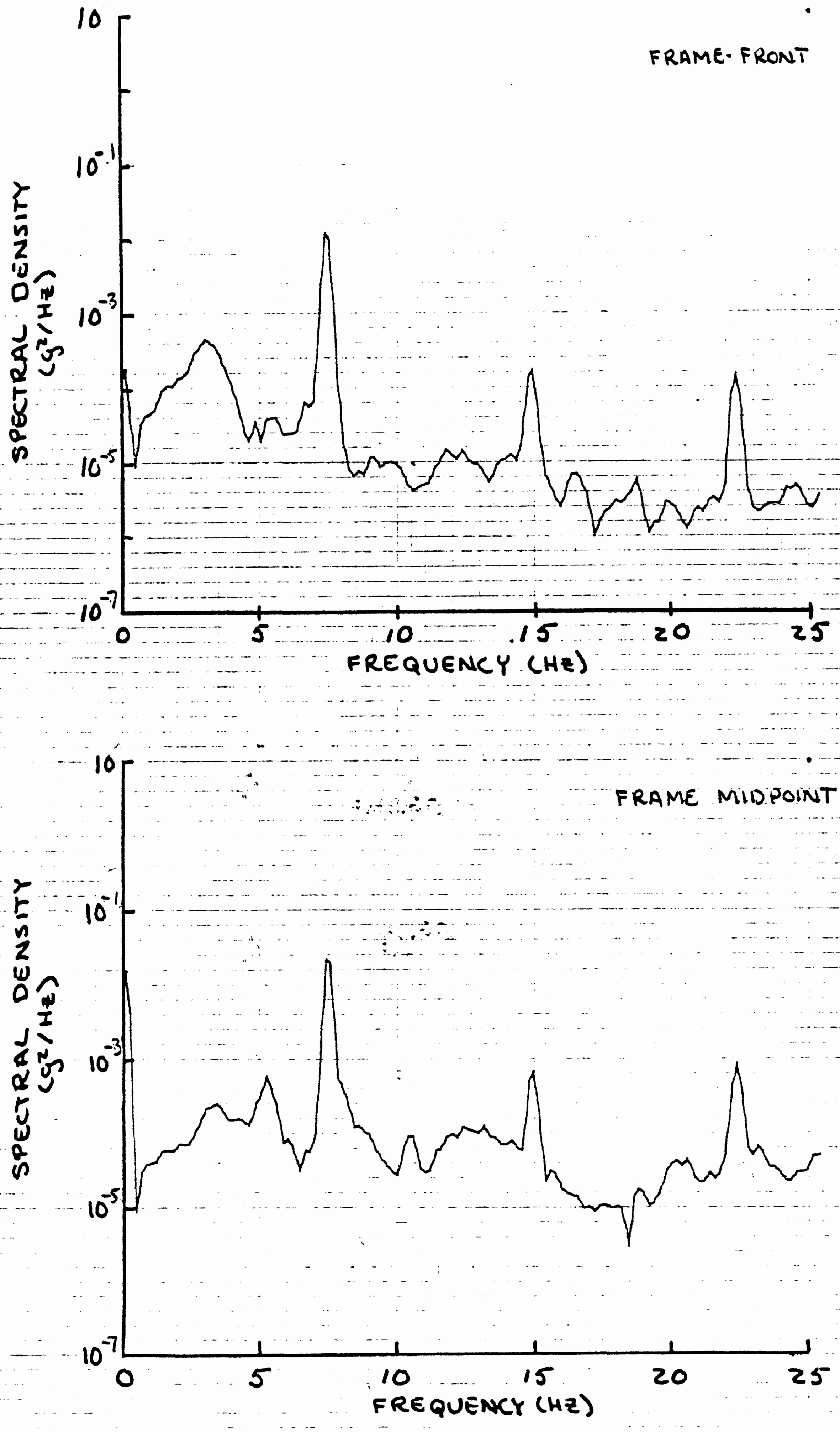
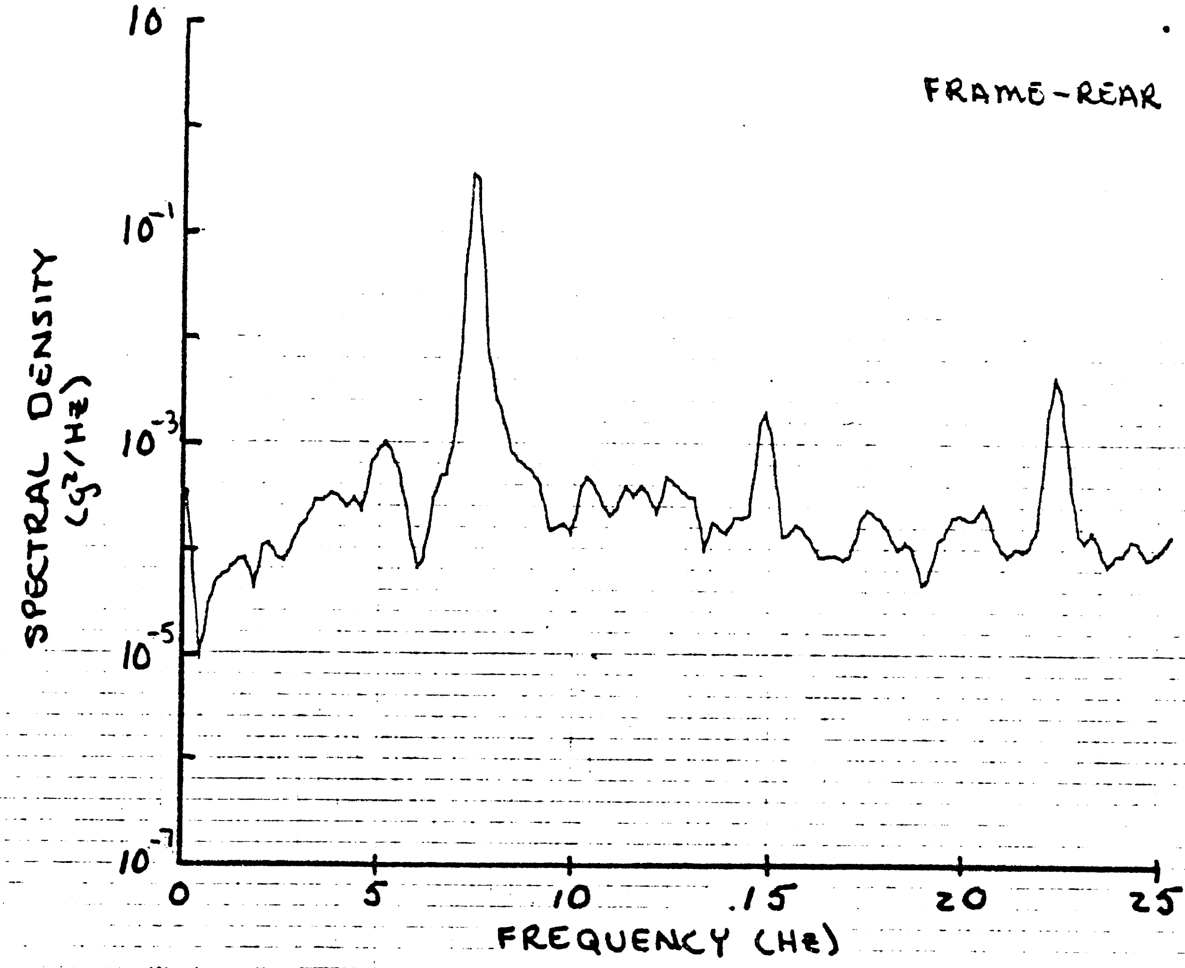


Figure VI.1. Power spectral densities, bobtail COE tractor over site #1 at 55 mph.



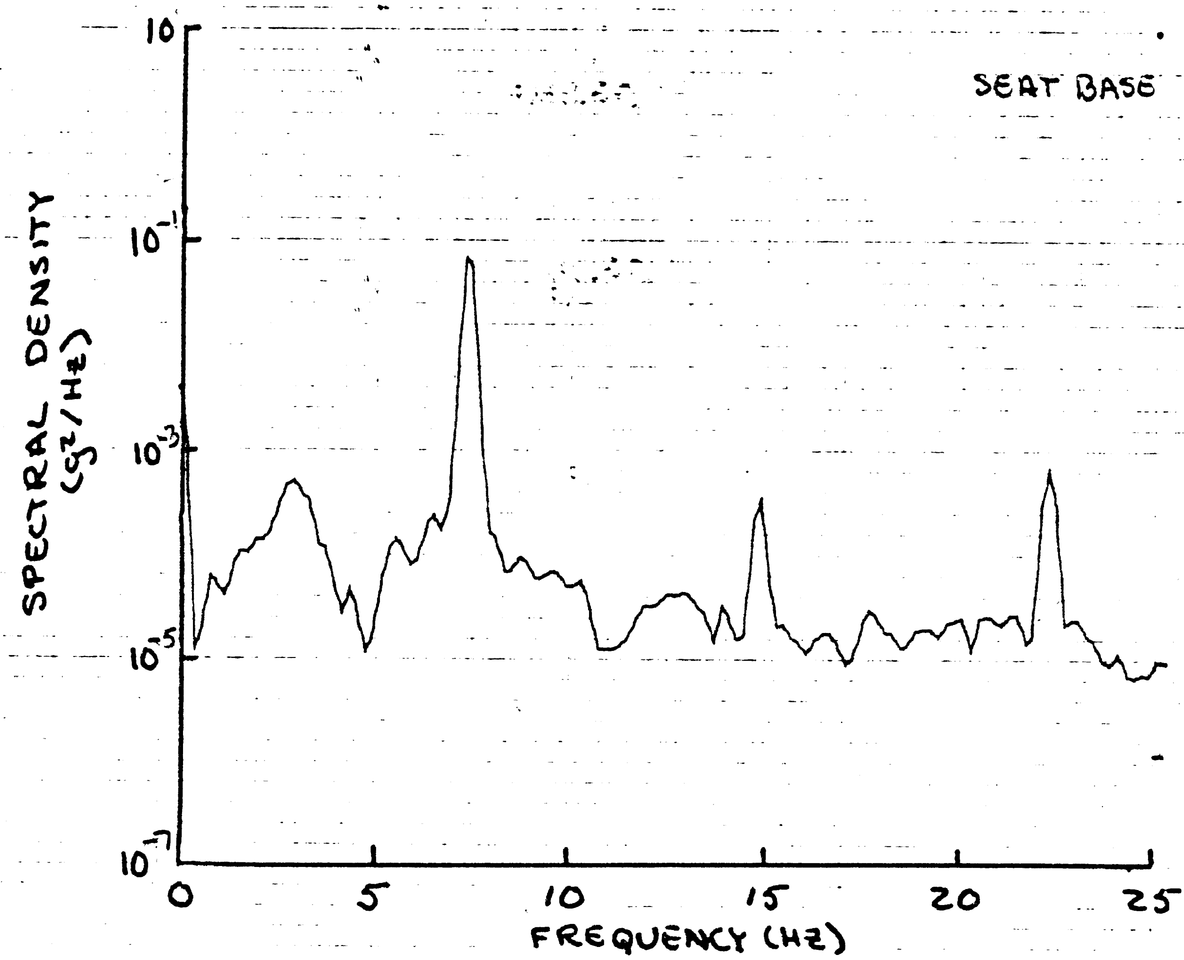
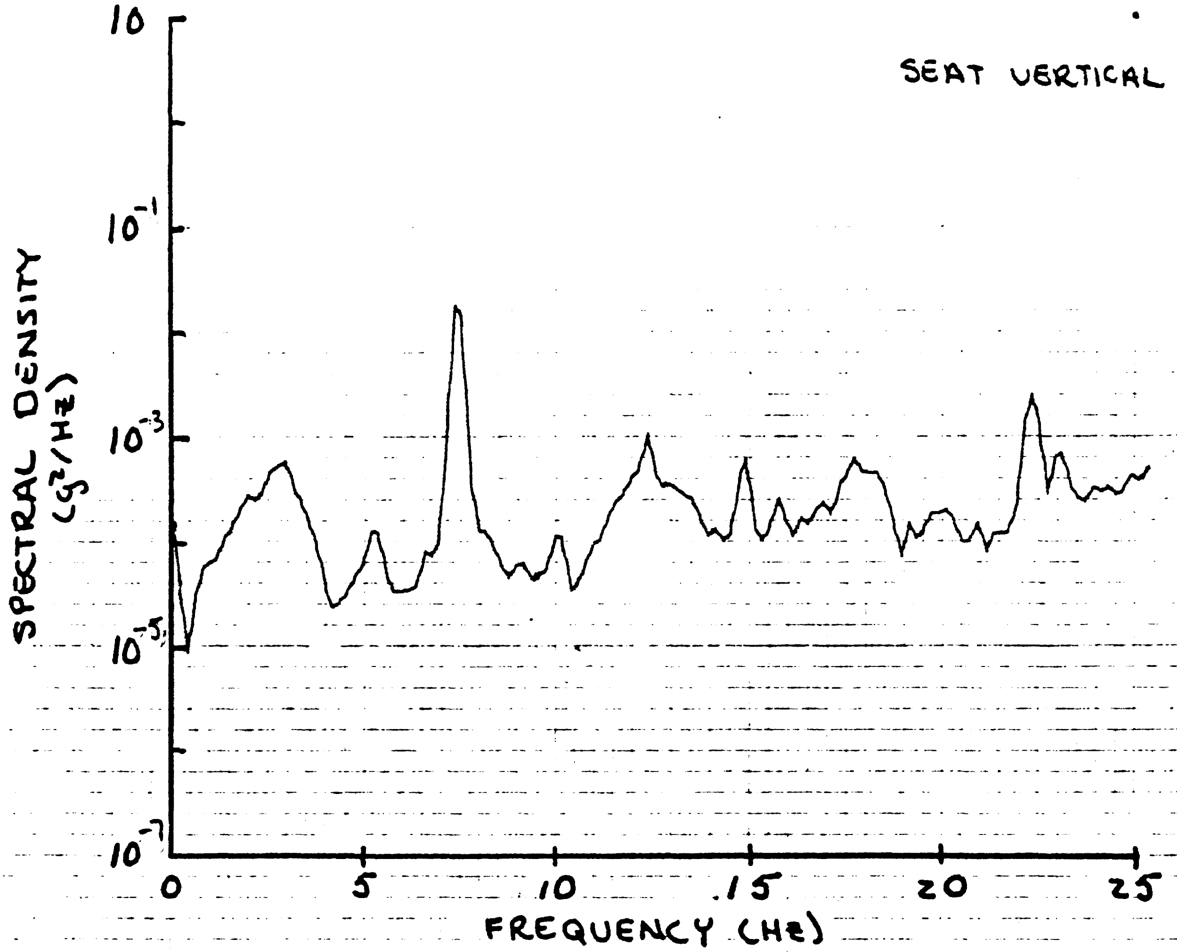


Figure VI.1 (Cont.)



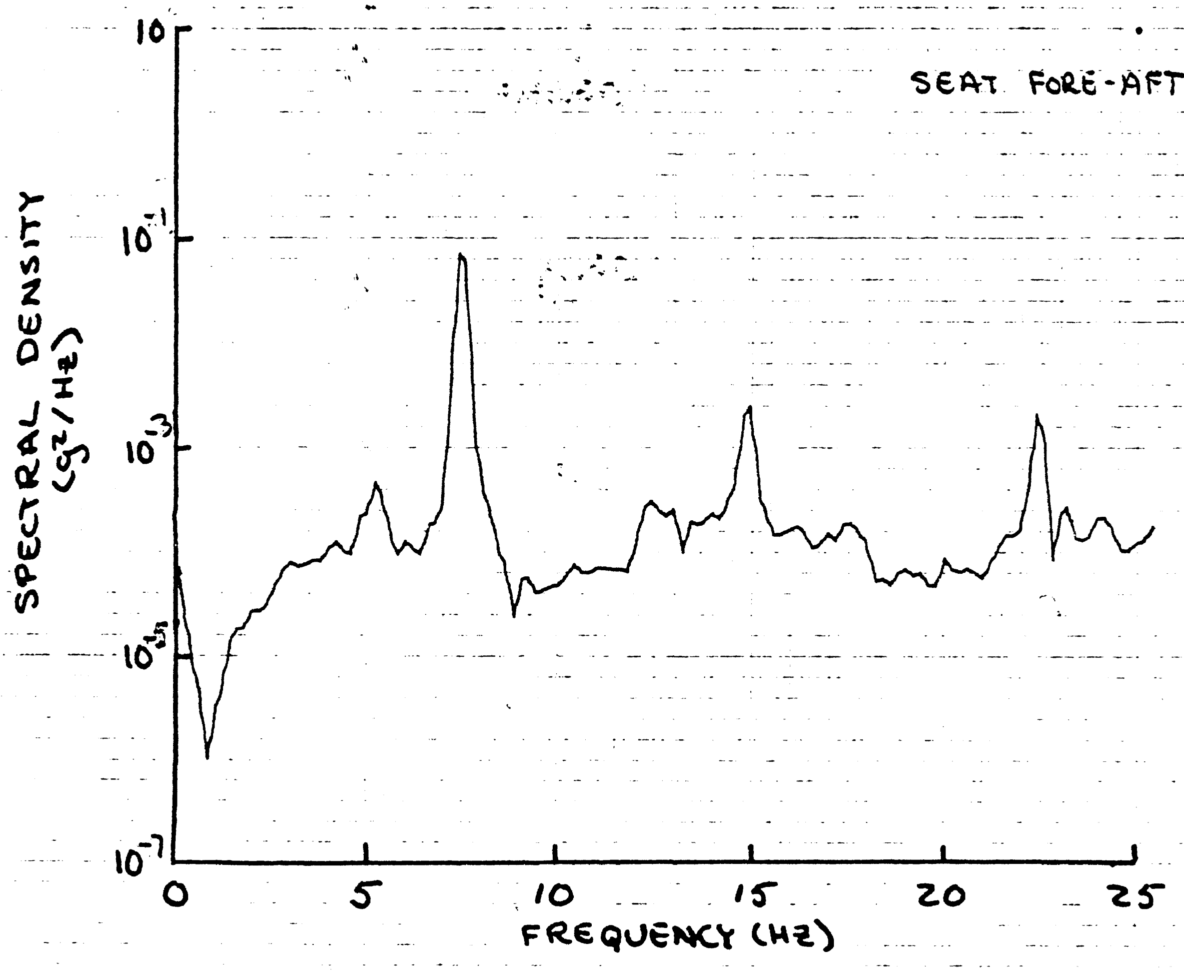
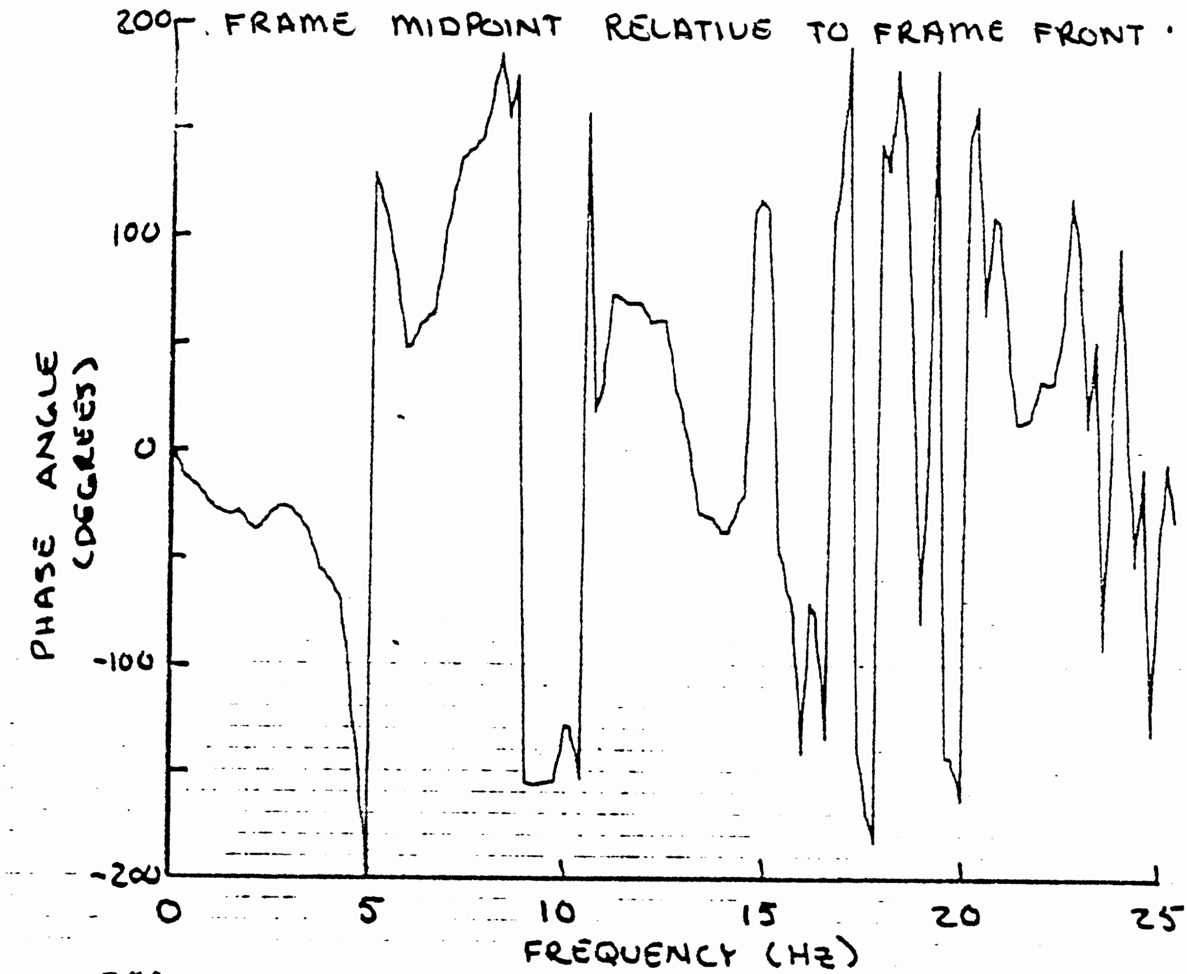


Figure VI.1 (Cont.)



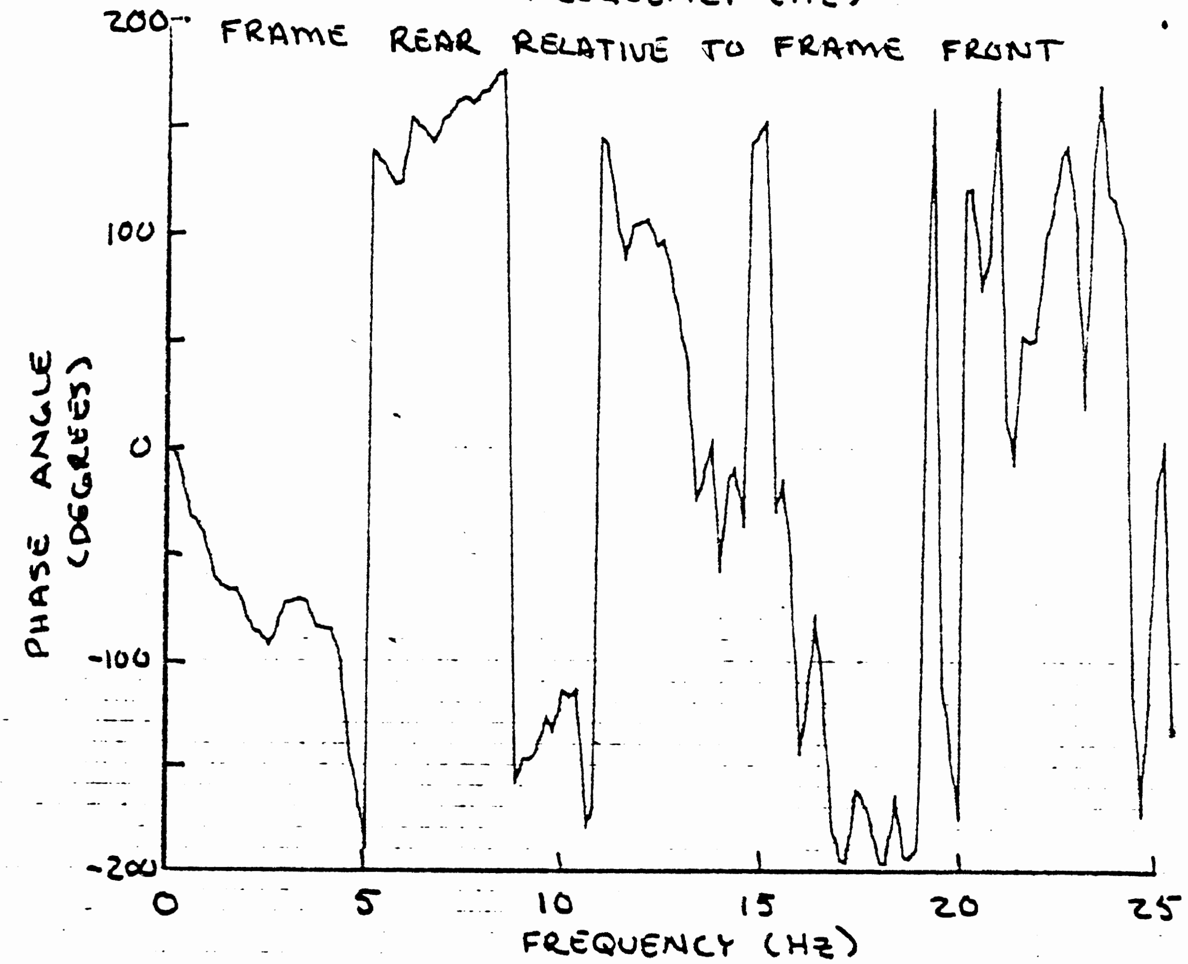
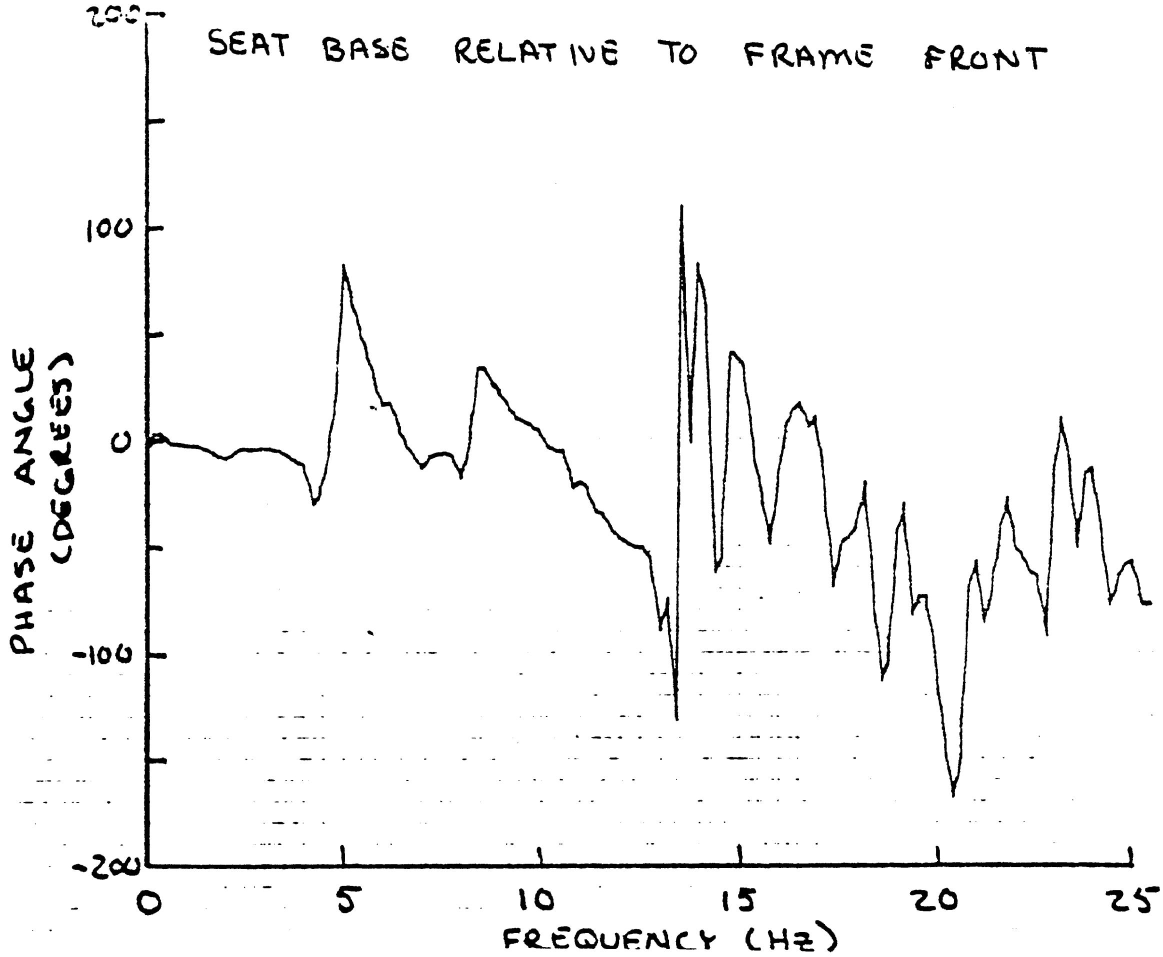


Figure VI.2. Phase relationships, bobtail COE tractor over site #1 at 55 mph.



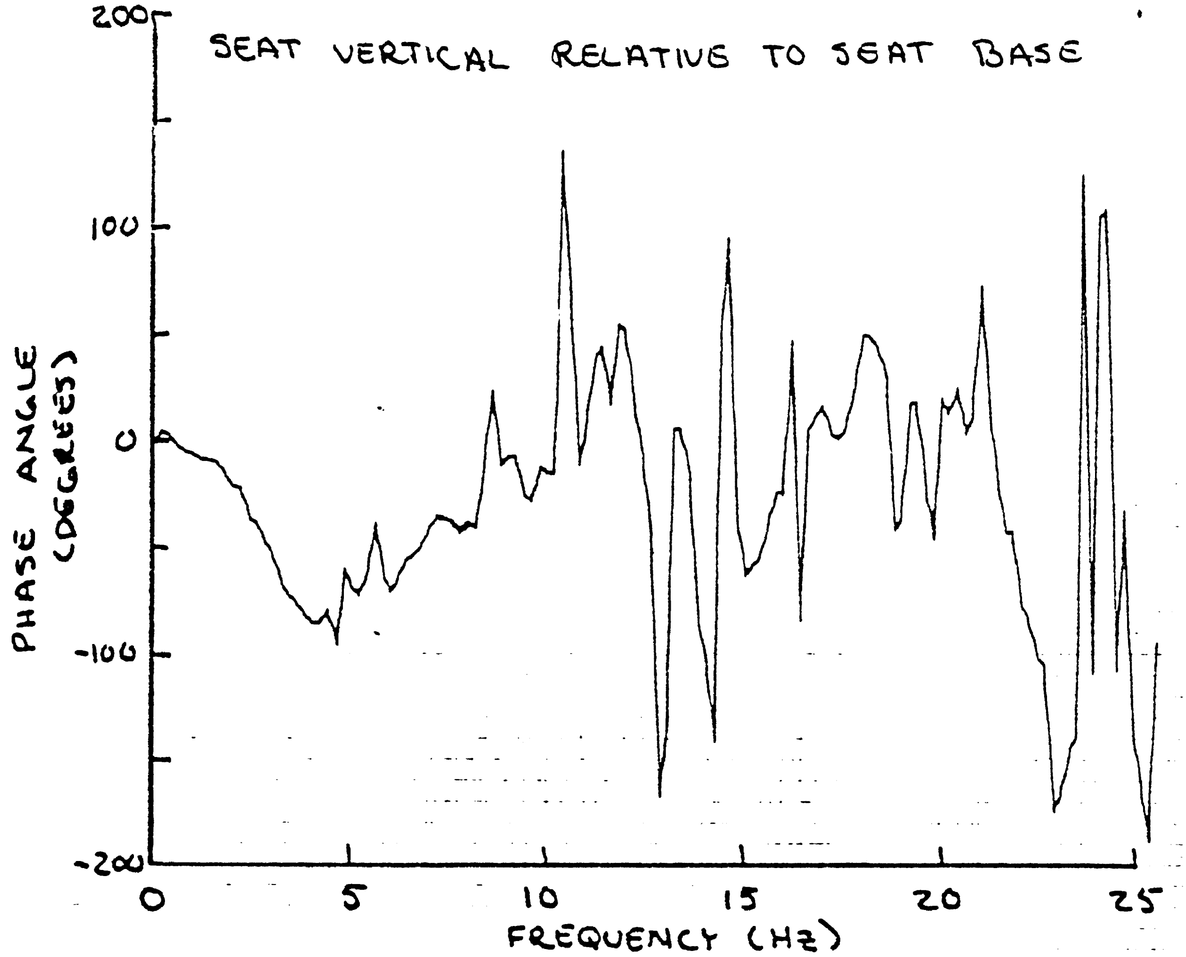


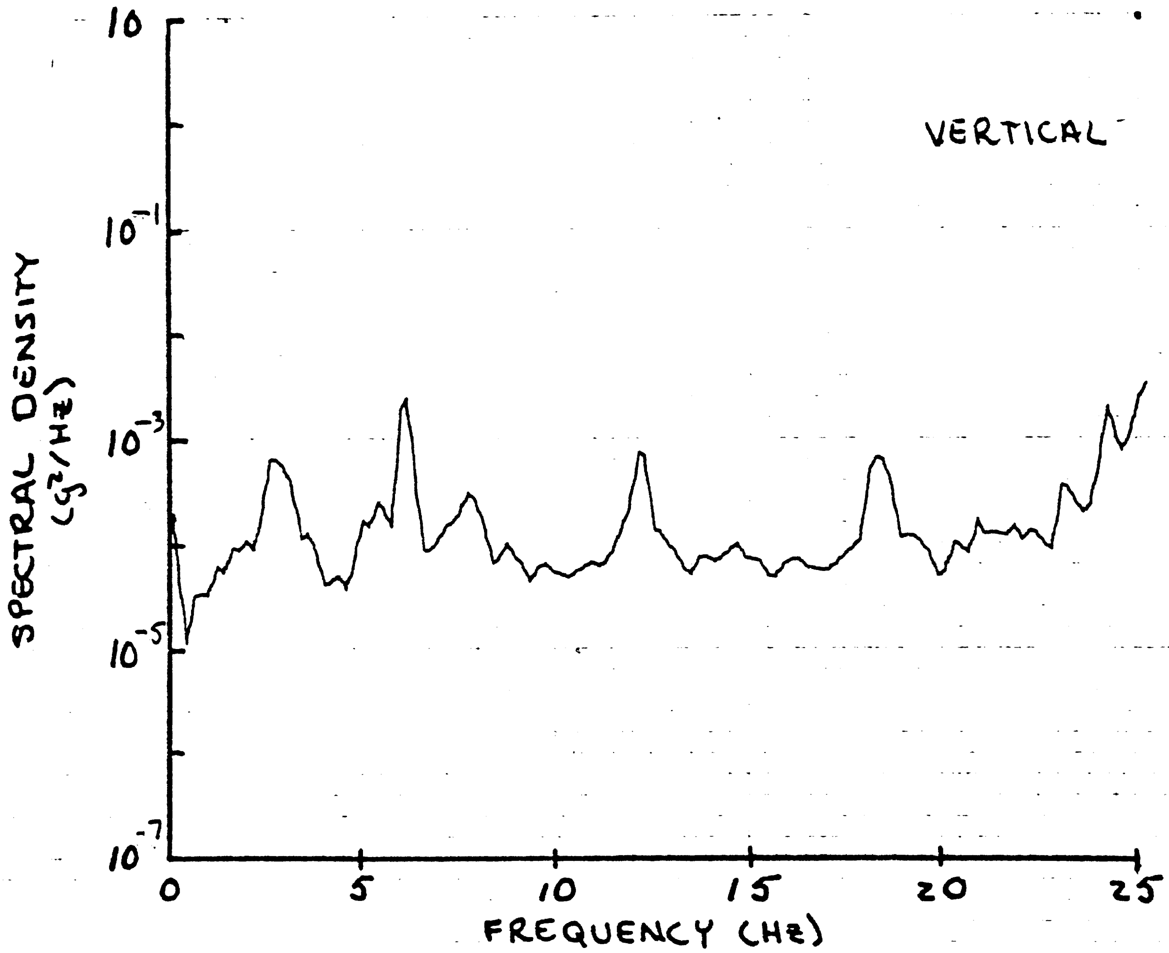
Figure VI.2 (Cont.)

Figure VI.1 also shows PSD's of the vertical and fore/aft accelerations on the seat and vertical acceleration at the seat base. Figure VI.2 shows the corresponding phase relationships between the seat base and front frame accelerations, and seat base and seat vertical accelerations. From these it can be seen that the cab has a natural frequency on its mounts of approximately 13 Hz and the natural frequency of the seat suspension is in the neighborhood of 5 Hz.

Effects of Surface and Speed on Cab Vibrations:

Given the dominant modes of a vehicle's ride motions, the vibrations experienced by the operator are primarily dependent on the inputs from the road surface and inputs dependent on the vehicle's forward speed. For the very smooth bituminous surface of Site #1, the input from the surface irregularities compared to that of the tire-wheel systems is small, this fact is illustrated in the spectral densities of the vertical and fore/aft accelerations at the seat, shown in Figures VI.1 and VI.3. These are the responses at the seat of the COE tractor at 55 and 45 mph on Site #1. The dominant peaks appearing in each of these PSD's are directly related to first-, second-, and third-order wheel rotation. At 55 mph, the frequencies are 7.5, 15 and 22.5 Hz; at 45 mph the tire-wheel components appear at 6.25, 12.5, and 18.5 Hz. Another significant contribution to the seat vertical spectra comes from the bounce mode previously identified at 3.0 Hz. The pitch mode contribution to both vertical and fore/aft motions occurs at 5.5 Hz. At 45 mph a peak appears at 8 Hz. From the phase information, the peak at 8 Hz appears to be a pitching mode, but at this frequency it is more likely a frame beaming mode. Insufficient information is available, however, to provide a conclusive identification.

On Site #2, the tire-wheel harmonics are not as dominant, but still present and significant, in the seat vertical spectra (Figures VI.4 and VI.5). In this case, the dominant peak in the seat vertical spectrum occurs at 2.5 Hz and corresponds to the vehicle's bounce mode. This frequency is slightly lower than that at which the bounce mode was observed on the smooth surface. The apparent reduction in the frequency of a natural mode can be explained by an effective "softening" of the



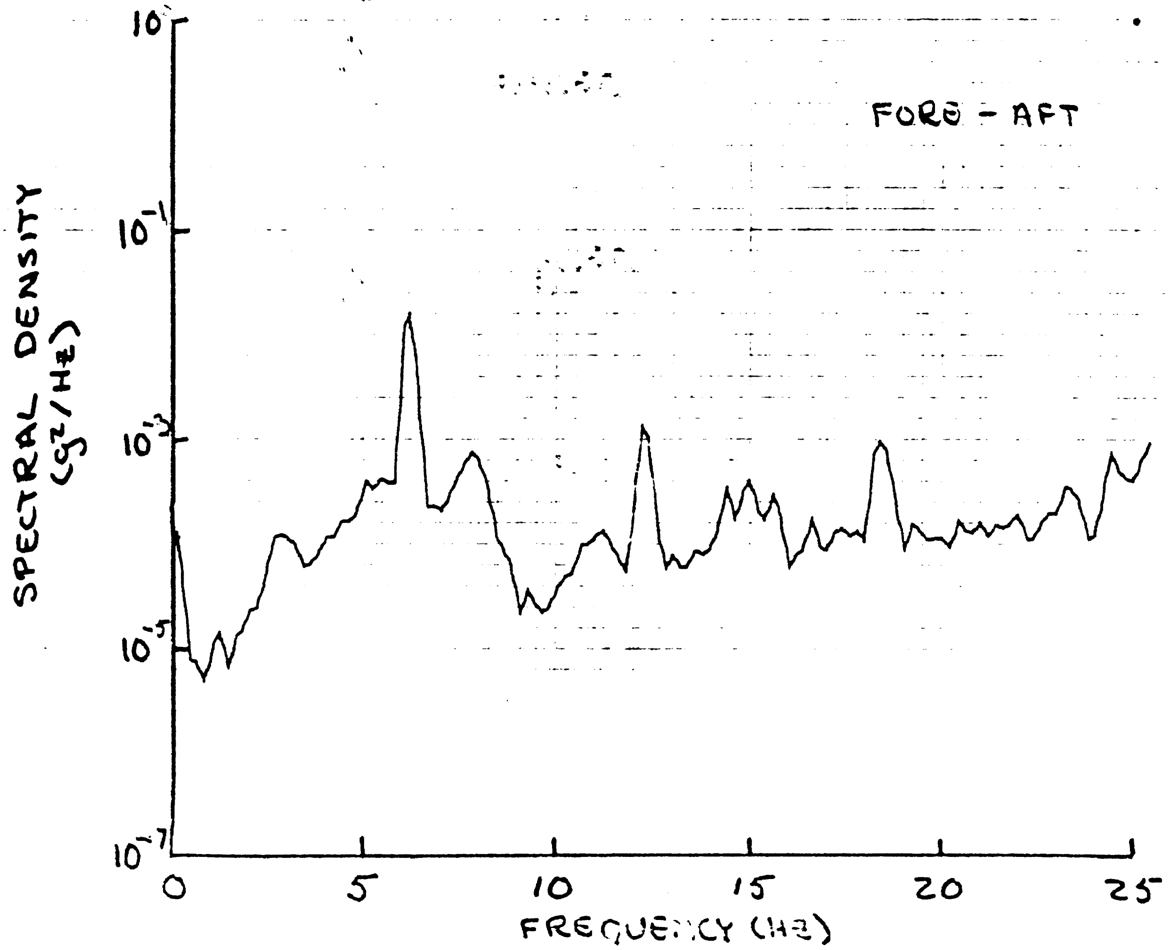


Figure VI.3. PSD's at seat, bobtail COE tractor over site #1 at 45 mph.

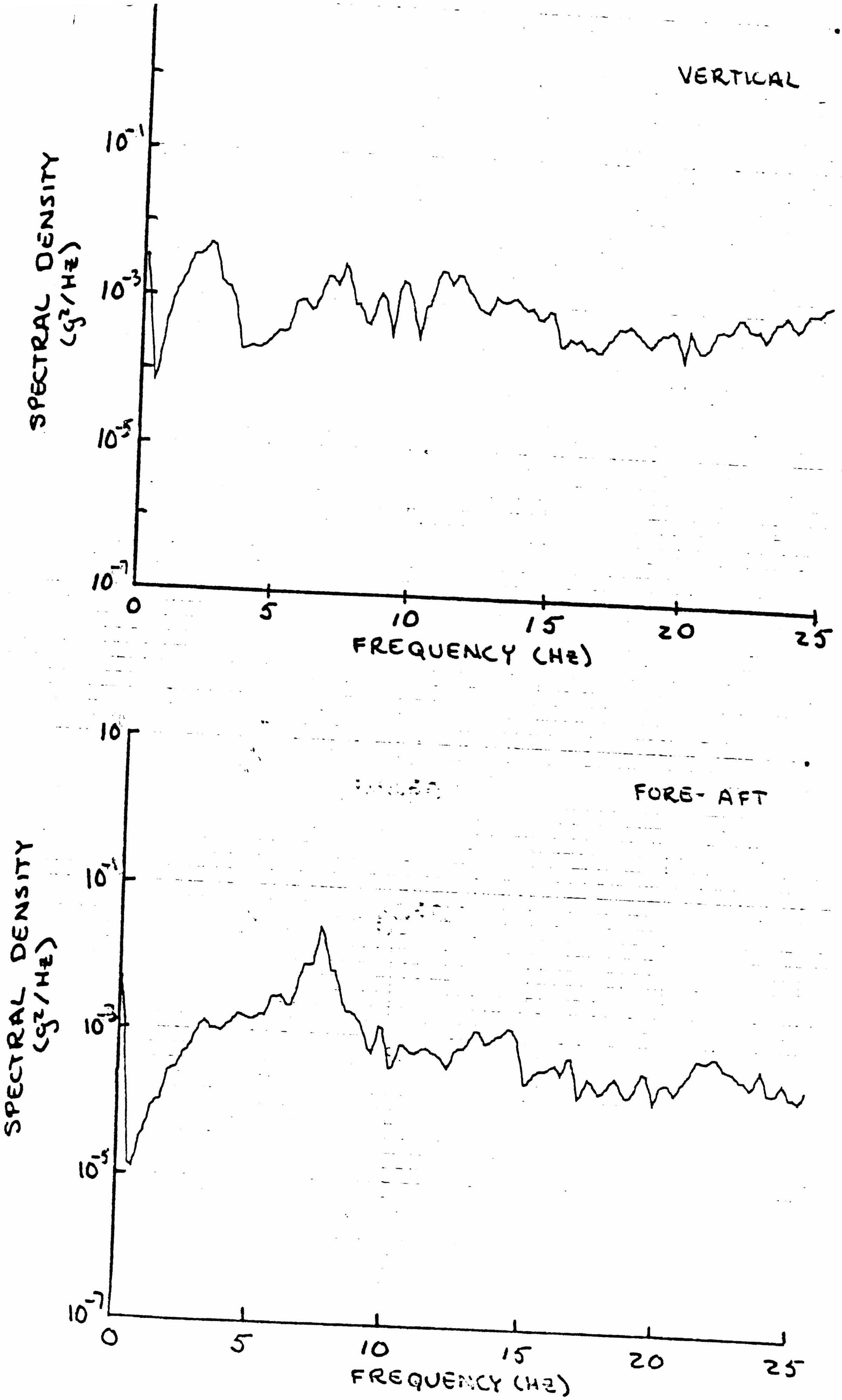


Figure VI.4. PSD's at seat, bobtail COE tractor over site #2 at 55 mph.

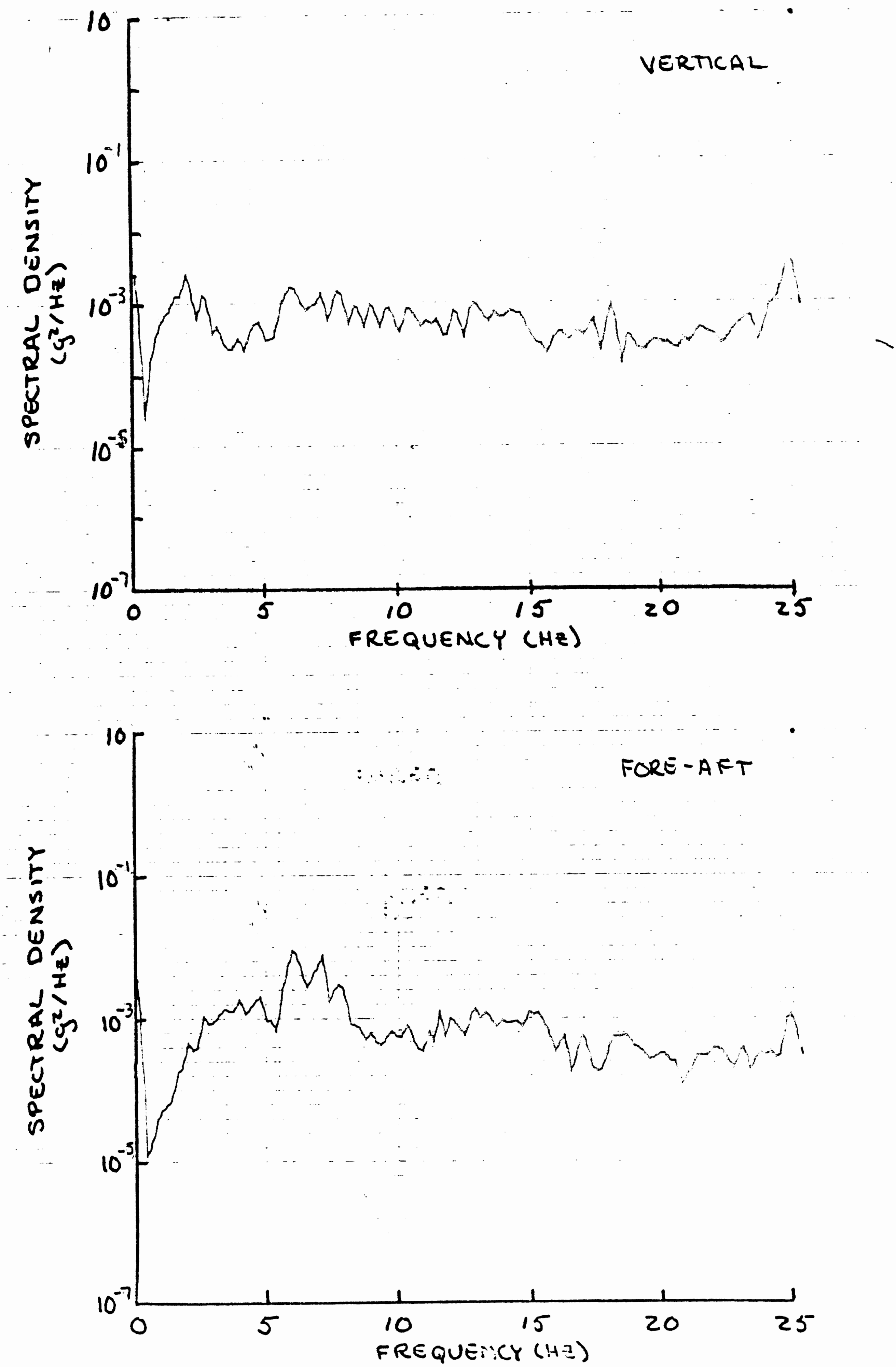


Figure IV.5. PSD's at seat, bobtail COE tractor over site #2 at 45 mph.

suspension due to larger deflections causing the springs to "break through" the coulomb friction in the leaf springs. The seat fore/aft acceleration is still dominated by the tire-wheel rotational frequencies at 45 and 55 mph with some contribution coming from 7-8 Hz at 45 mph. Once again, the phase relationships show signals at the midpoint and rear of the frame about 180° out of phase with the front at this frequency.

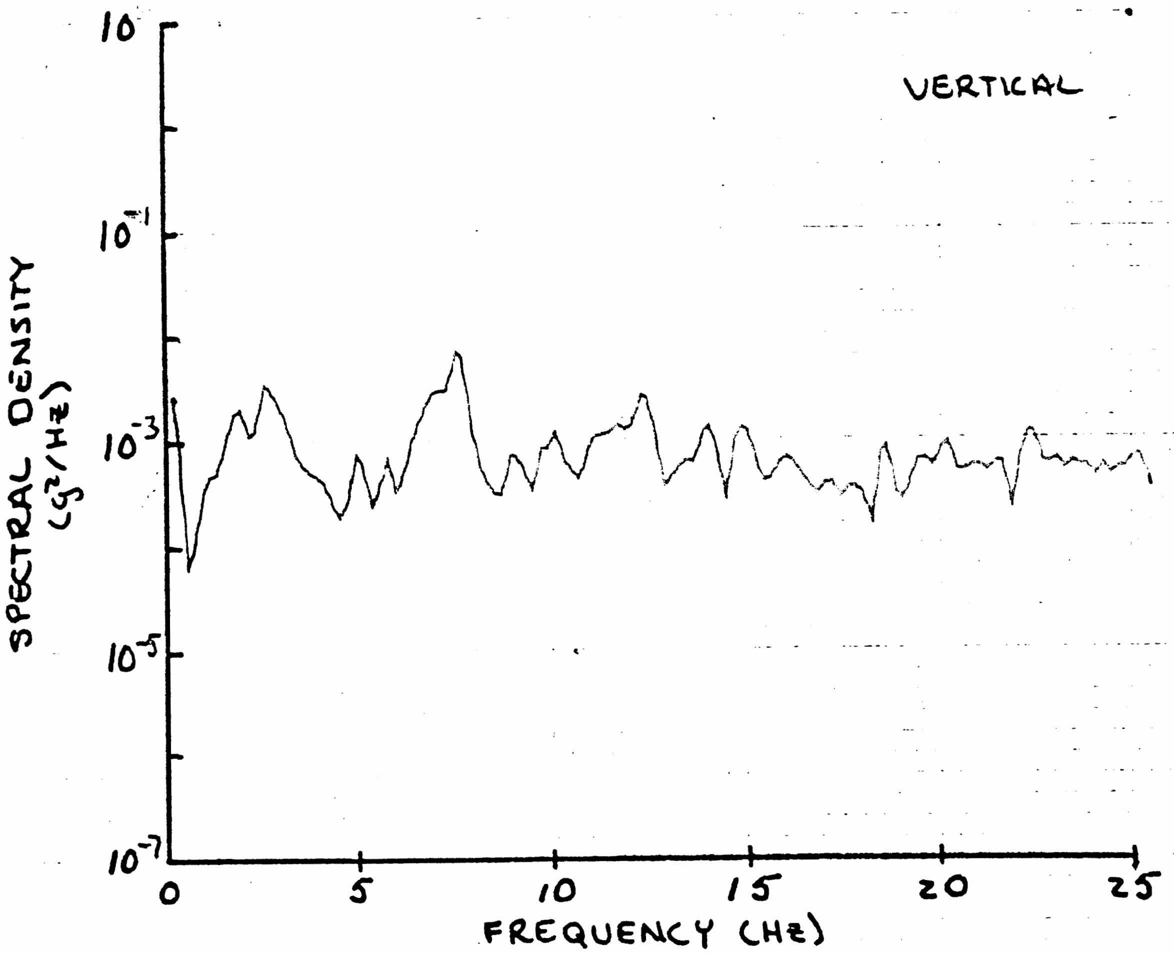
The previously described trends are the same for Sites #3 and 4 (Figures VI.6-9), with vertical vibrations dominated by the bounce resonance and by tire inputs. The bounce mode contribution contains less power than in the case of Site #2.

The fore/aft spectra have significant power at 5 Hz (pitch mode) and at the tire-wheel rotational frequencies. At 45 mph the natural mode appearing at 7.5-8 Hz becomes distinct from the tire-wheel input excitation that was seen to coincide with this mode at 55 mph.

Site #5 (Huron Parkway) was run at 35 mph resulting in a tire rotational frequency of approximately 5 Hz which is near the vehicle's pitch frequency. This frequency is a major contributor to both vertical and longitudinal power content as shown in Figure VI.10. The vertical spectra also contains peaks at 2.5 and 7.5 Hz, corresponding, respectively, to bounce and pitching motions. Longitudinal vibrations are dominated by the 5 Hz pitch/tire rotational mode and the 7.5 Hz pitching mode.

VI.1.2 Cab-Over-Engine Tractor - Loaded. The loaded COE tractor demonstrates three dominant ride modes in addition to the tire-wheel related responses. One bouncing and two pitching modes are seen as the dominant ride responses.

Bounce appears at 2.5-3 Hz with decreasing magnitude from front to rear indicating a node rear of the tractor. Pitching modes occur with frequencies of 3.5 Hz and 4.5 Hz. In both cases, the node is located between the front axle and the frame midpoint. The interaction of these pitching modes with the trailer cannot be determined because the trailer was not instrumented. Spectral densities and phase relationships for the loaded cab-over-engine tractor at 55 mph on Site #1 are presented in Figures VI.11 and VI.12.



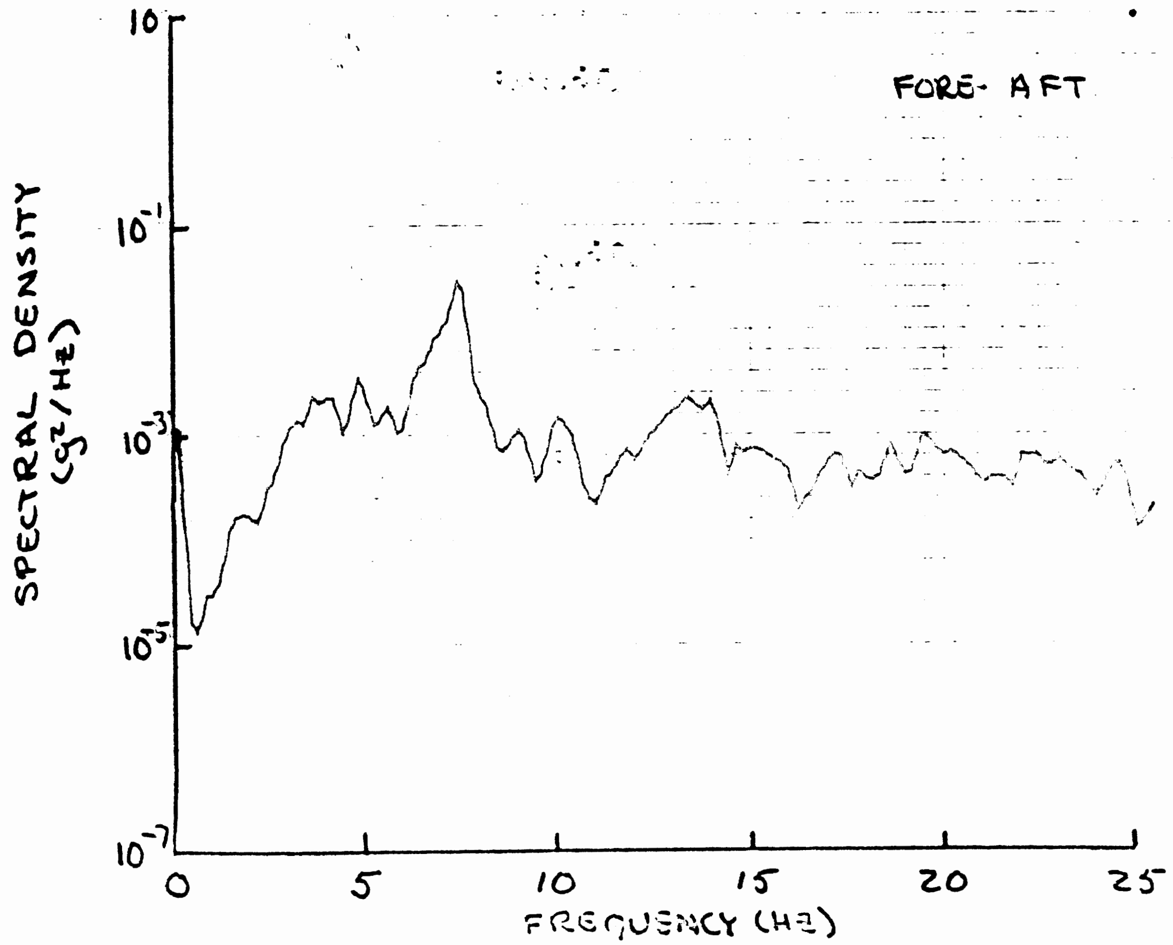
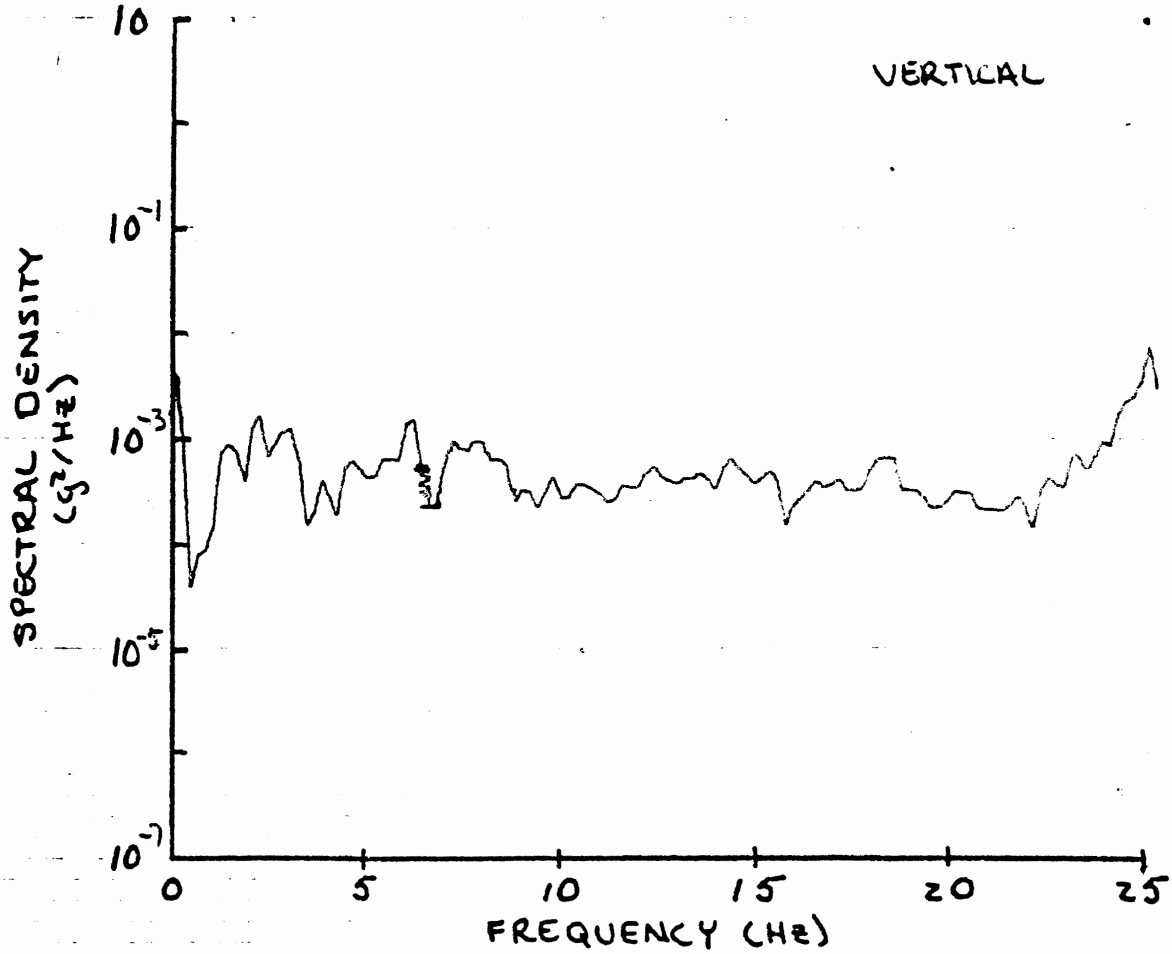


Figure VI.6. PSD's at seat, bobtail COE tractor over site #3 at 55 mph.



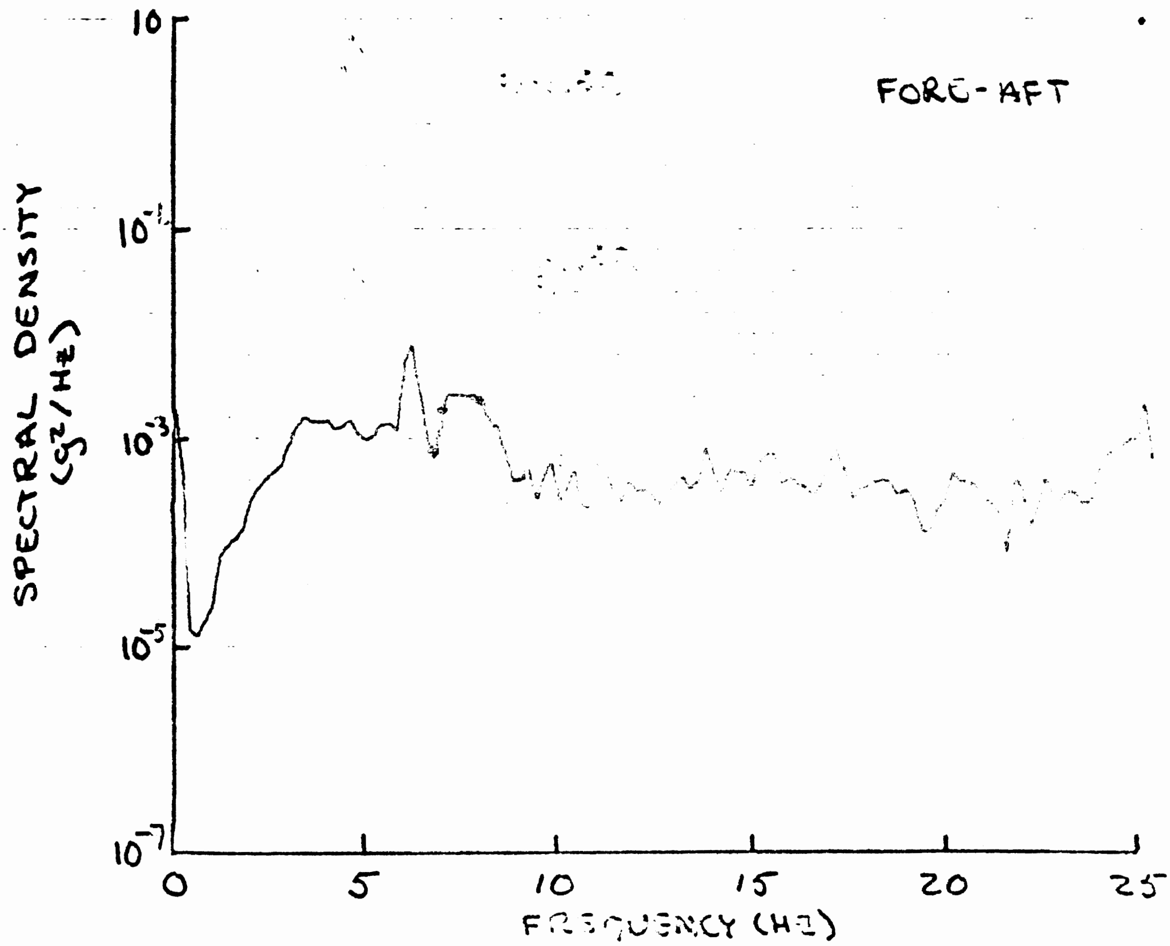


Figure VI.7. PSD's at seat, bobtail COE tractor over site #3 at 45 mph.

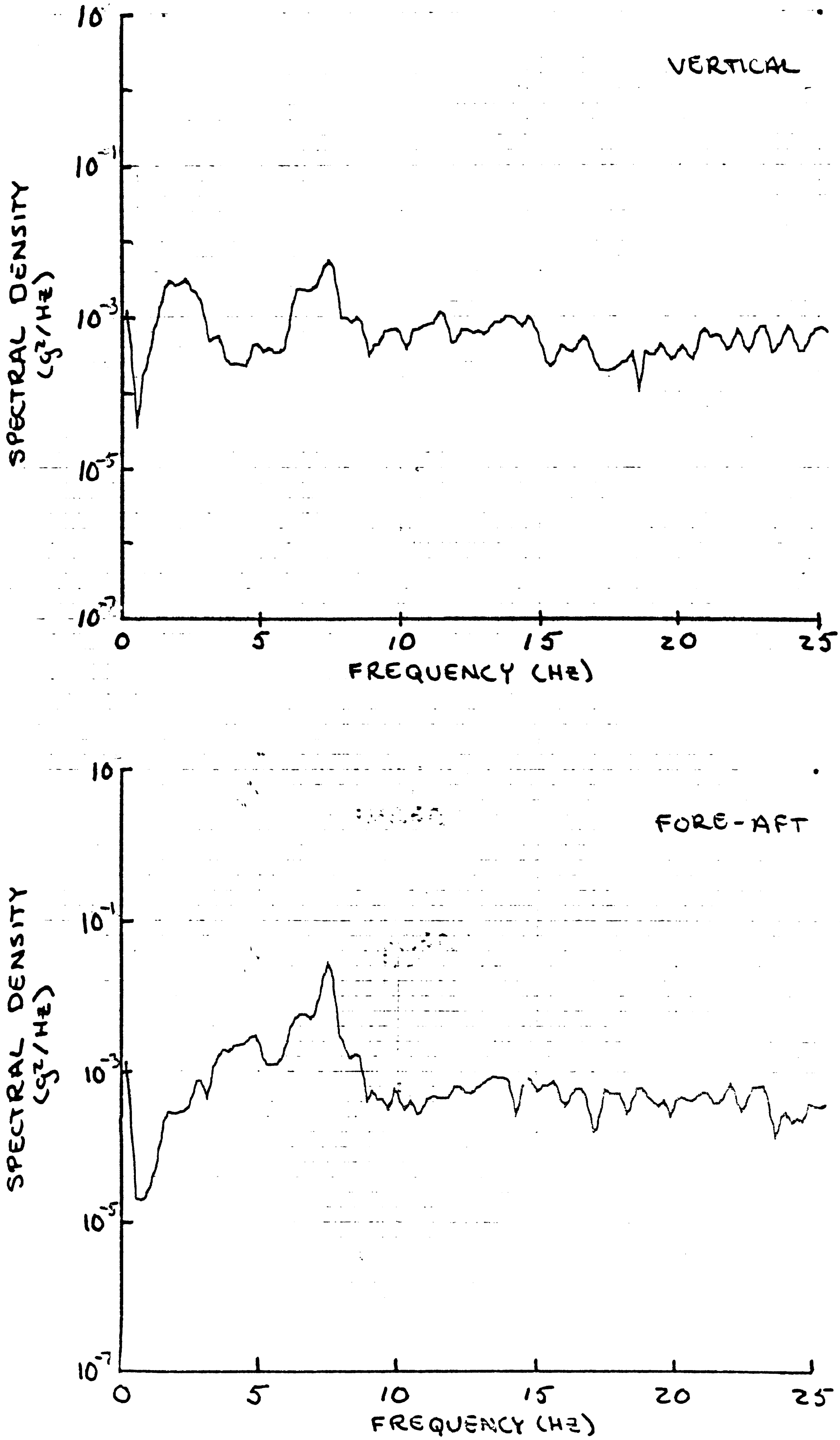


Figure VI.8. PSD's at seat, bobtail COE tractor over site #4 at 55 mph.

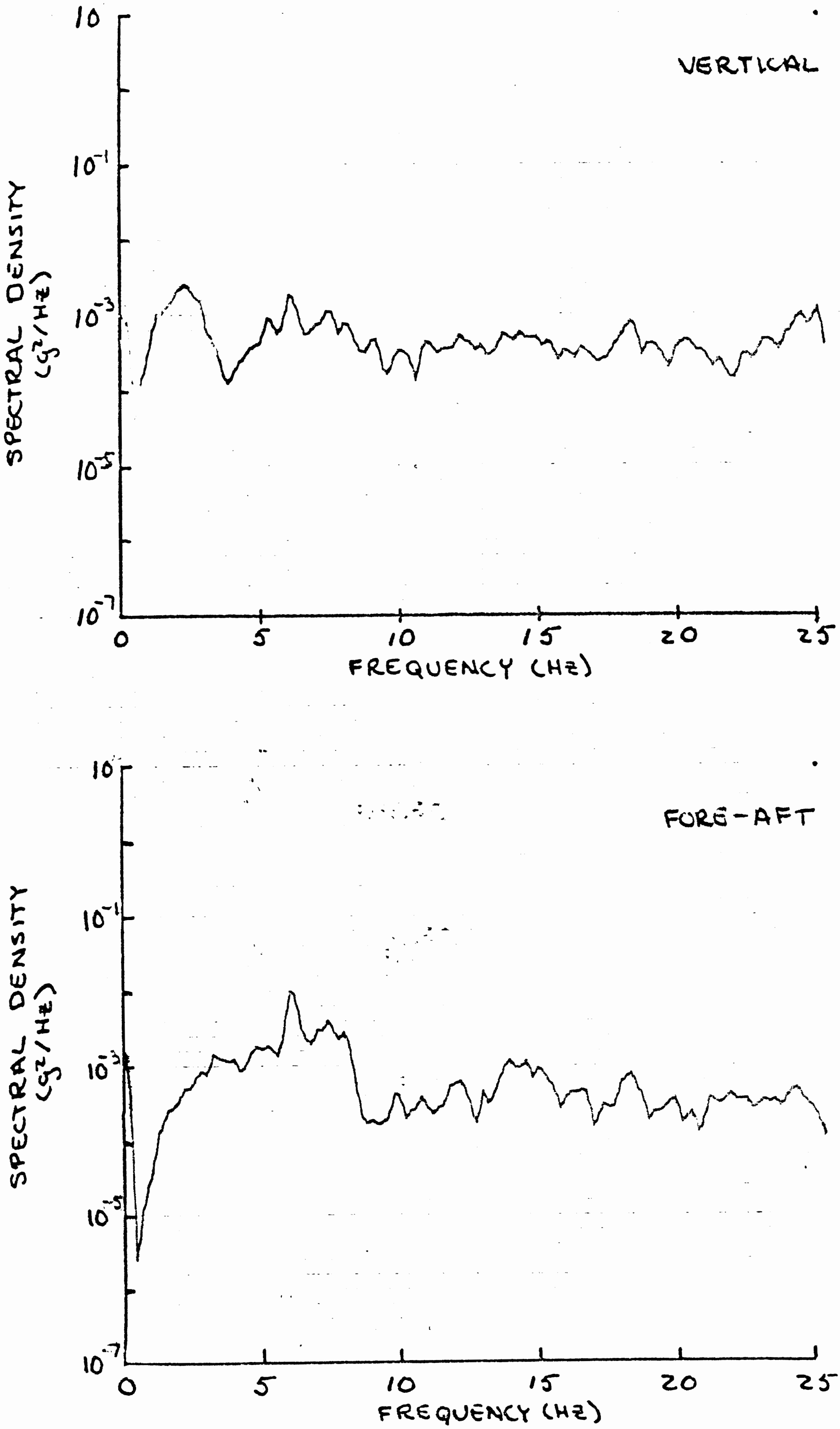


Figure VI.9. PSD's at seat, bobtail COE tractor over site #4 at 45 mph.

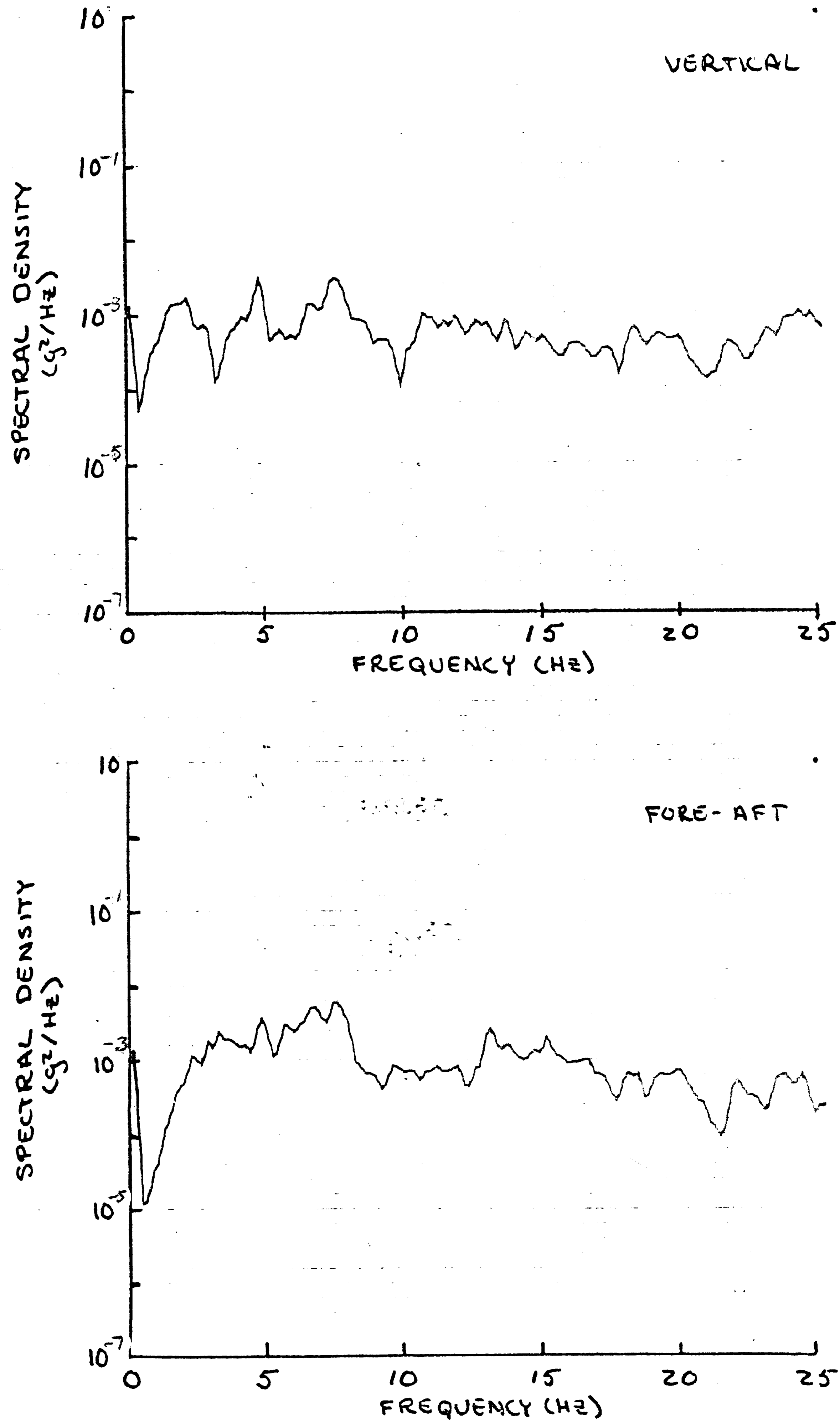
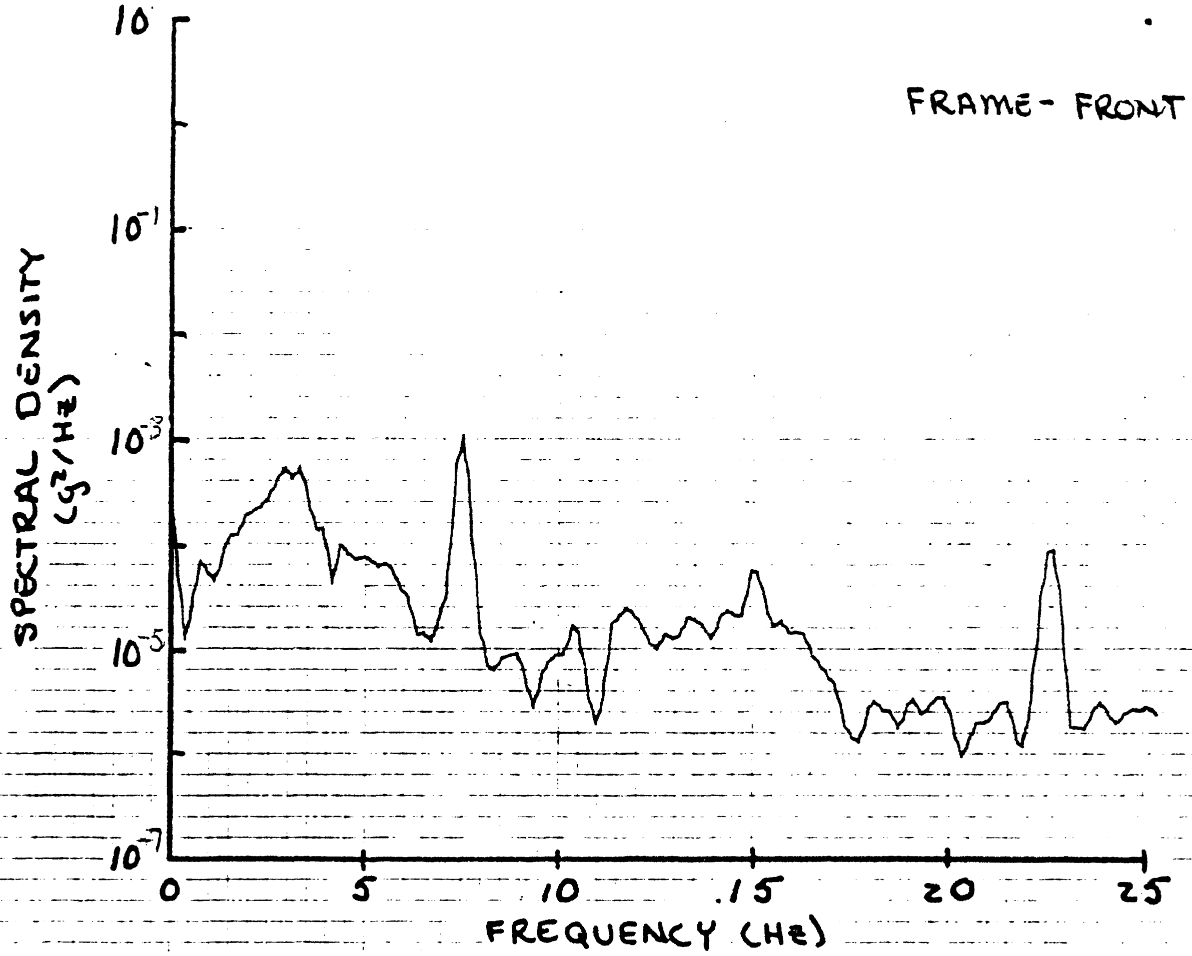


Figure VI.10. PSD's at seat, bobtail COE tractor over site #5 at 35 mph.



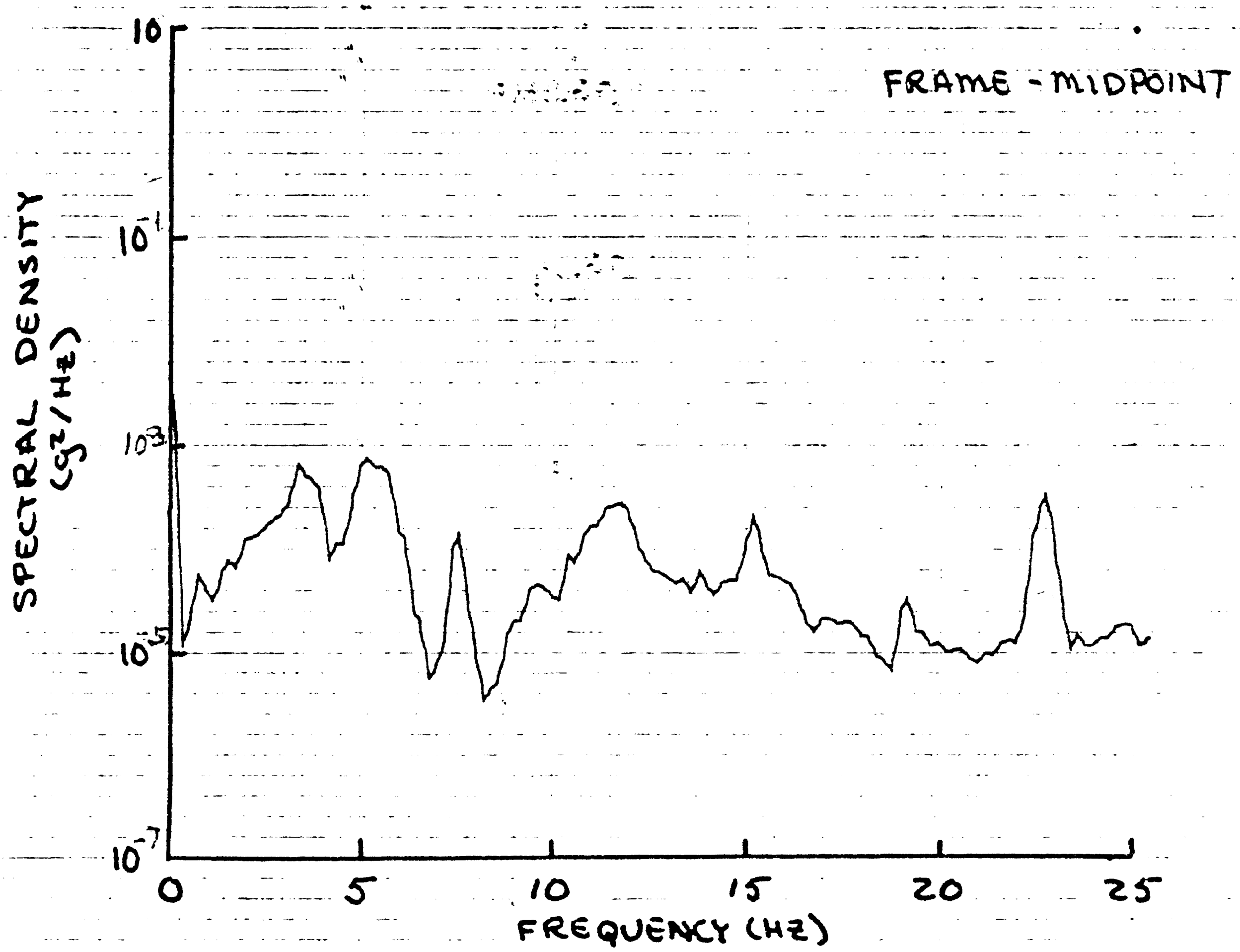
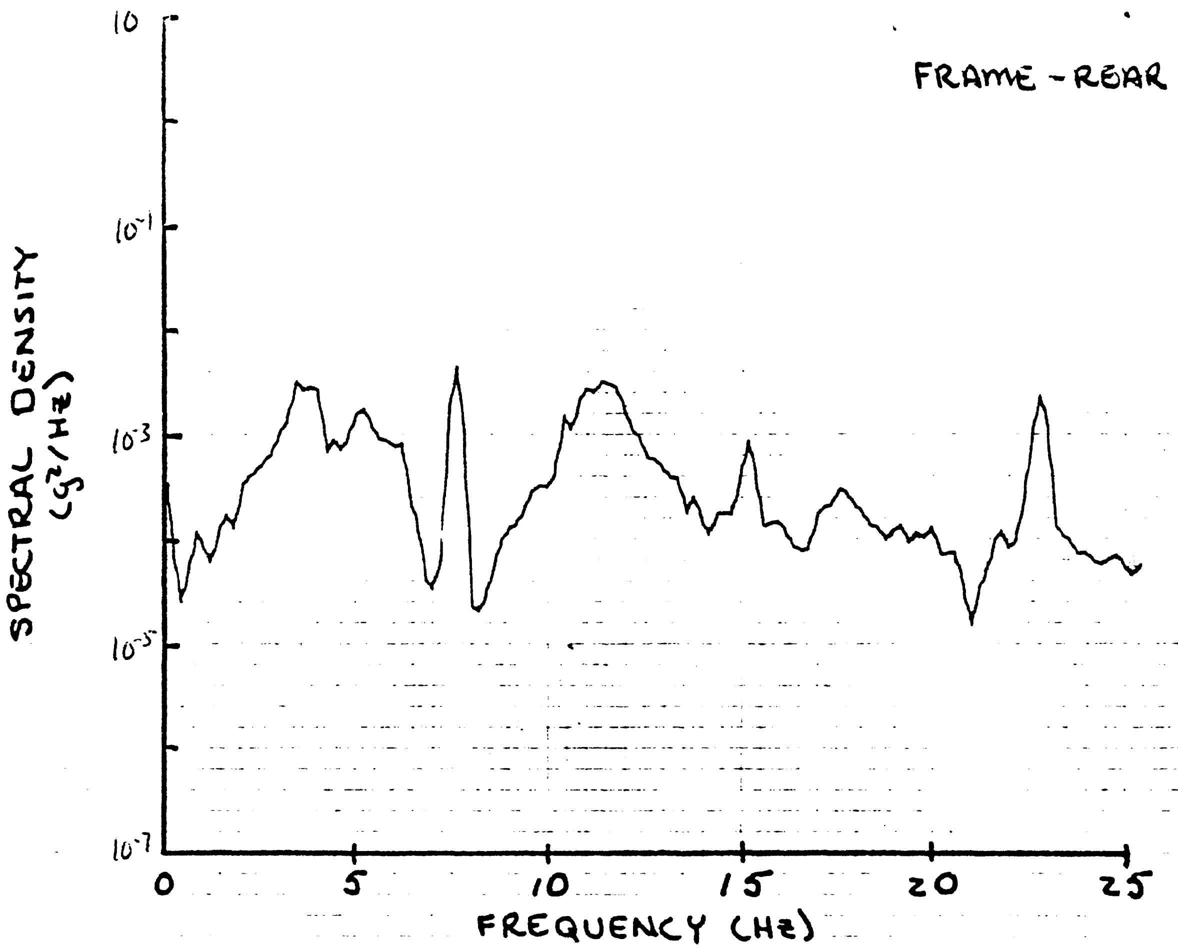


Figure VI.11. Power spectral densities, loaded COE tractor over site #1 at 55 mph.



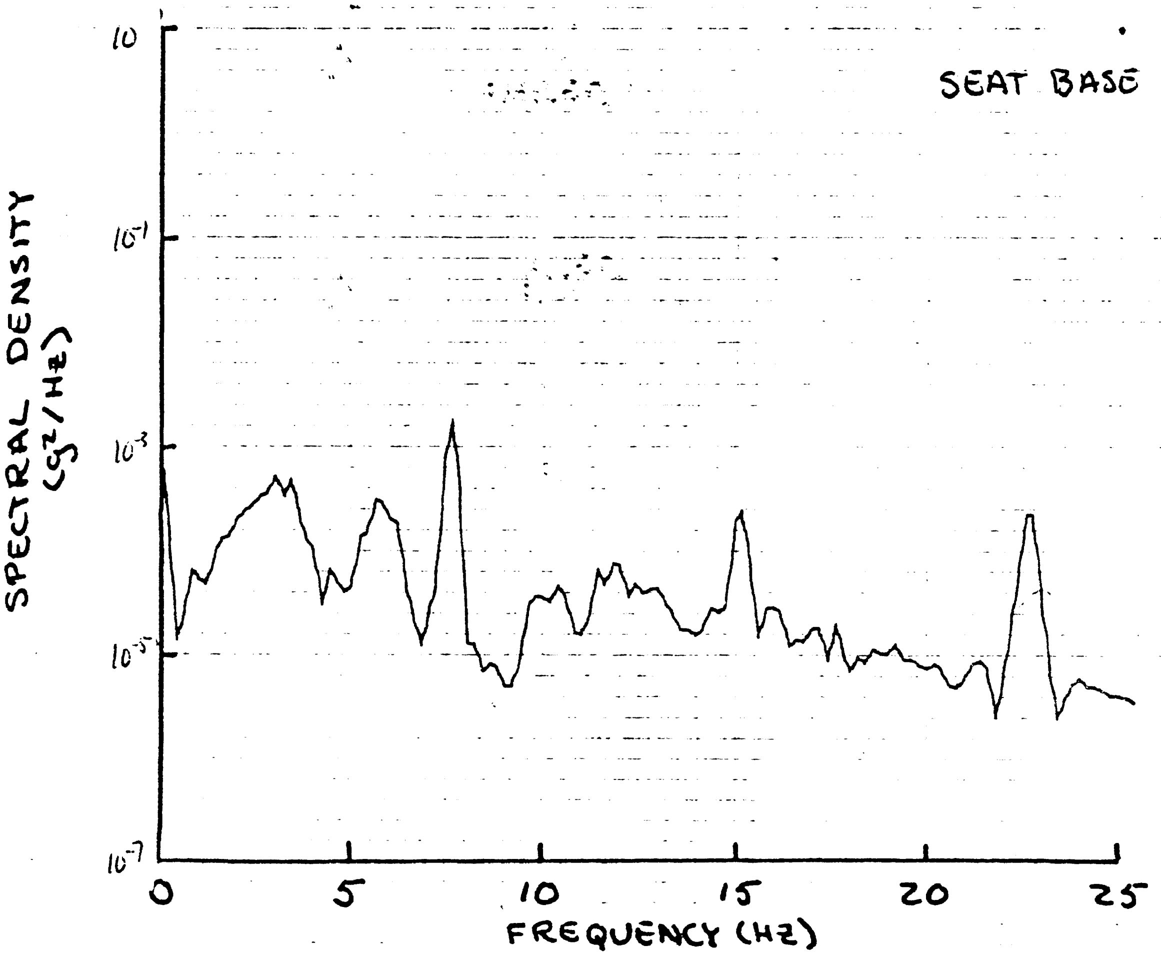
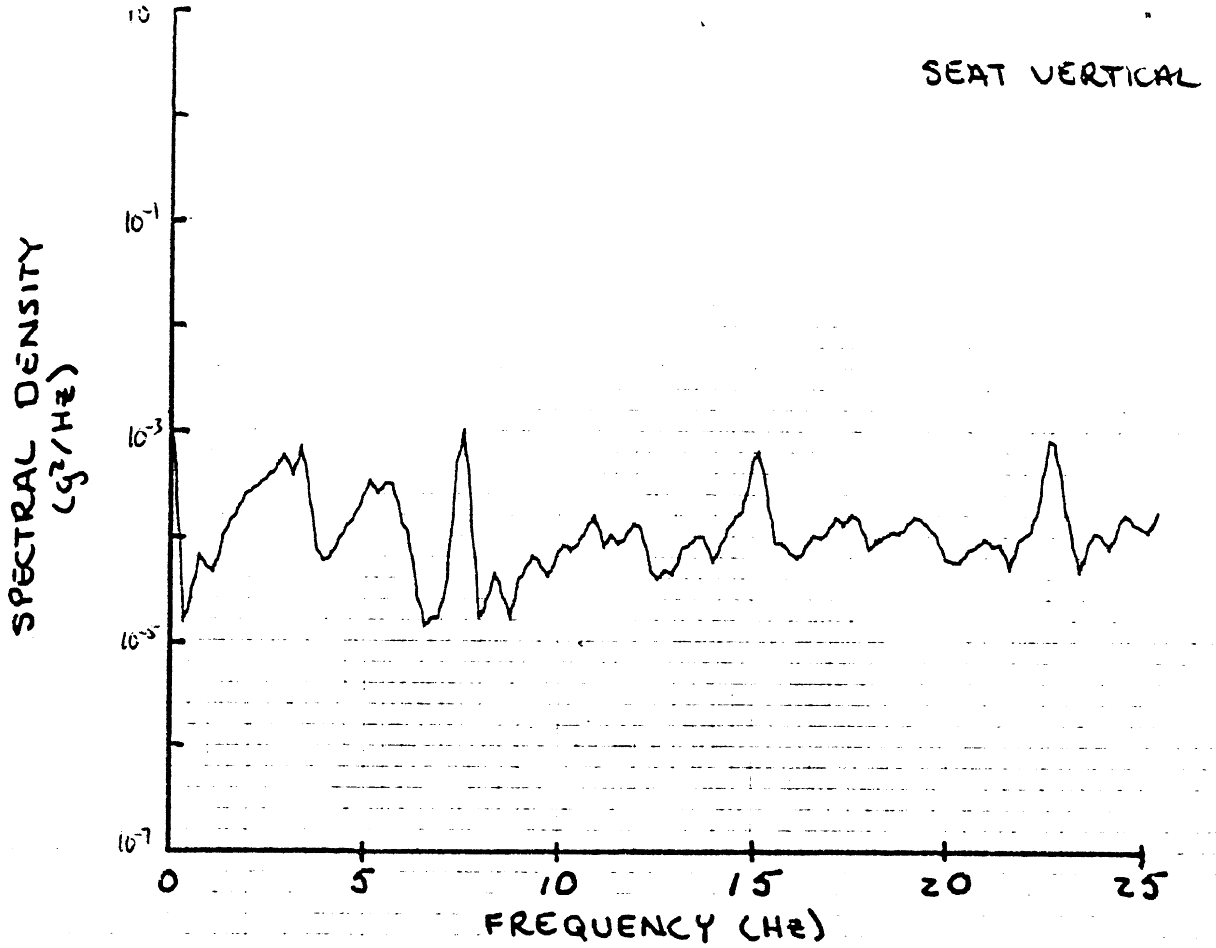


Figure VI.11 (Cont.)



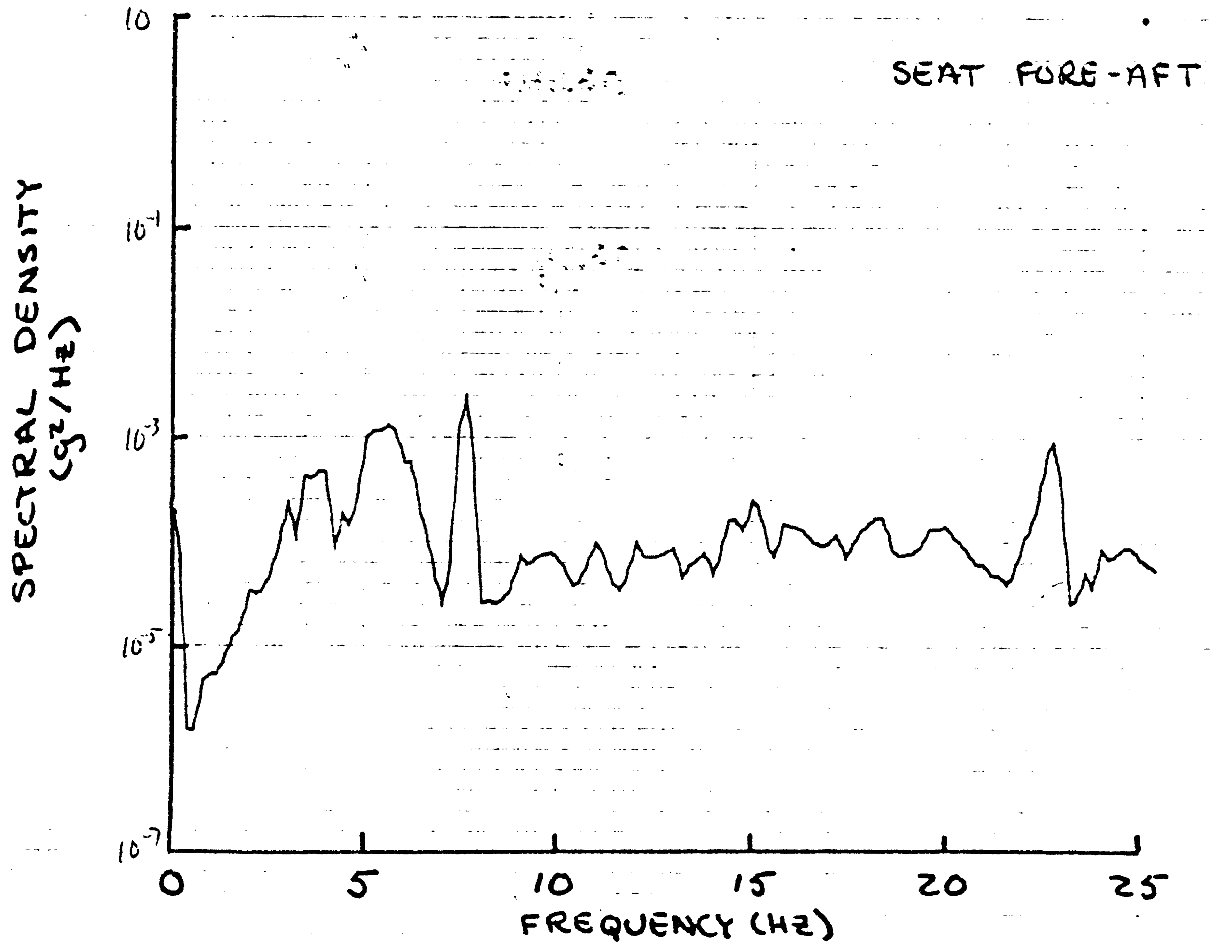


Figure VI.11 (Cont.)

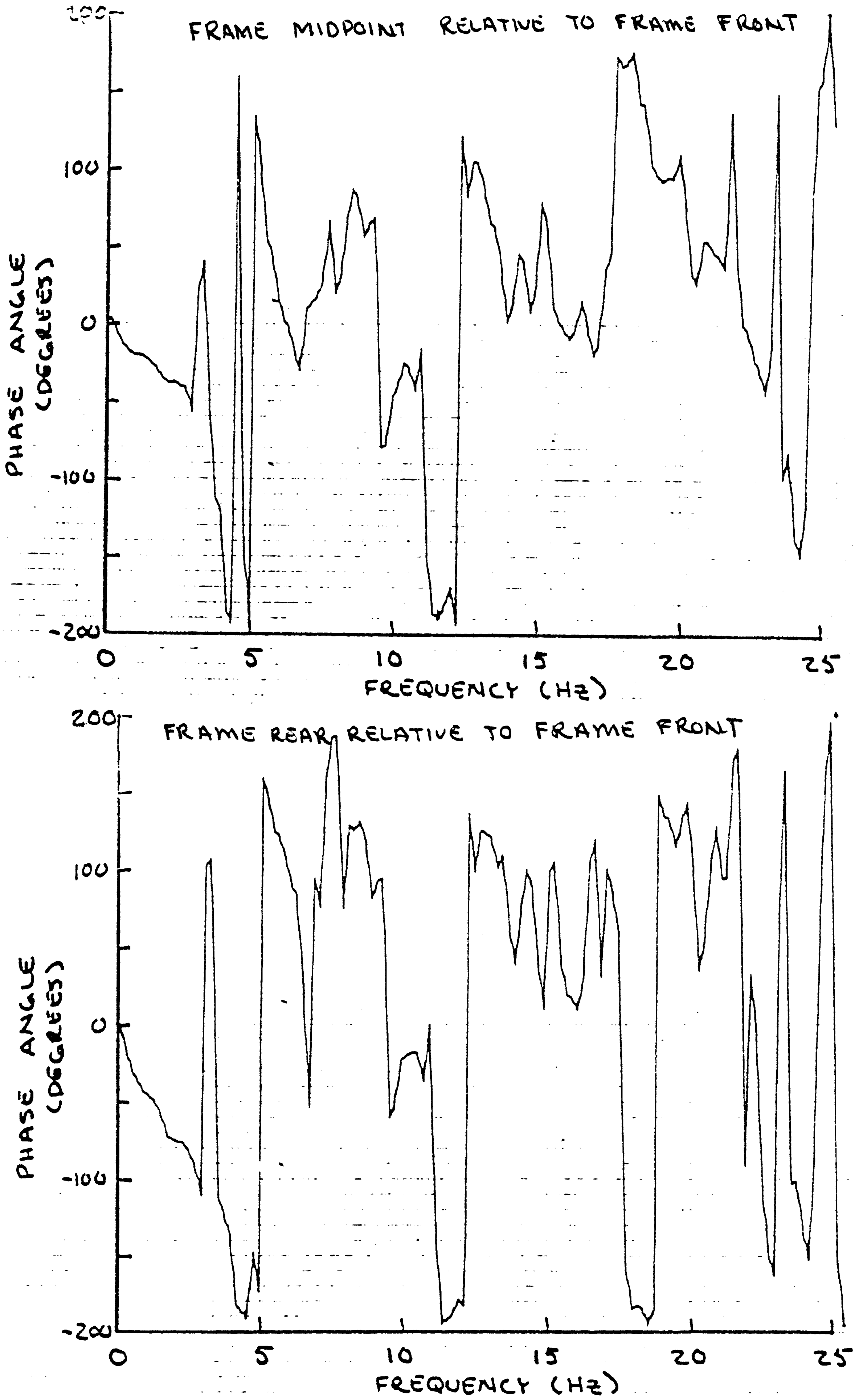
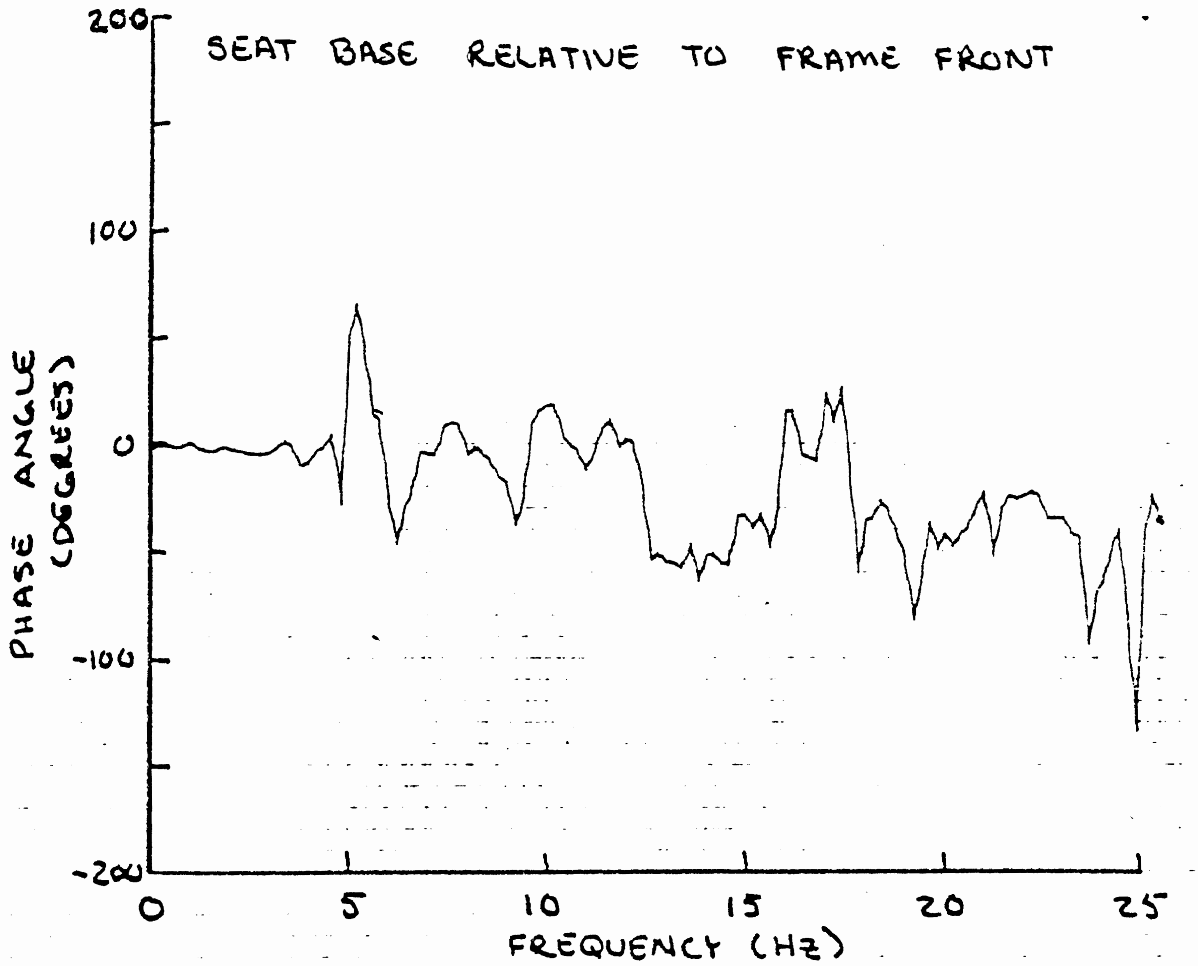


Figure VI.12. Phase relationships, loaded COE tractor over site #1 at 55 mph.



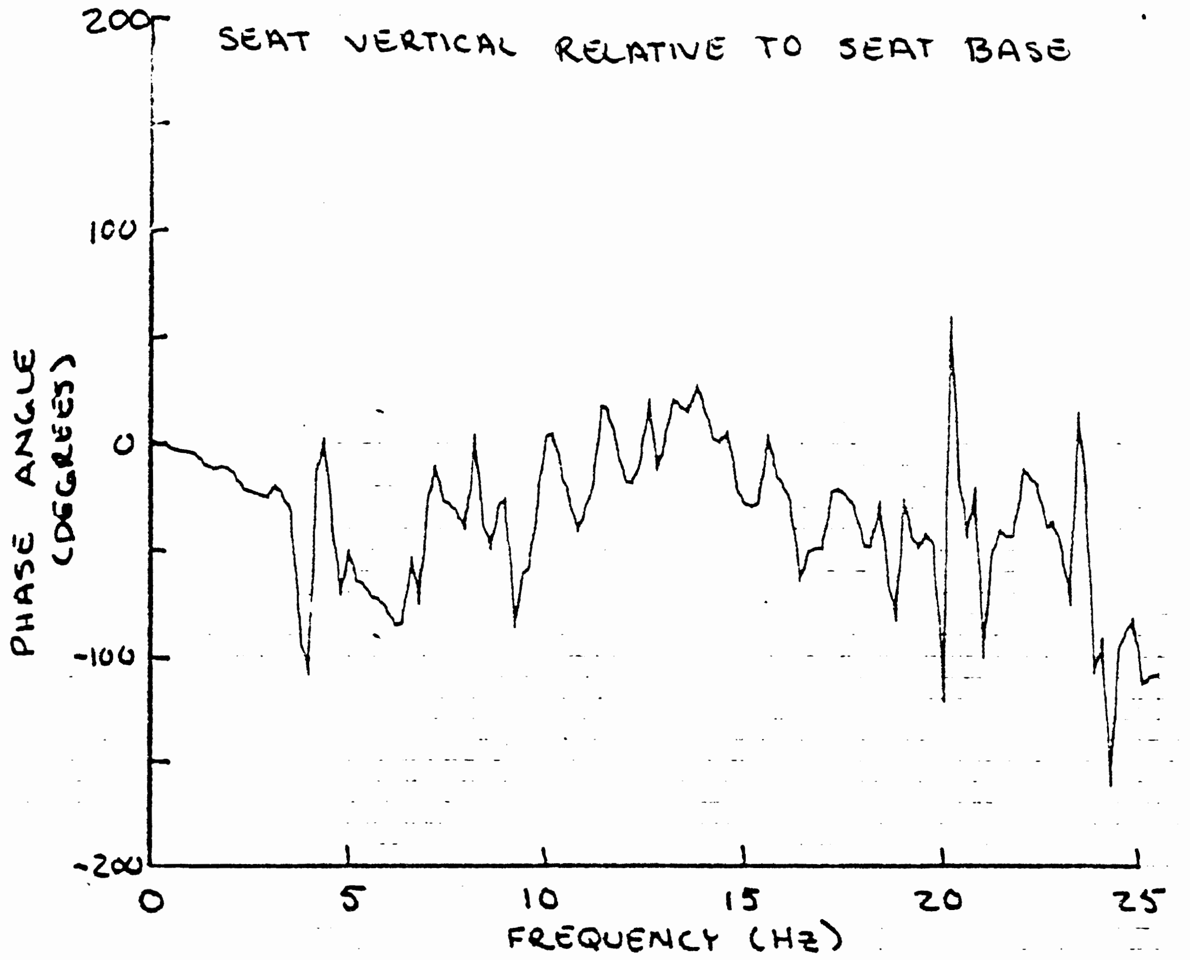


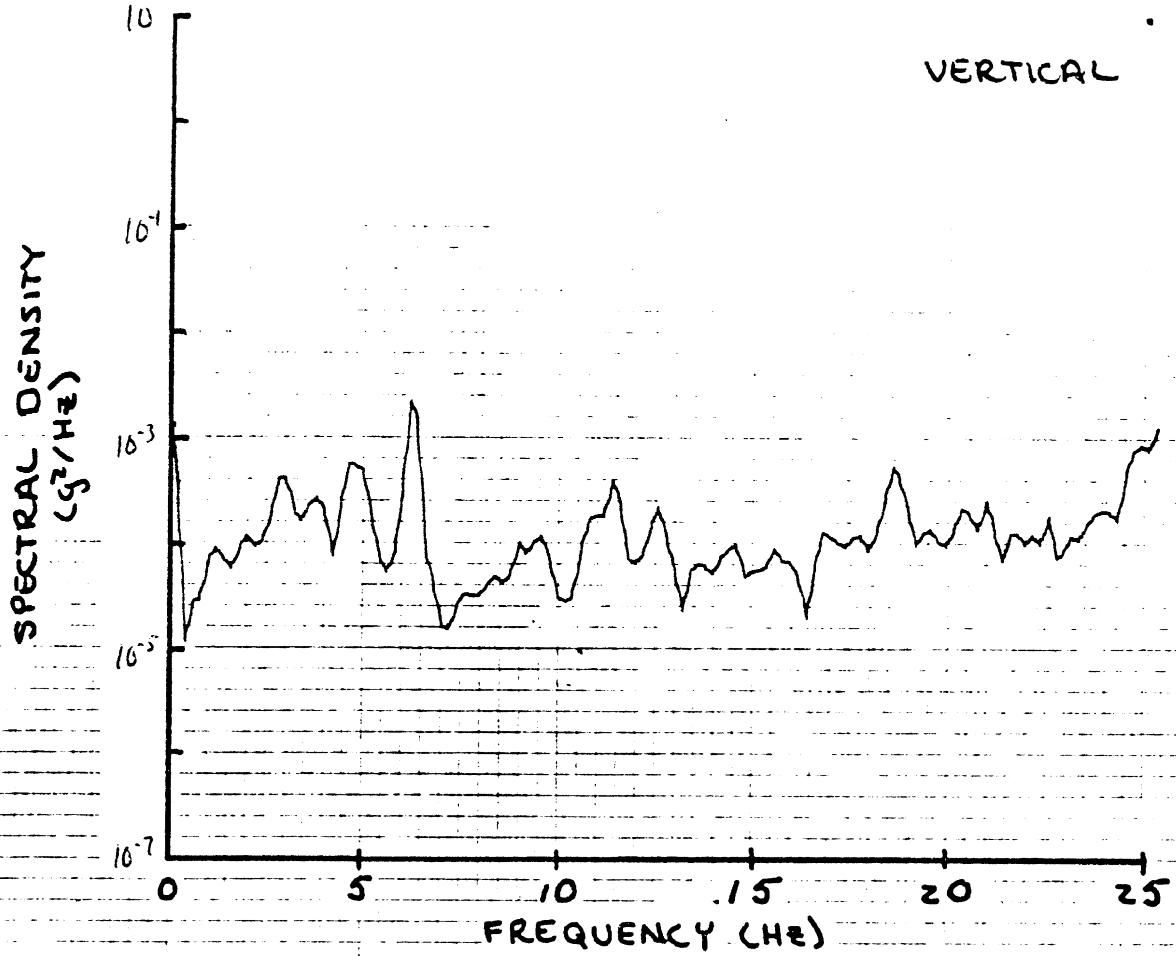
Figure VI.12 (Cont.)

As with the bobtail COE unit, the loaded unit traveling over the smooth bituminous roadway of Site #1 has major contributions to both vertical and fore/aft seat acceleration spectra (Figures VI.11 and 13) corresponding to the primary tire rotational frequency, but the second- and third-order tire rotational frequencies are less dominant in the loaded condition than in the bobtail condition. Additional power in the seat vertical motion comes from the bounce mode and both pitching modes at 2.5-3, 3.5, and 4.5 Hz, respectively. Reducing speed from 55 to 45 mph does not cause the peak at 7.5 Hz, observed in the bobtail configuration, to appear. The fore/aft acceleration of the seat is dominated by the two pitching modes at 3.5 and 4.5 Hz in addition to the tire rotational contribution.

The irregularities of Site #2 provide sufficient input to the suspension of the vehicle to cause the power contained at frequencies relating to ride motions to outweigh the tire-wheel inputs. The dominant peak of the vertical seat spectra (Figures VI.14 and 15) occurs at 2 Hz, as seen with the bobtail unit. The bounce frequency is slightly lower on this rougher surface than on the smooth surface of Site #1.

The pitching modes and tire-wheel inputs also contribute to the seat vertical motions. The seat fore/aft spectra shows major contributions from the two pitch modes (3.5 and 4.5 Hz), the wheel rotations, and, at 55 mph, a contribution from the 2 Hz bounce mode. Power levels are higher for all the modes at 55 than at 45 mph.

While visually appearing less irregular than Site #2, vibrations encountered traveling over Sites #3 and #4 show considerably more power in both fore/aft and vertical seat motions, corresponding to the vehicle ride modes (Figures VI.16-19). On these sites, reducing speed from 55 to 45 mph results in decreased power contained in the bouncing mode with little change in the power content due to pitching motions.



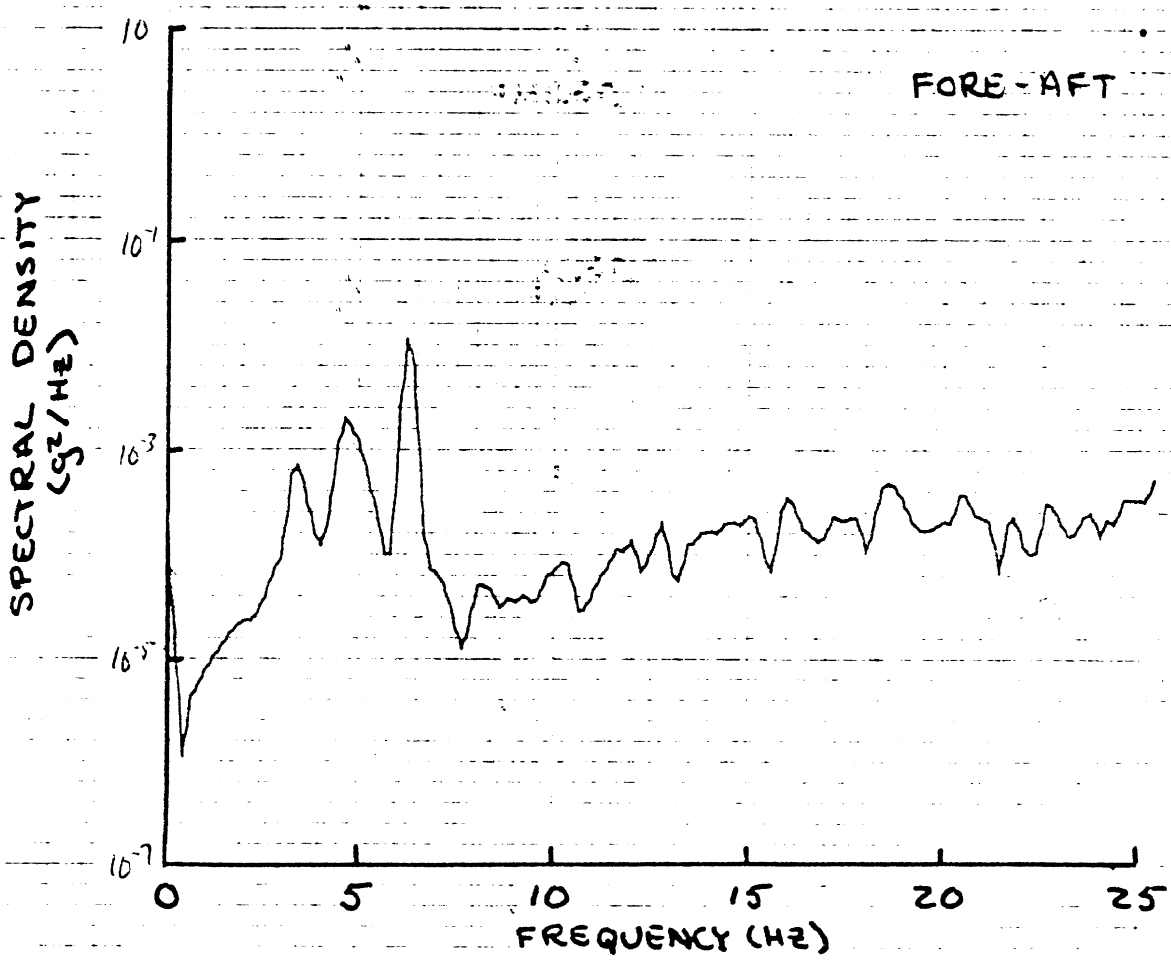


Figure VI.13. PSD's at seat, loaded COE tractor over site #1 at 45 mph.

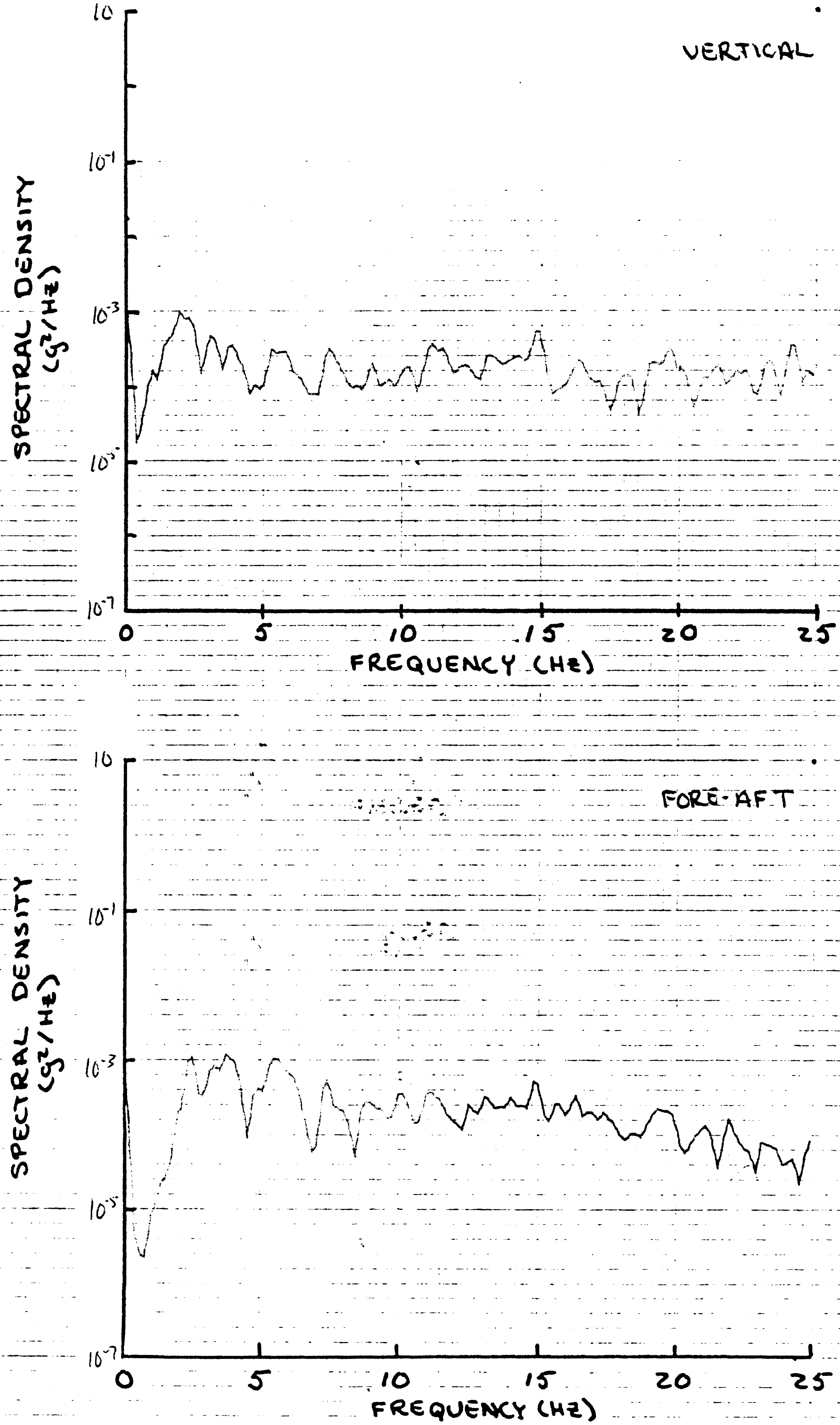
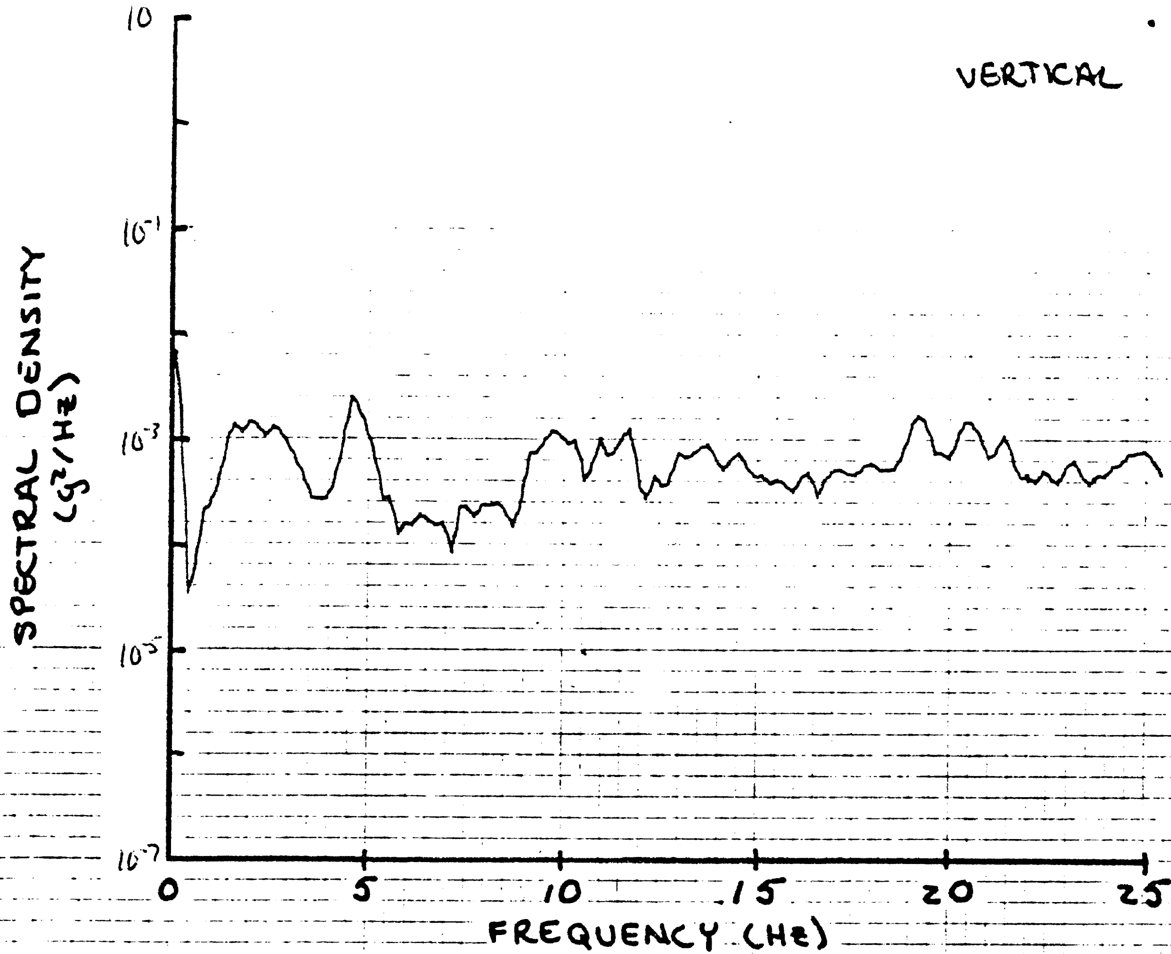


Figure VI.14. PSD's at seat, loaded COE tractor over site #2 at 55 mph.



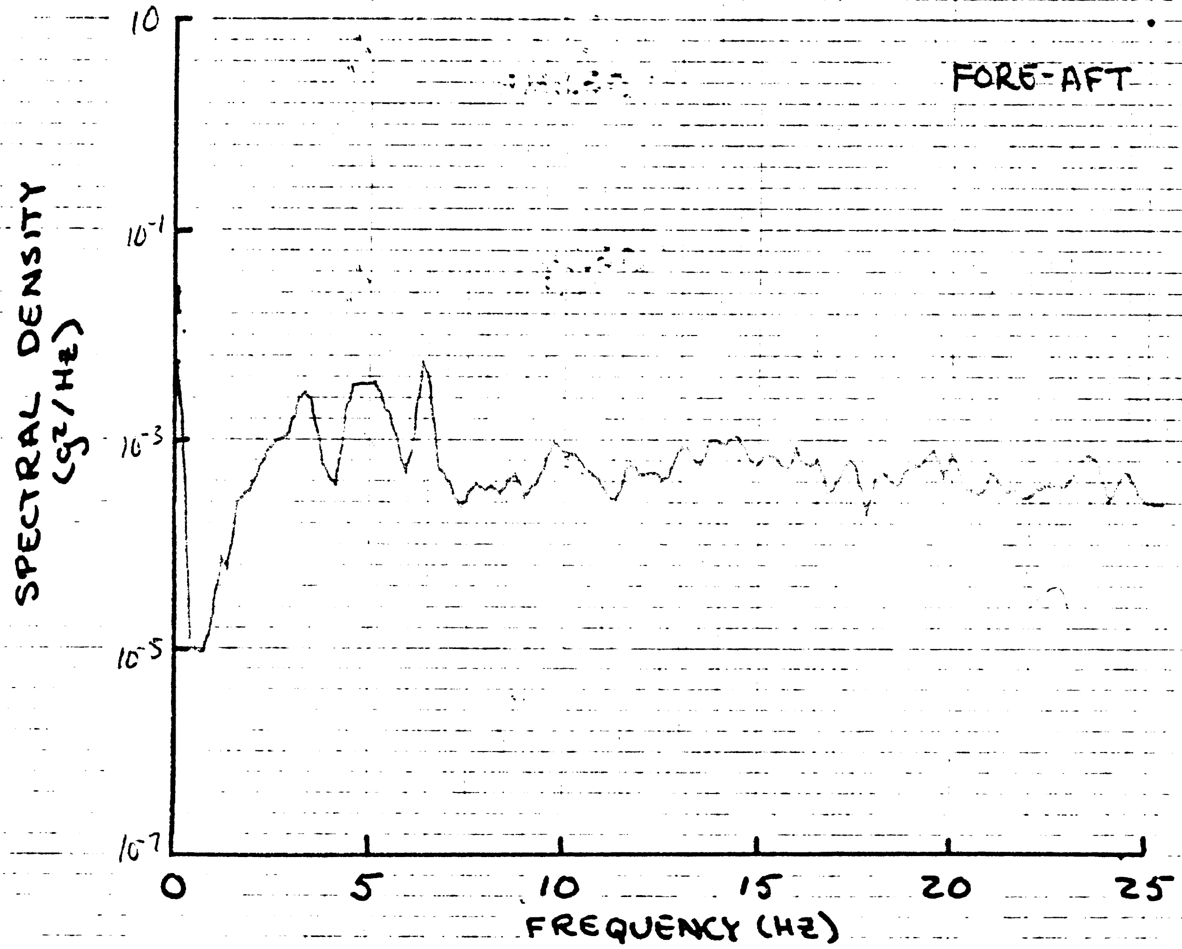
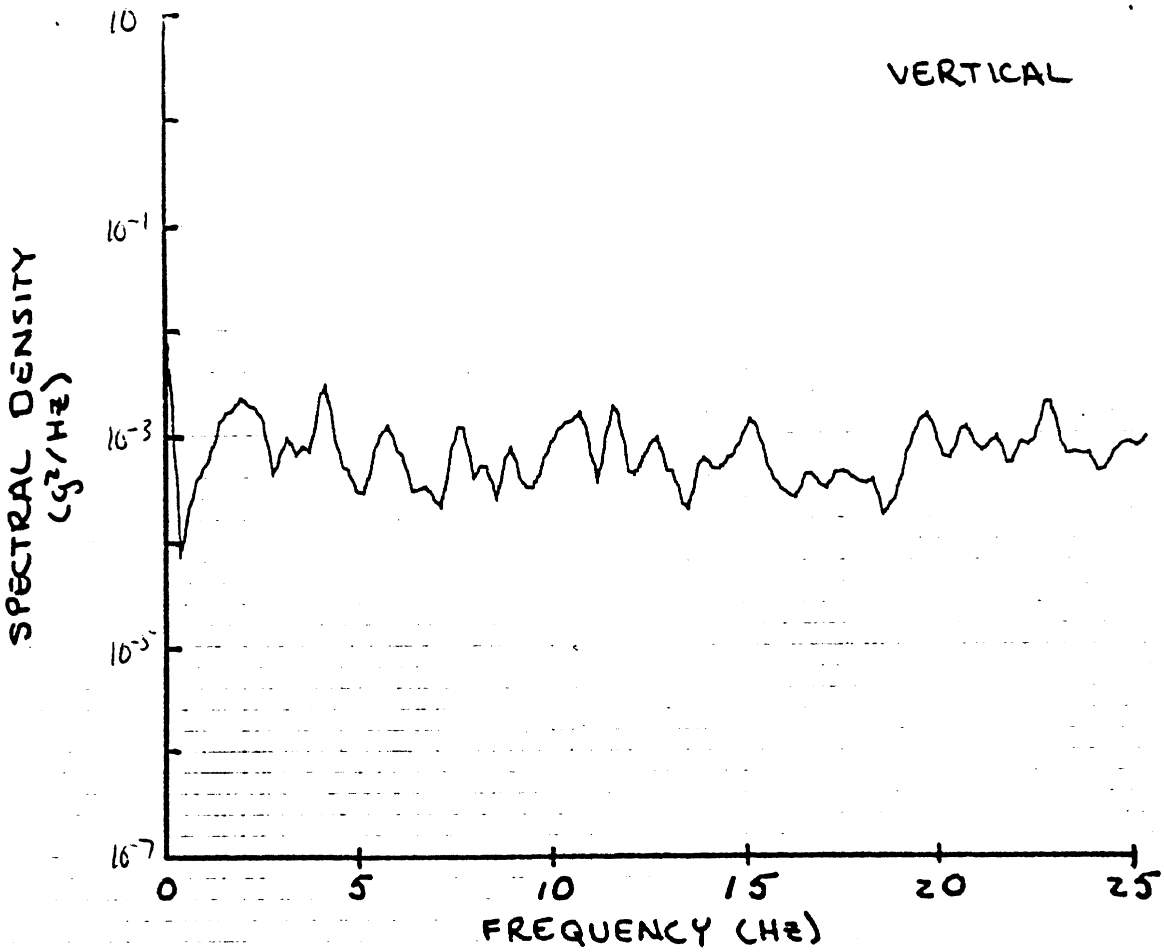


Figure VI.15. PSD's at seat, loaded COE tractor over site #2 at 45 mph.



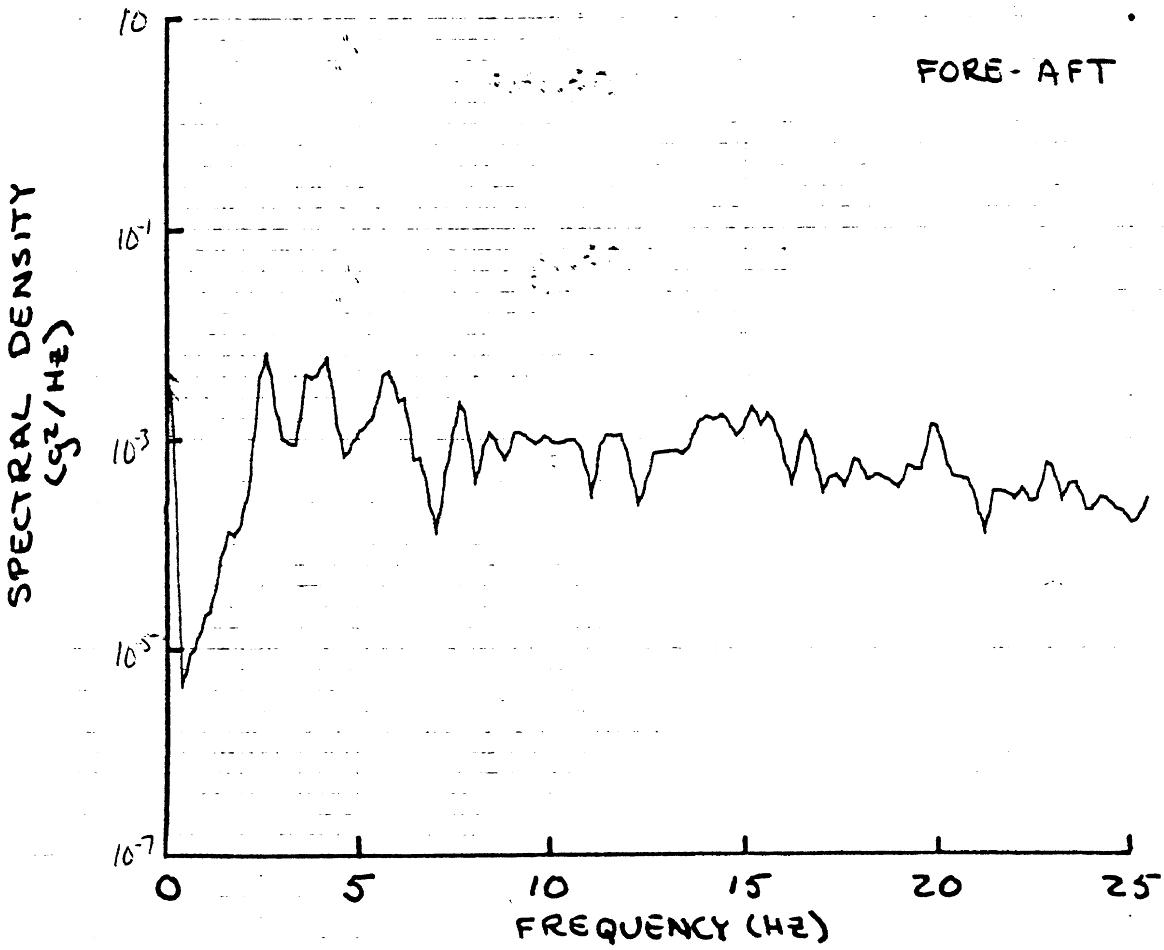
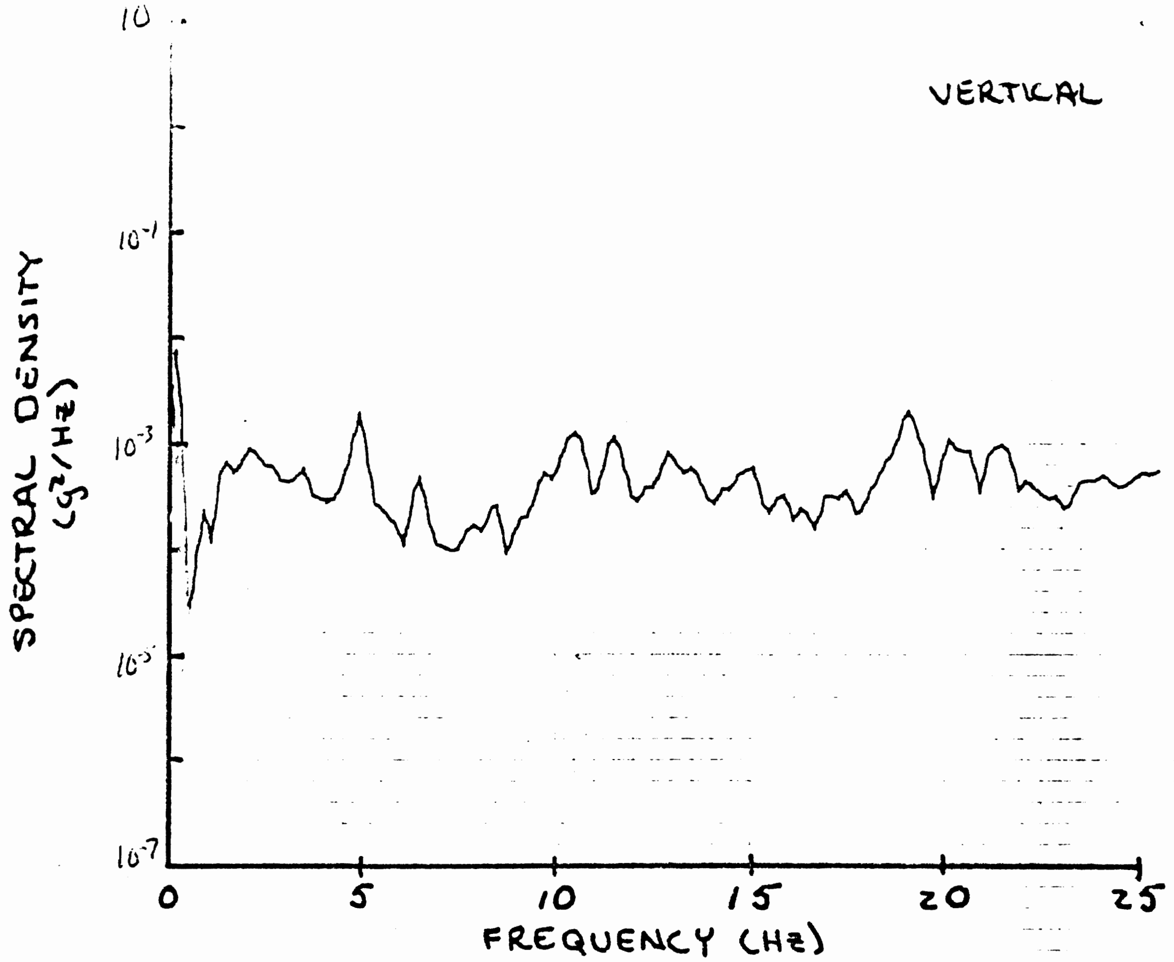


Figure VI.16. PSD's at seat, loaded COE tractor over site #3 at 55 mph.



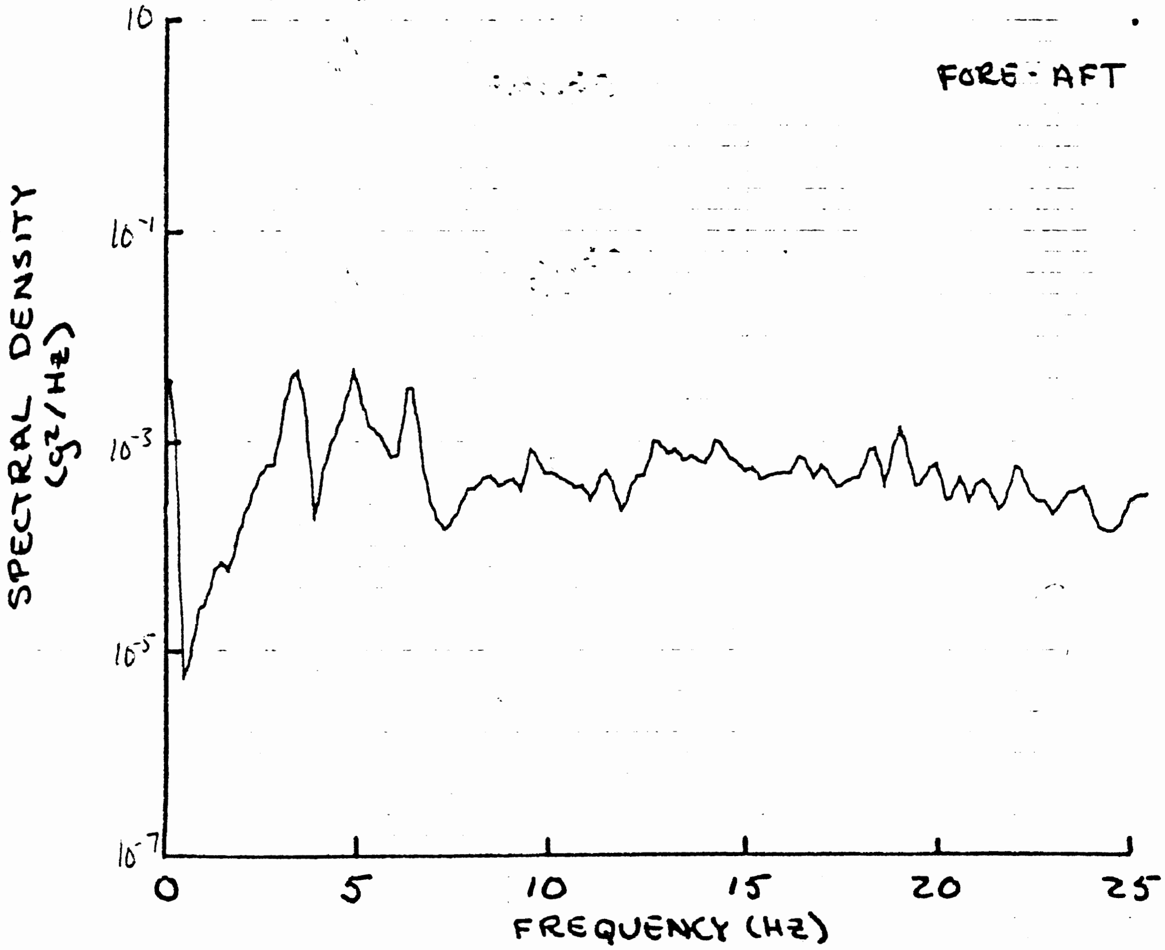
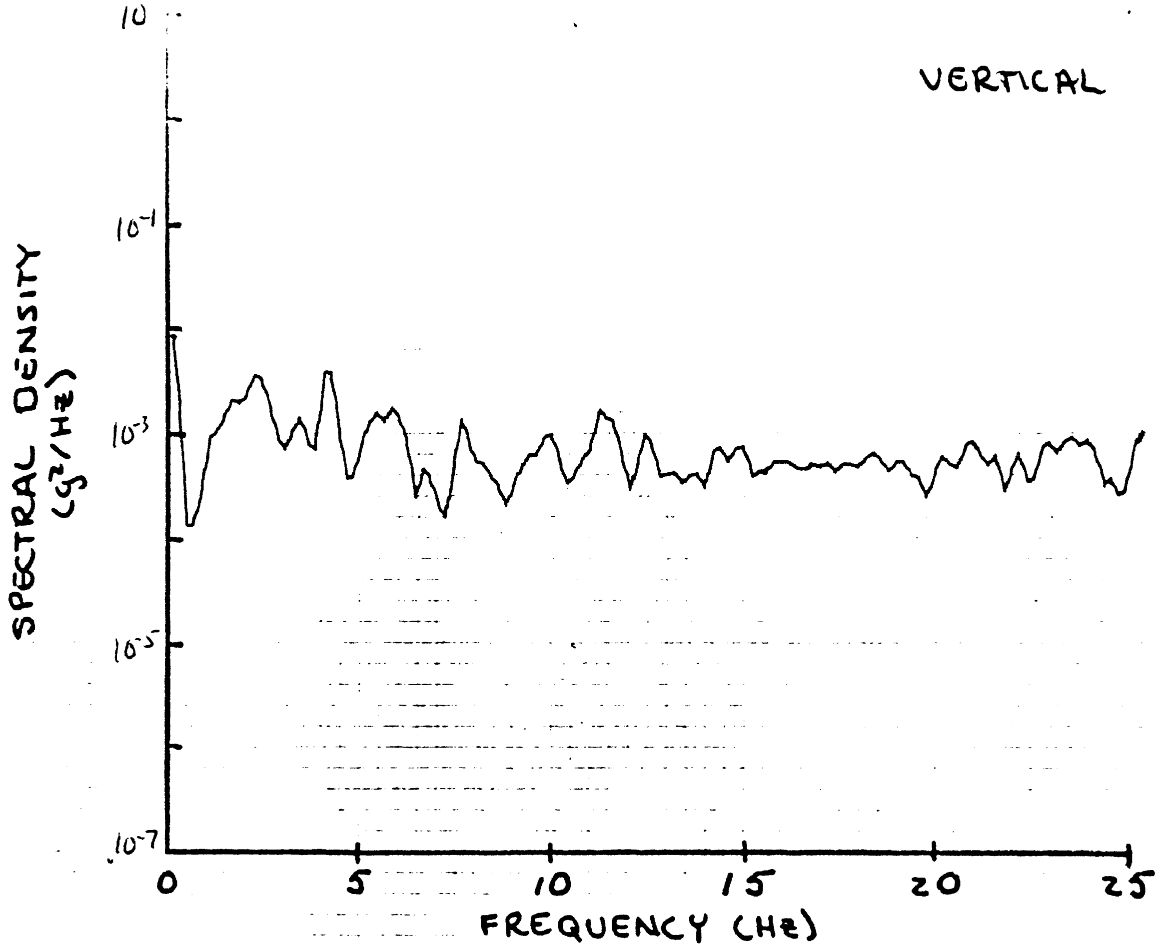


Figure VI.17. PSD's at seat, loaded COE tractor over site #3 at 45 mph.



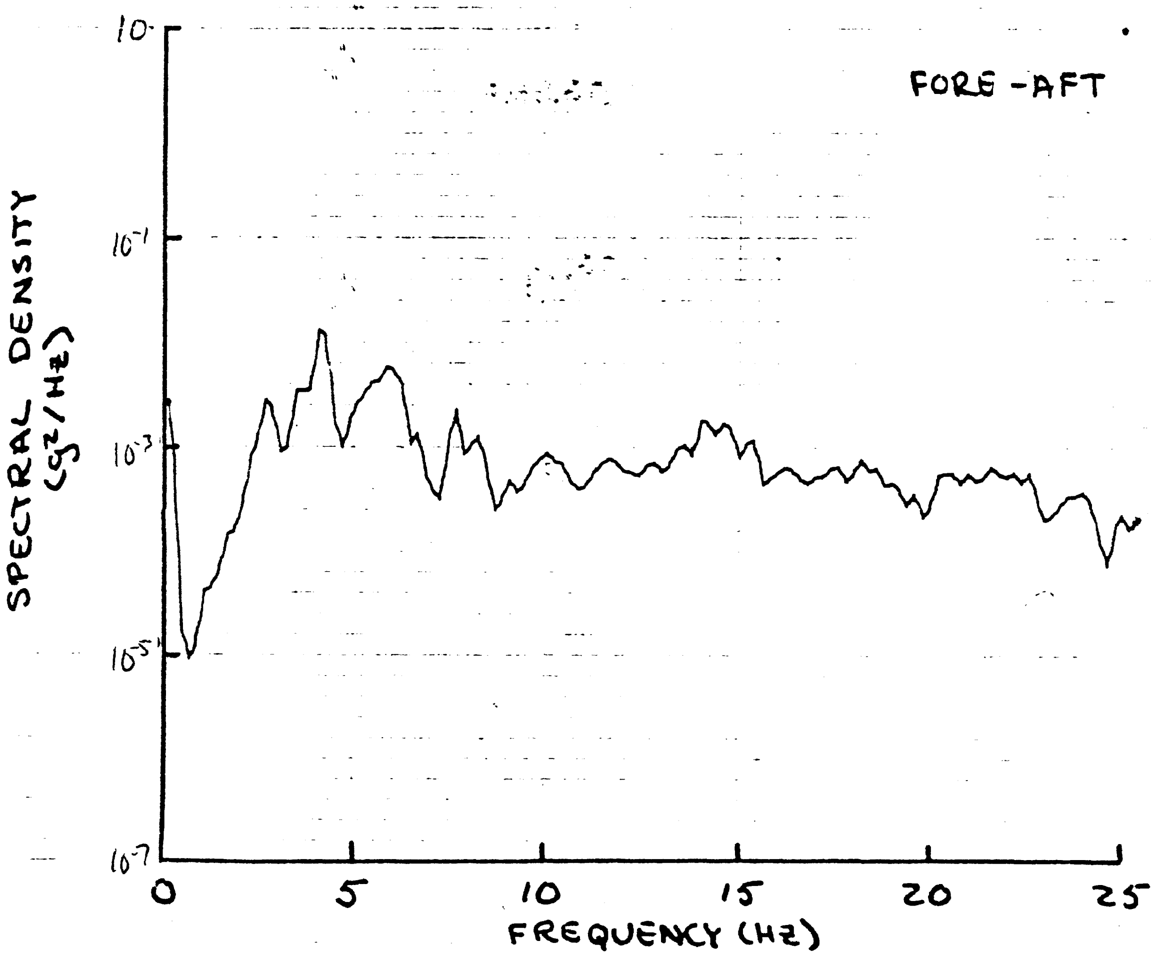
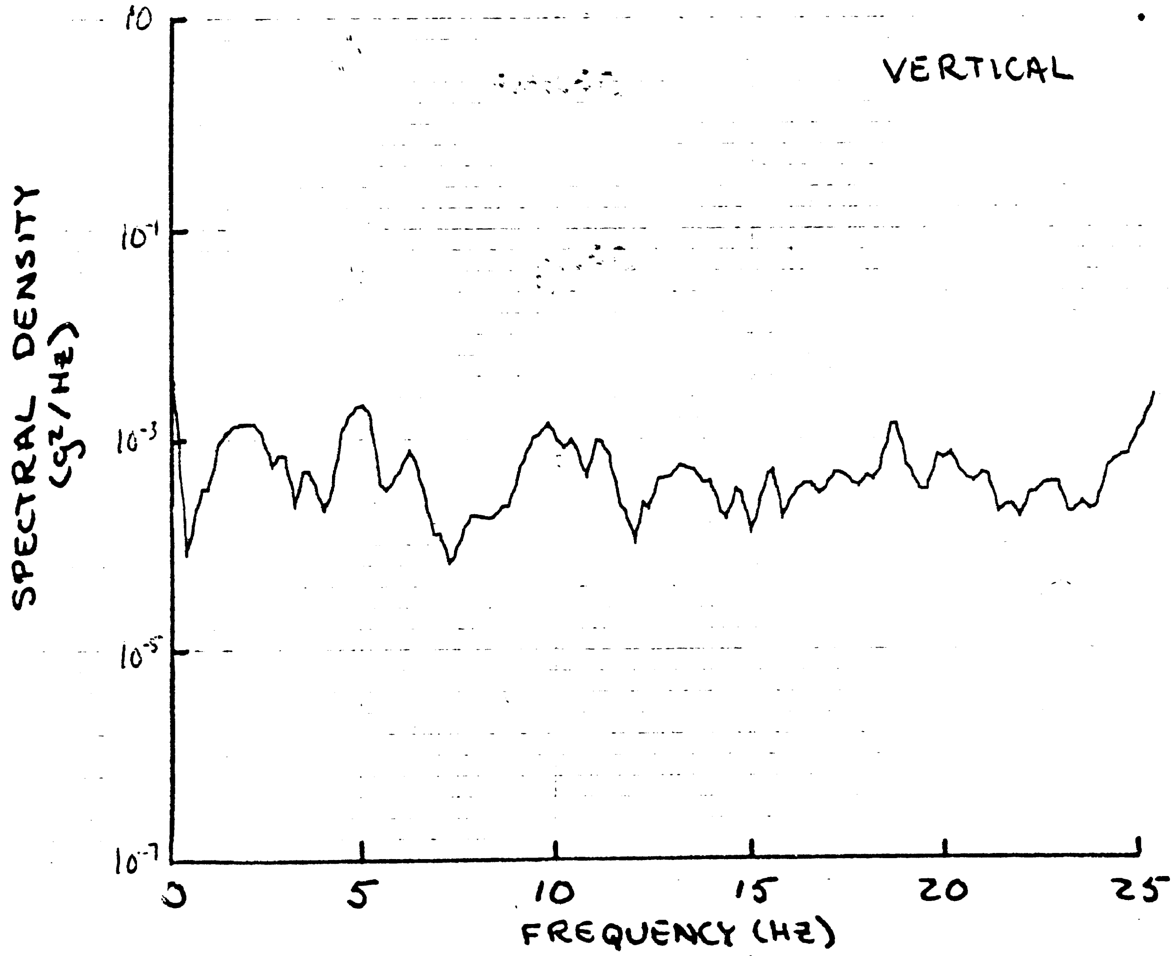


Figure VI.18. PSD's at seat, loaded COE tractor over site #4 at 55 mph.



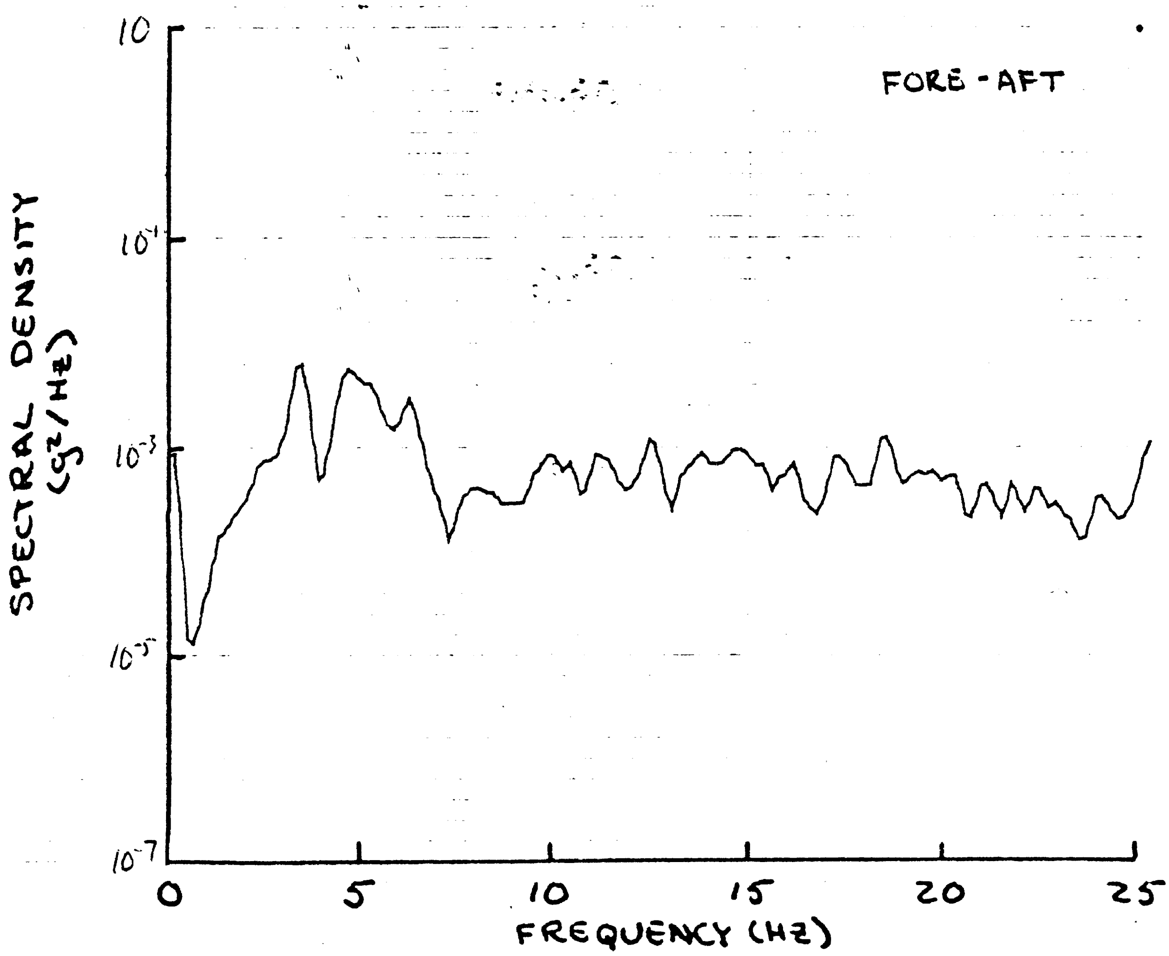


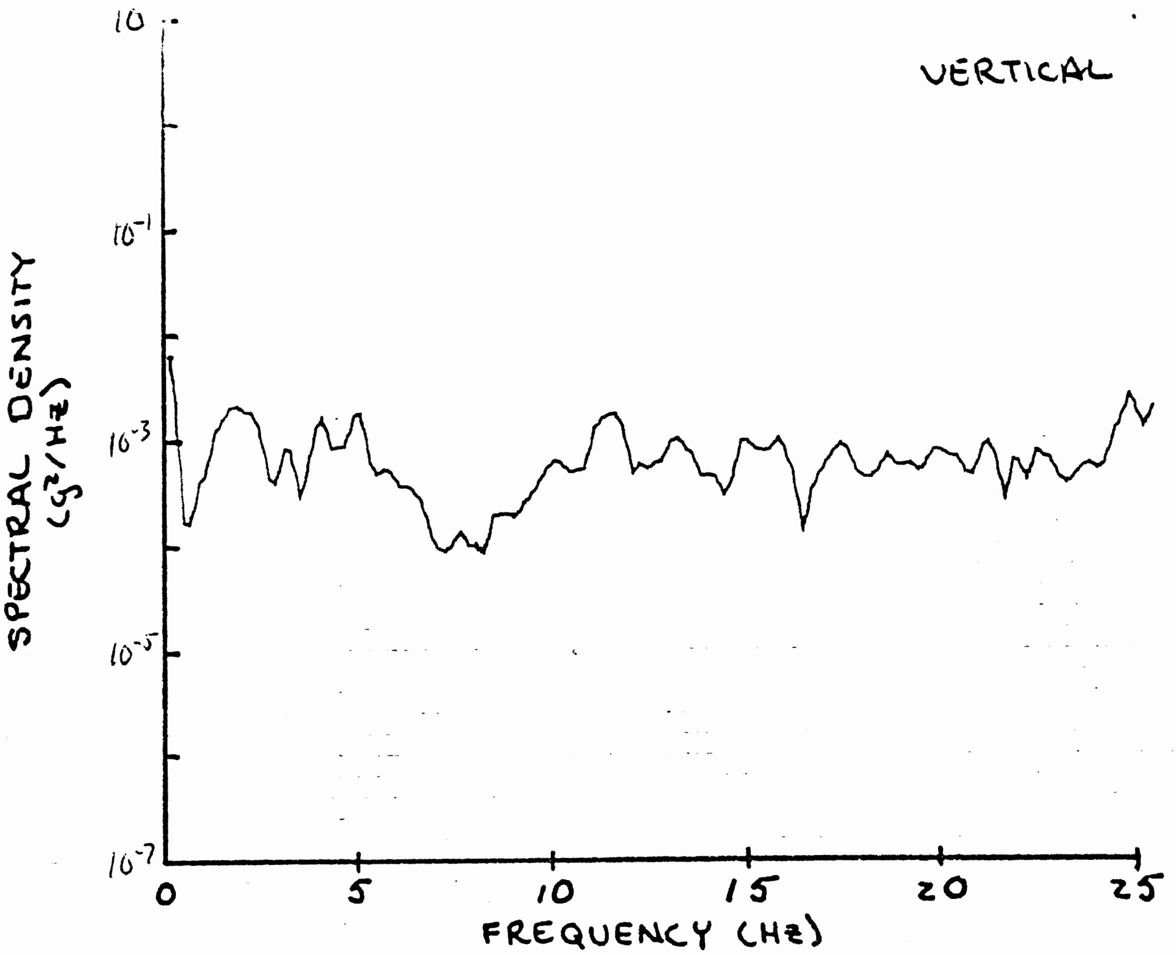
Figure VI.[illegible]. P[illegible]'s at [illegible], [illegible]

On the urban road, Site #5, peaks corresponding to the bounce and both pitch modes appear in both vertical and longitudinal seat spectra (Figure VI.20) with the dominant peak on both directions attributable to the tractor bounce mode. The level of vibrational power on this surface is comparable with those encountered on Sites #3 and #4.

VI.1.3 Conventional Tractor - Bobtail. The dominant natural ride modes of the bobtail conventional tractor are a bounce mode at 3-3.5 Hz and a pitch mode at 5.5 Hz. The spectral densities and phase relationships are shown in Figures VI.21 and VI.22. The frequencies and mode shapes are very similar to the COE tractor in the bobtail condition with the bounce mode showing a slight phase lag between front and rear accelerations and the pitch node occurring between the front axle and frame midpoint.

Seat vibrations of the conventional tractor traveling over Site #1 in the bobtail condition are totally dominated by the tire force inputs. Power present at these frequencies is orders-of-magnitude above the peaks corresponding to the pitch and bounce ride motions (Figures VI.21 and 23).

On the rougher surface of Site #2, the ride motions contribute more significant levels of power to the vibration environment of the operator. Bounce and pitch modes, at 2.5 Hz and 5.5 Hz, respectively, contribute approximately equal levels of power to the seat vertical vibration as that deriving from the tire-wheel rotation influence (Figures VI.24 and 25) at 55 mph. Also at 55 mph, the fore/aft vibration of the seat is excited primarily by the pitch mode and secondarily by the bounce and tire-wheel resonances. At 45 mph the power associated with the bounce and pitch modes decrease significantly in the seat vertical spectrum and tire rotational forces again become dominant. In the longitudinal direction, the major peak in the spectrum for the 45-mph test occurs at the first-order tire rotational frequency that is very near the pitch natural frequency and thus excites that mode.



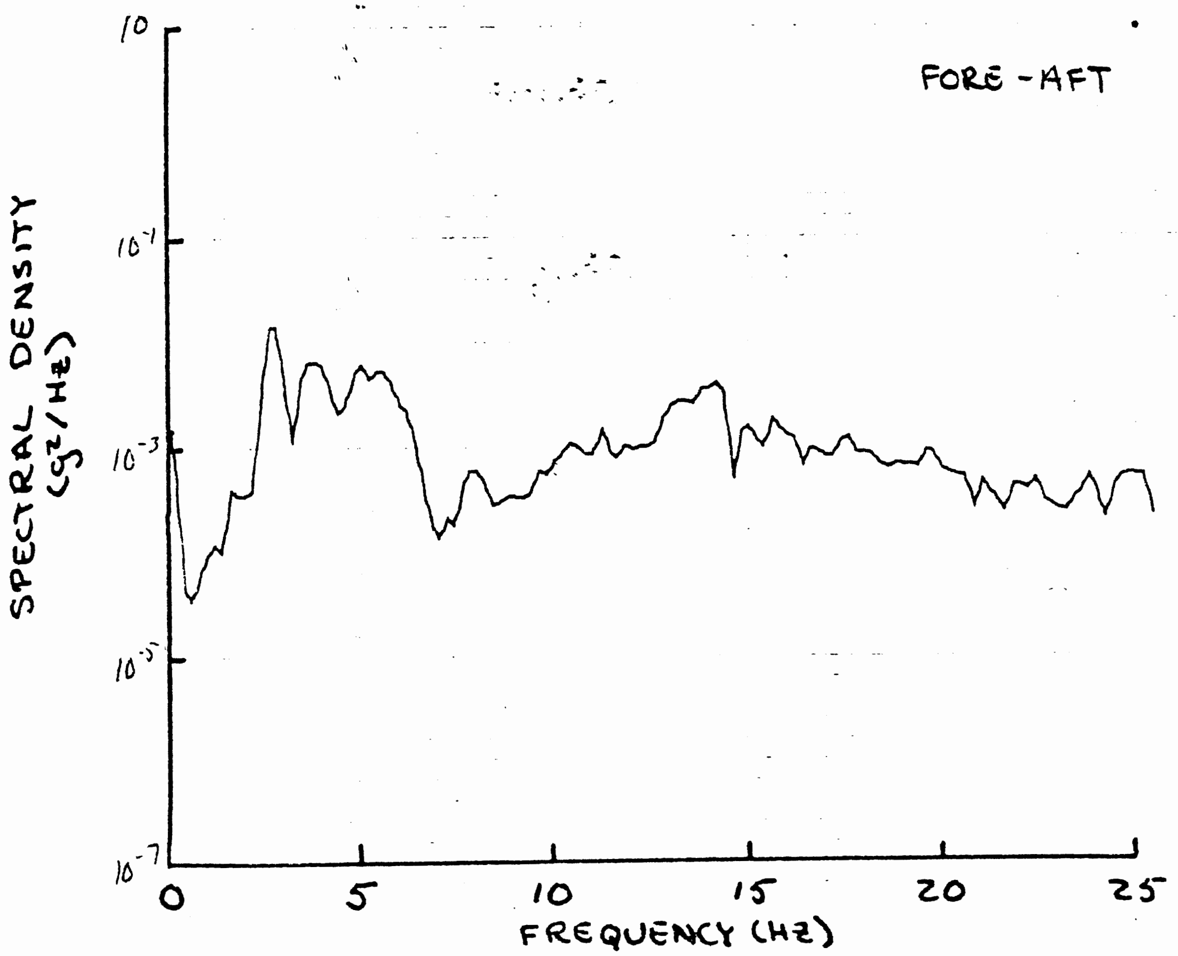
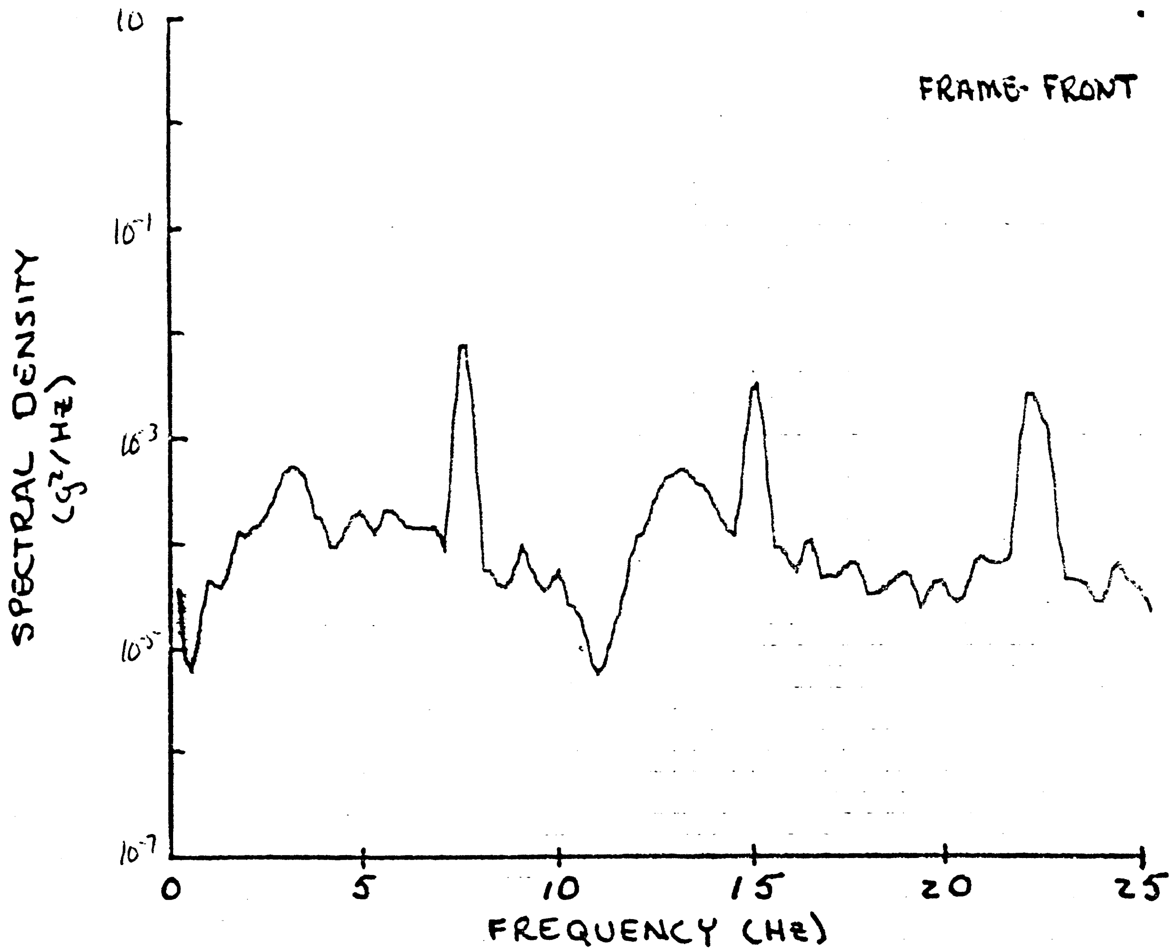


Figure VI.20. PSD's at seat, loaded COE tractor over site #5 at 35 mph.



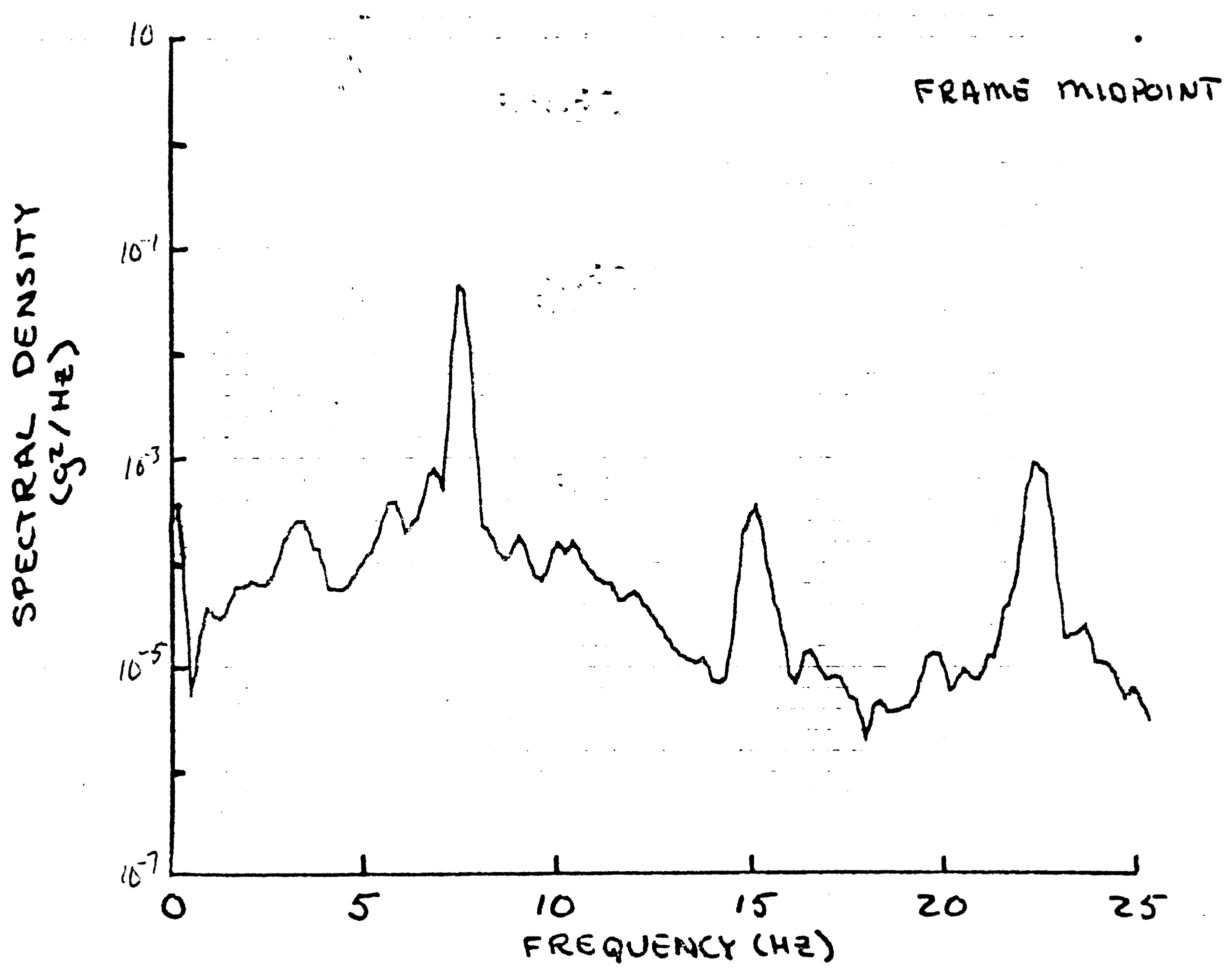
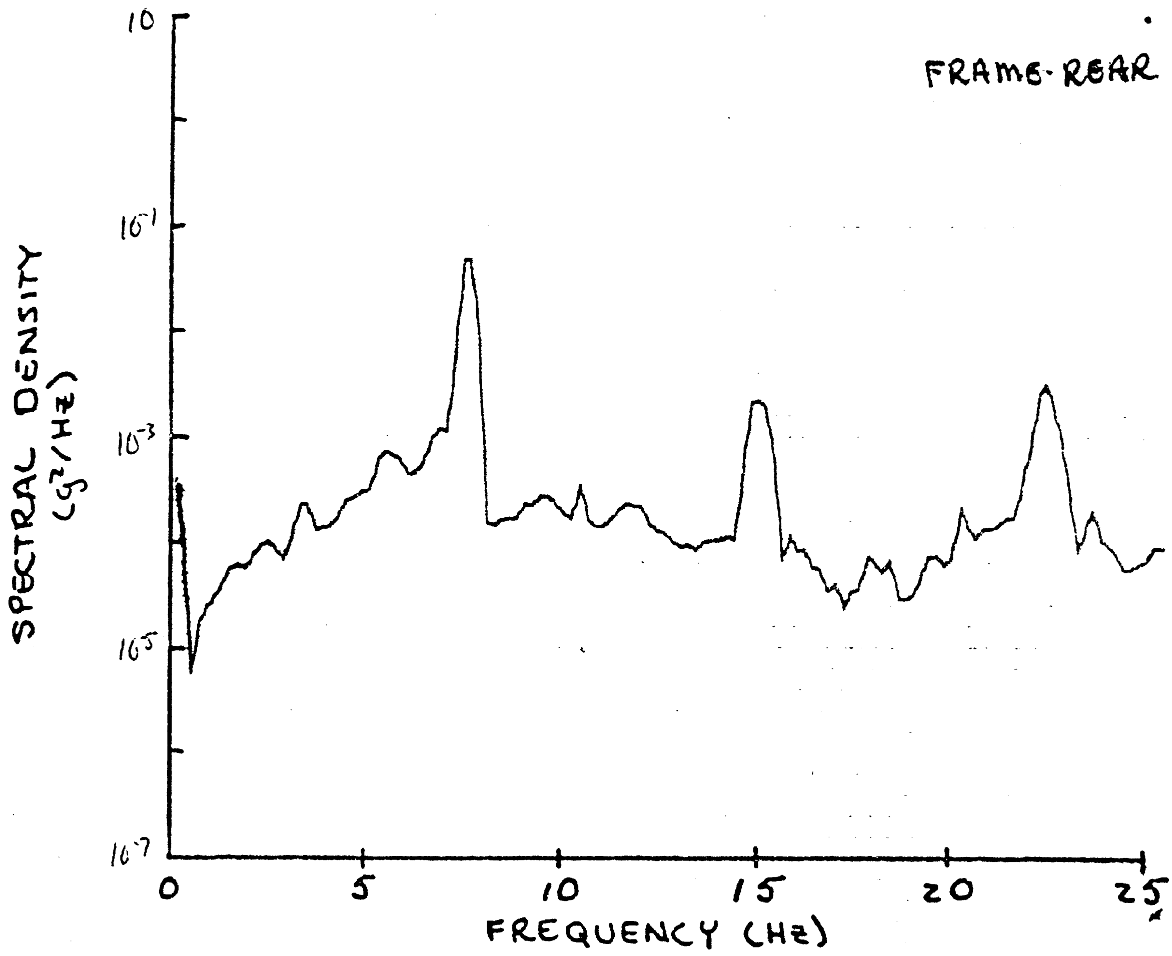


Figure VI.21. Power spectral densities, bobtail conventional tractor over site #1 at 55 mph.



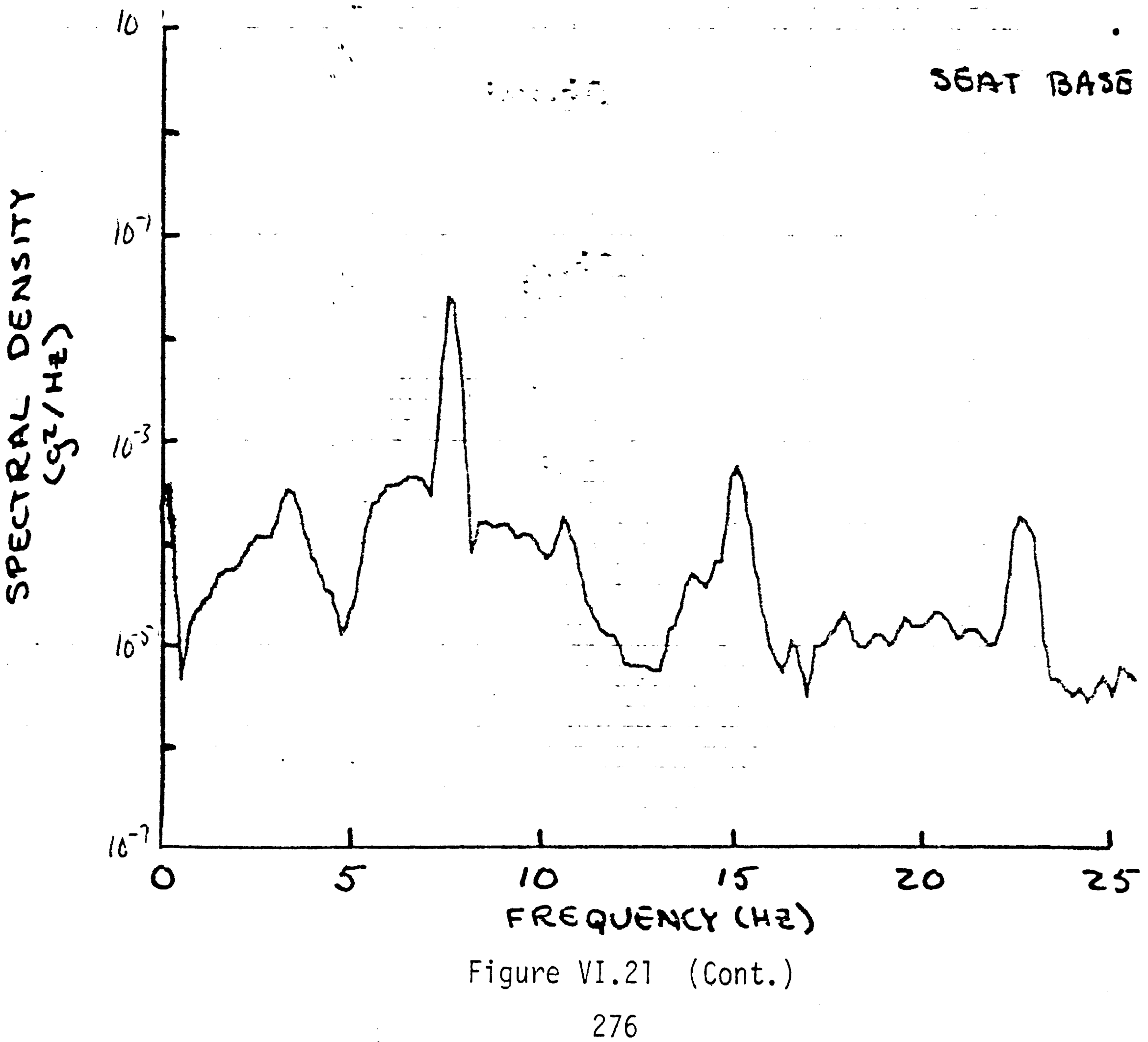
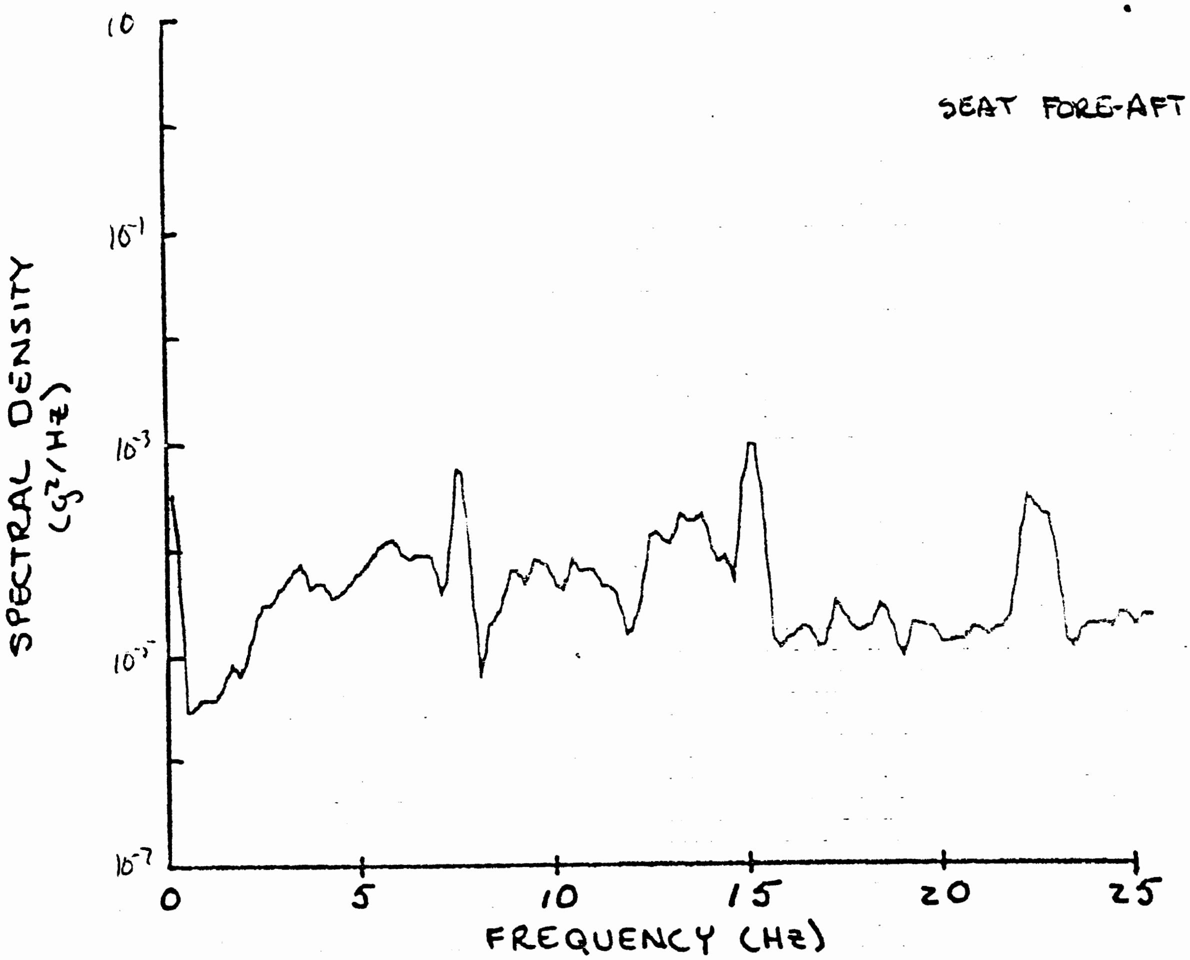


Figure VI.21 (Cont.)



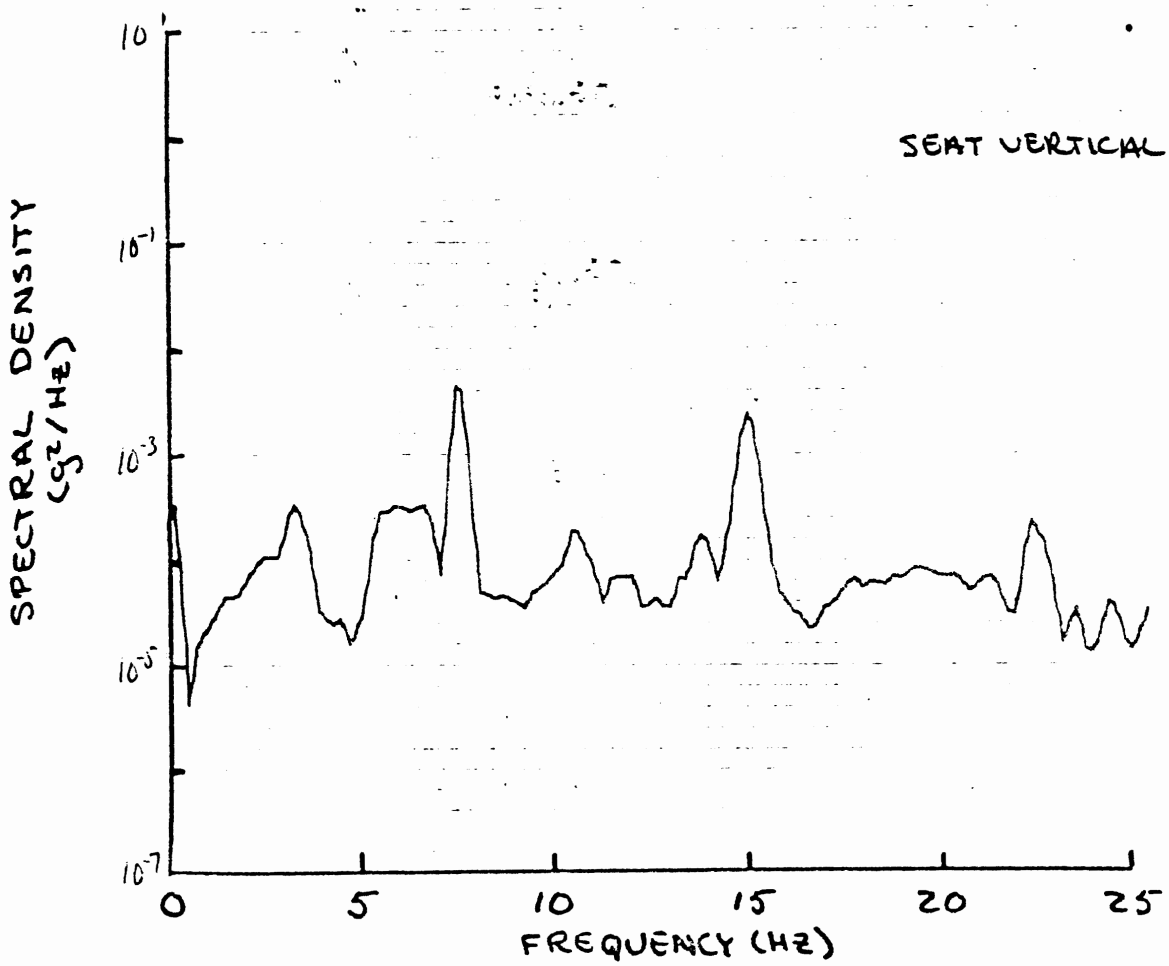


Figure VI.21 (Cont.)

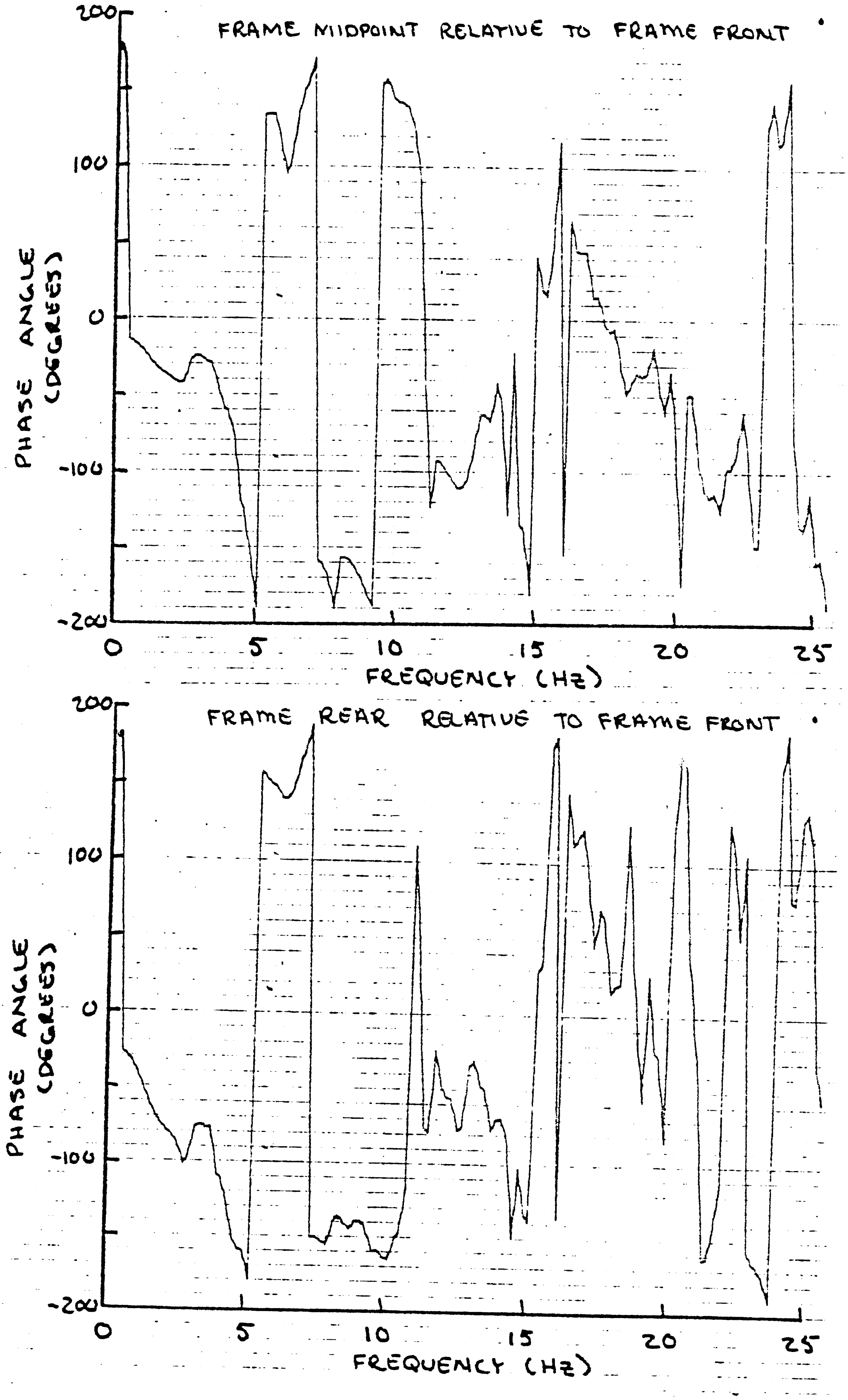
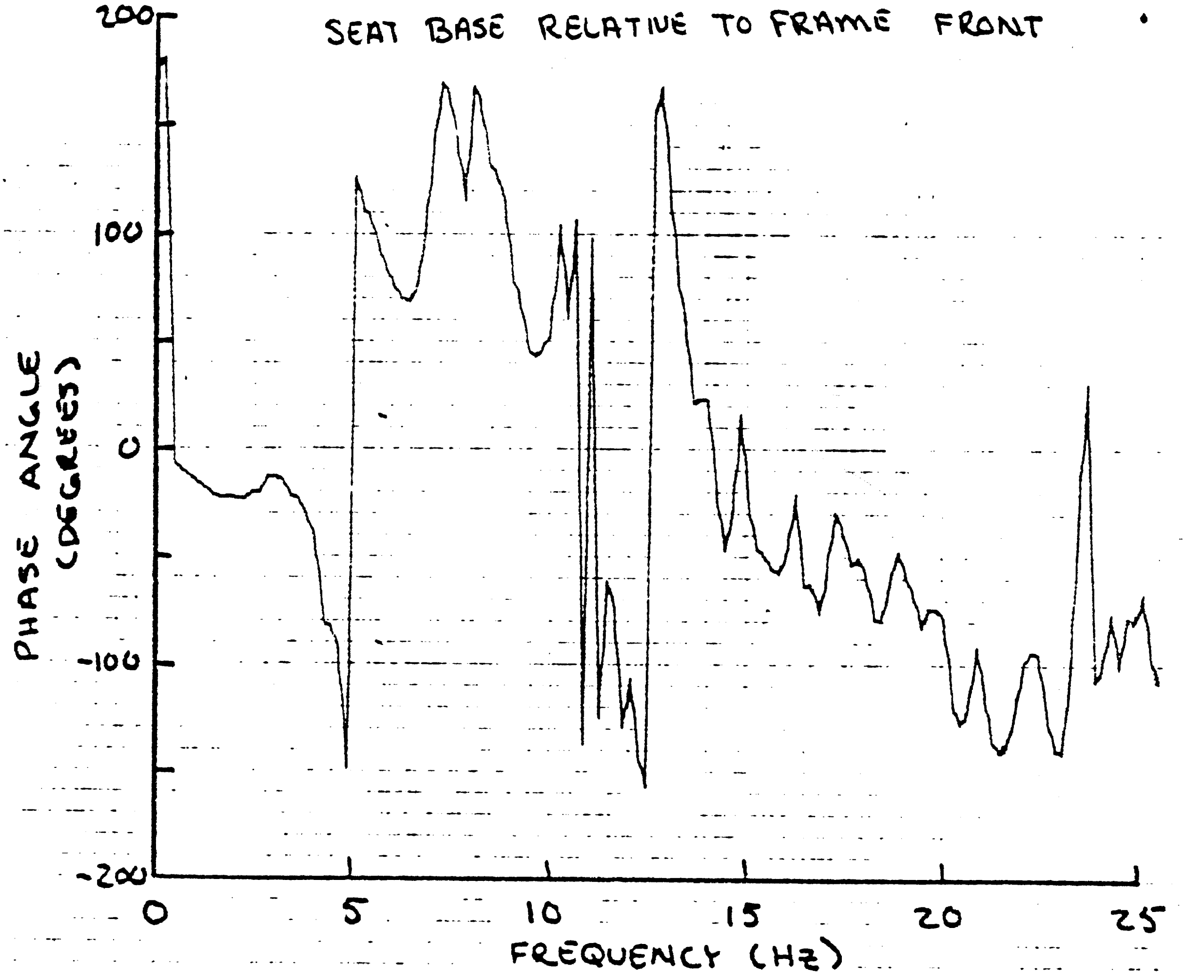


Figure VI.22. Phase relationships, bobtail conventional tractor over site #1 at 55 mph.



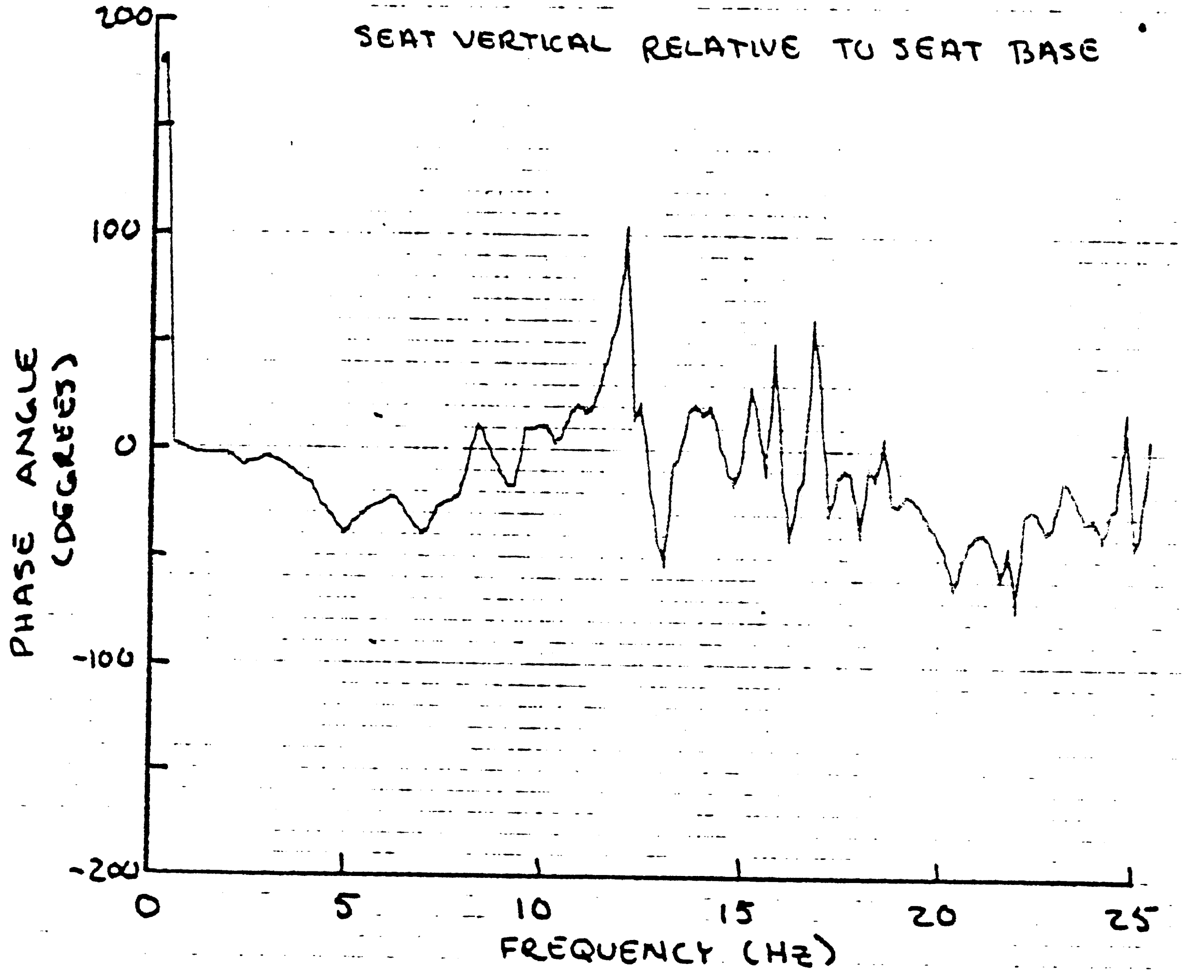


Figure VI.22 (Cont.)

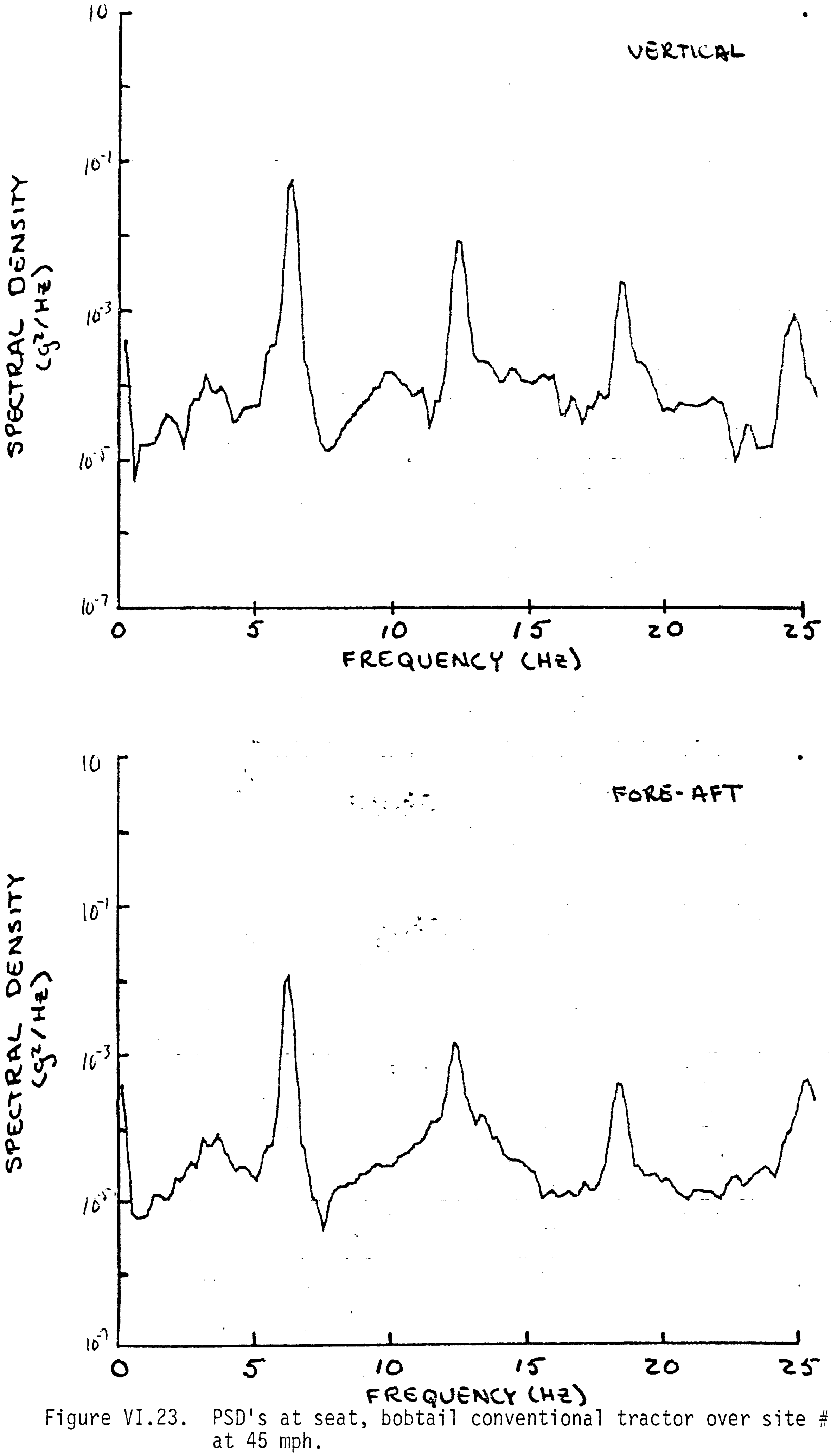


Figure VI.23. PSD's at seat, bobtail conventional tractor over site #1 at 45 mph.

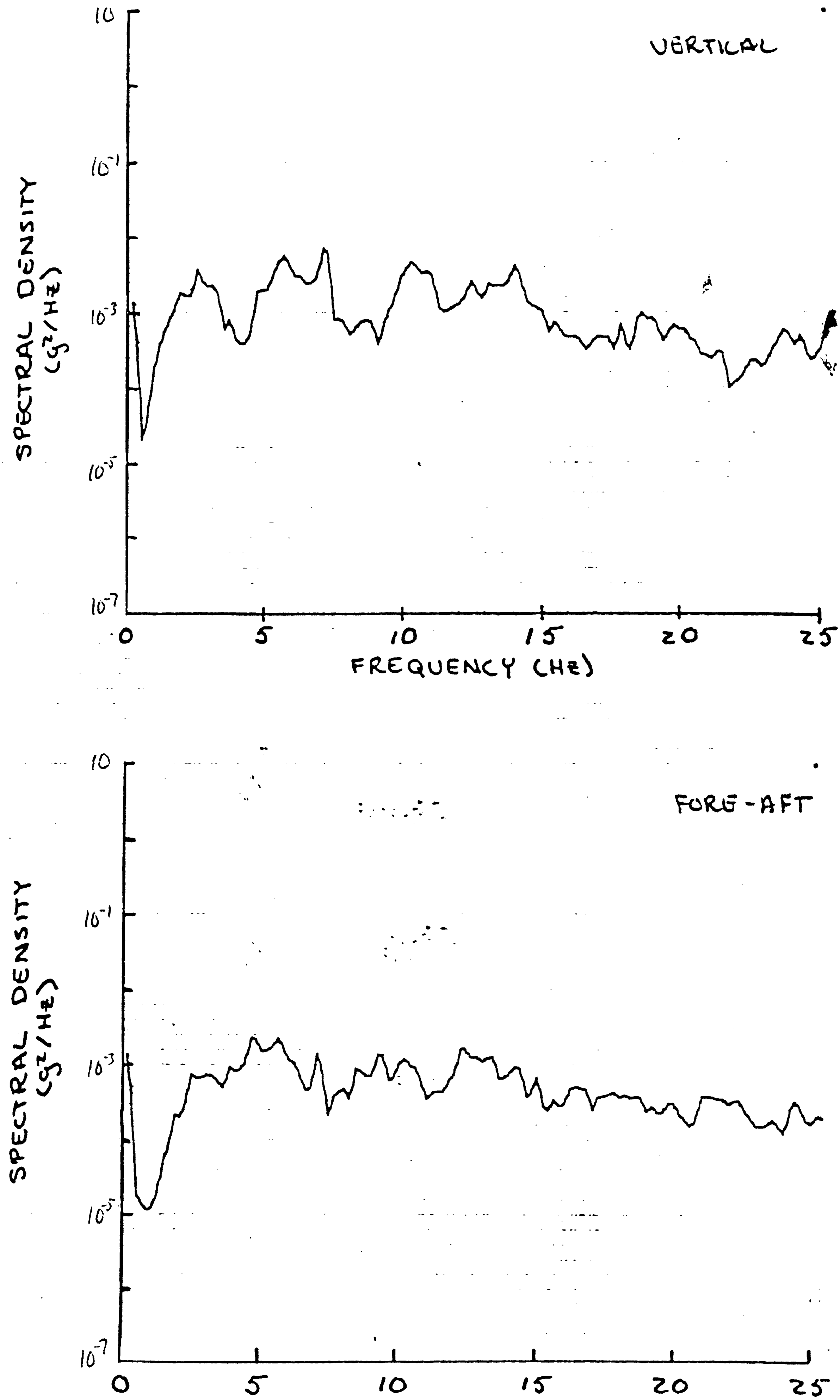
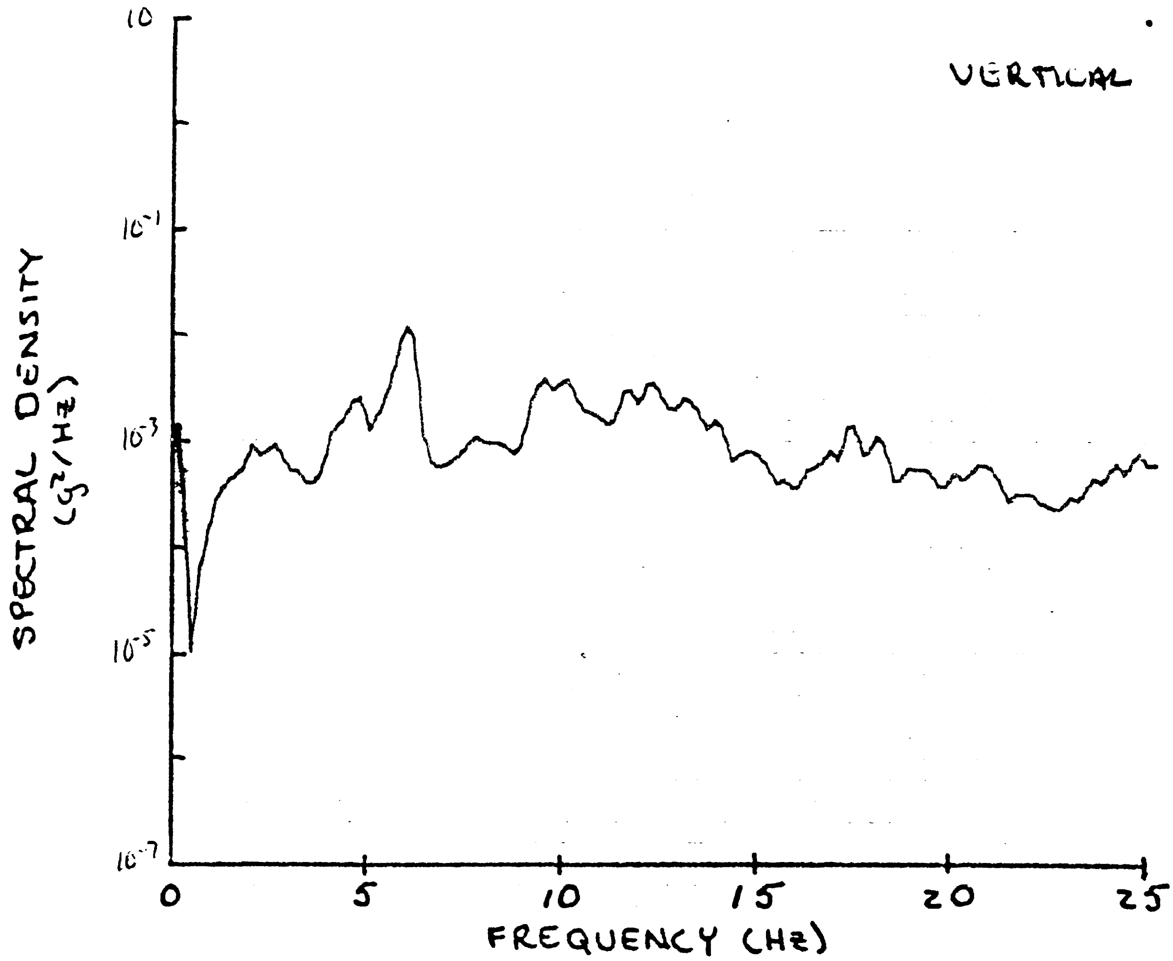


Figure VI.24. PSD's at seat, bobtail conventional tractor over site #2 at 55 mph.



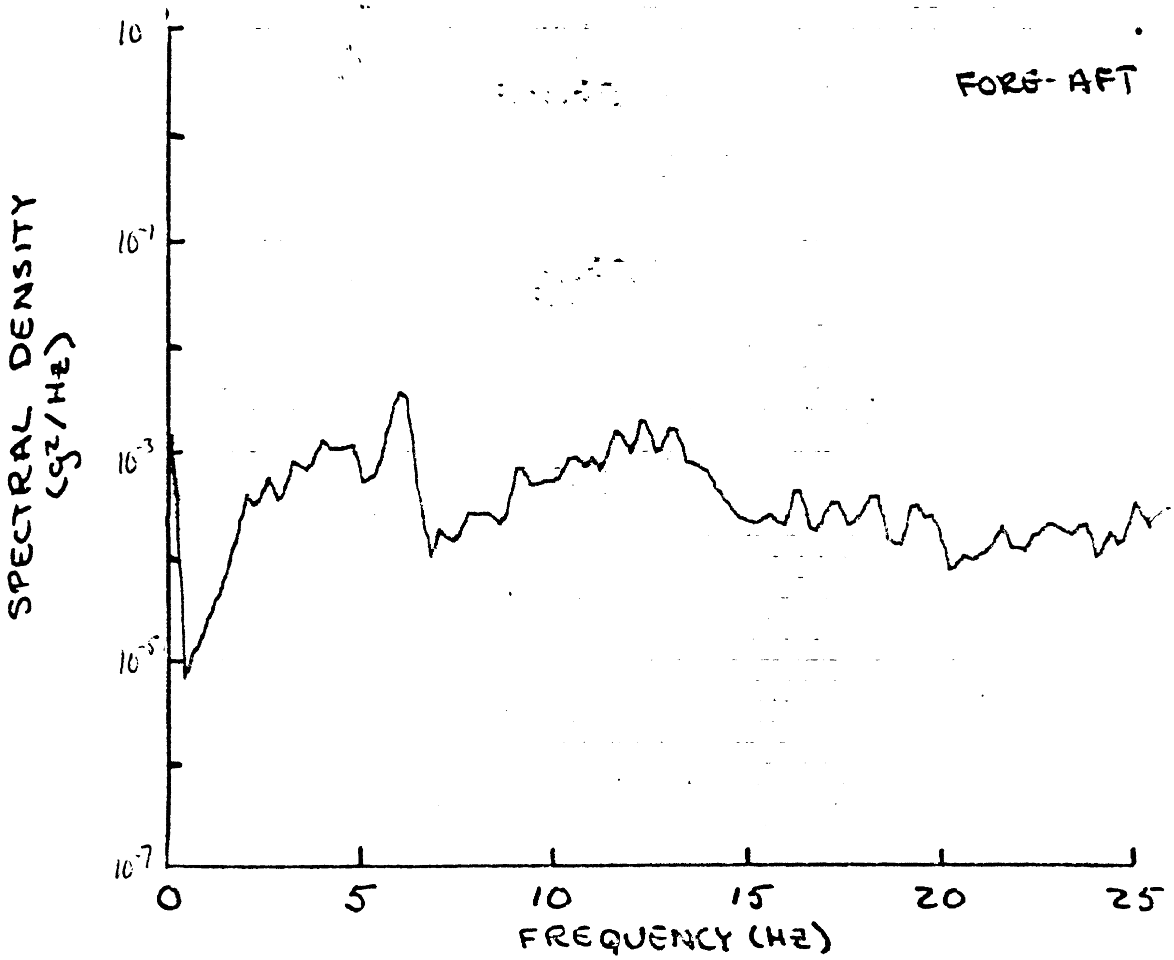


Figure VI.25. PSD's at seat, bobtail conventional tractor over site #2 at 45 mph.

Responses on Sites #3 and #4 are very similar to those observed on Site #2 with bounce and pitch motions controlling the seat vertical spectra and pitch controlling the longitudinal vibrations at 55 mph. With the speed reduced to 45 mph, the bounce mode power decreases and tire-wheel rotational force variation input becomes a major contributor to both vertical and fore/aft accelerations. The spectra are shown in Figures VI.26-29.

On Site #5 vertical and longitudinal vibrations (Figure VI.30) are attributable, in large part, to the pitching motion of the vehicle, the natural frequency of which occurs very near to the tire rotational frequency.

IV.1.4 Conventional Tractor - Loaded. As with the COE unit, the loaded conventional tractor has three dmoninant ride modes: a bounce and two pitch modes. The "bounce" mode natural frequency is approximately 3 Hz with its node located aft of the tractor. The two pitch modes, at 3.5 and 5.5 Hz, have differing node shapes. The lower frequency mode has a node between the frame midpoint and the rear axle while the 5.5 Hz mode has its node between the front axle and the mid-point. Spectra and phase information are contained in Figures VI.31 and VI.32.

On the smooth surface at Site #1 the loaded conventional tractor's response at the driver's seat (Figures VI.31 and 33) is dominated by the vehicle's pitch mode, at 3.5 and 5.5 Hz, and the tire rotational frequencies. At 55 mph, the ride motions and response to tire rotation are of approximately equal magnitudes, while at 45 mph the tire-wheel contribution dominates.

On the rougher surface of Site #2, the bounce mode appears more strongly in the seat vertical spectrum at 55 mph, with a decreased influence at 45 mph at which the pitch modes and tire inputs become dominant (see Figures VI.34 and 35). The fore/aft vibration at both speeds is mainly attributable to pitch modes and tire inputs with comparable power levels for both speeds.

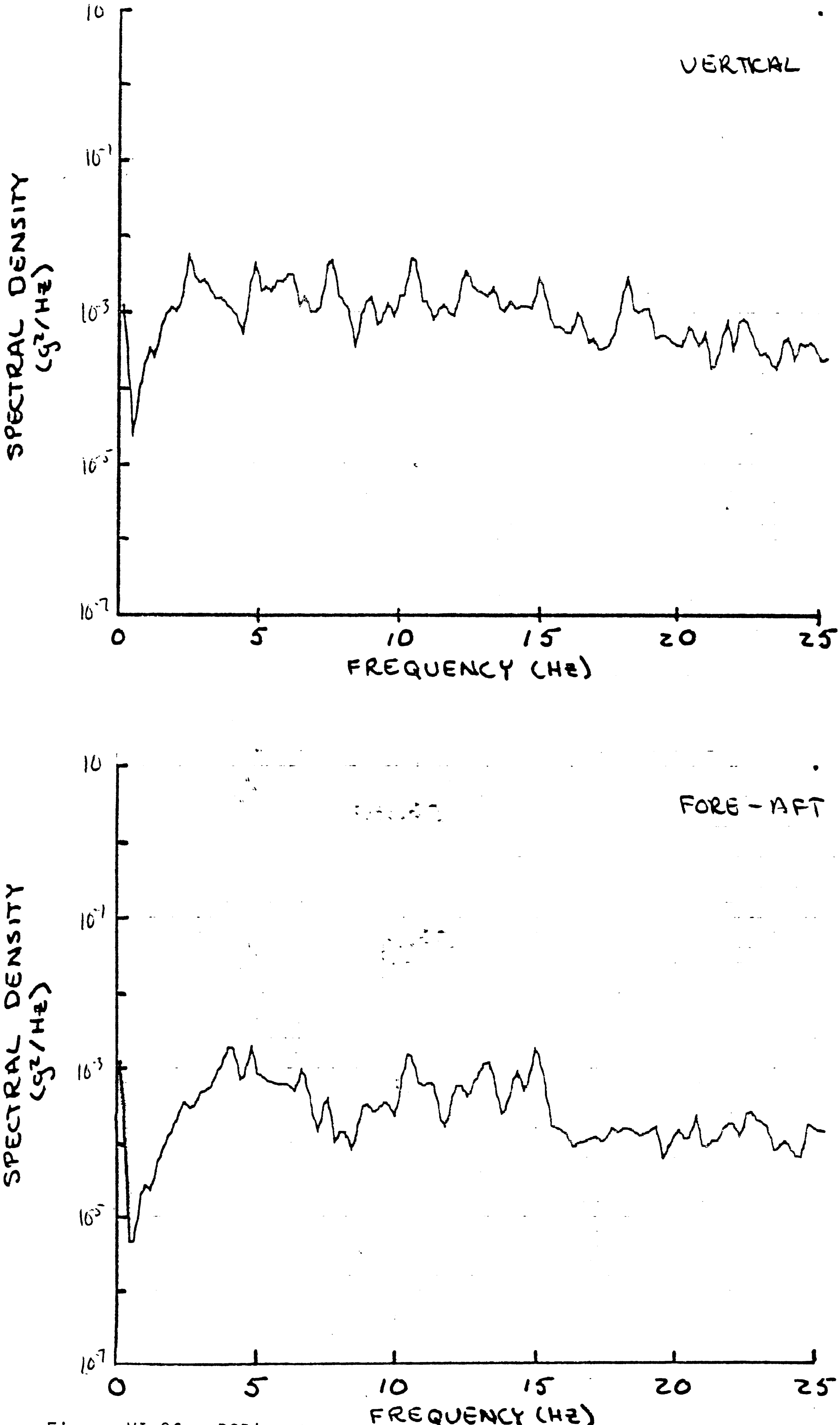


Figure VI.26. PSD's at seat, bobtail conventional tractor over site #3 at 55 mph.

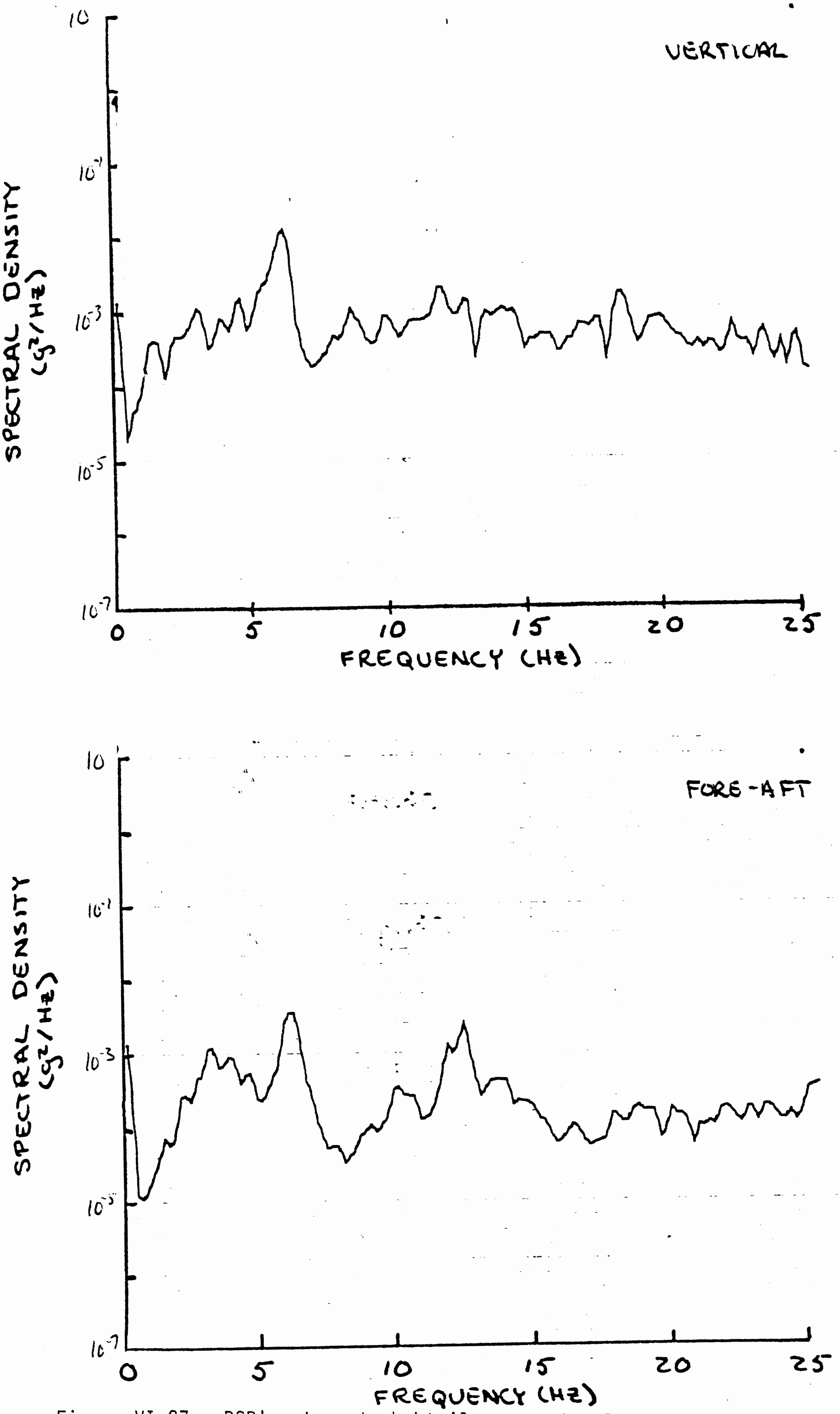
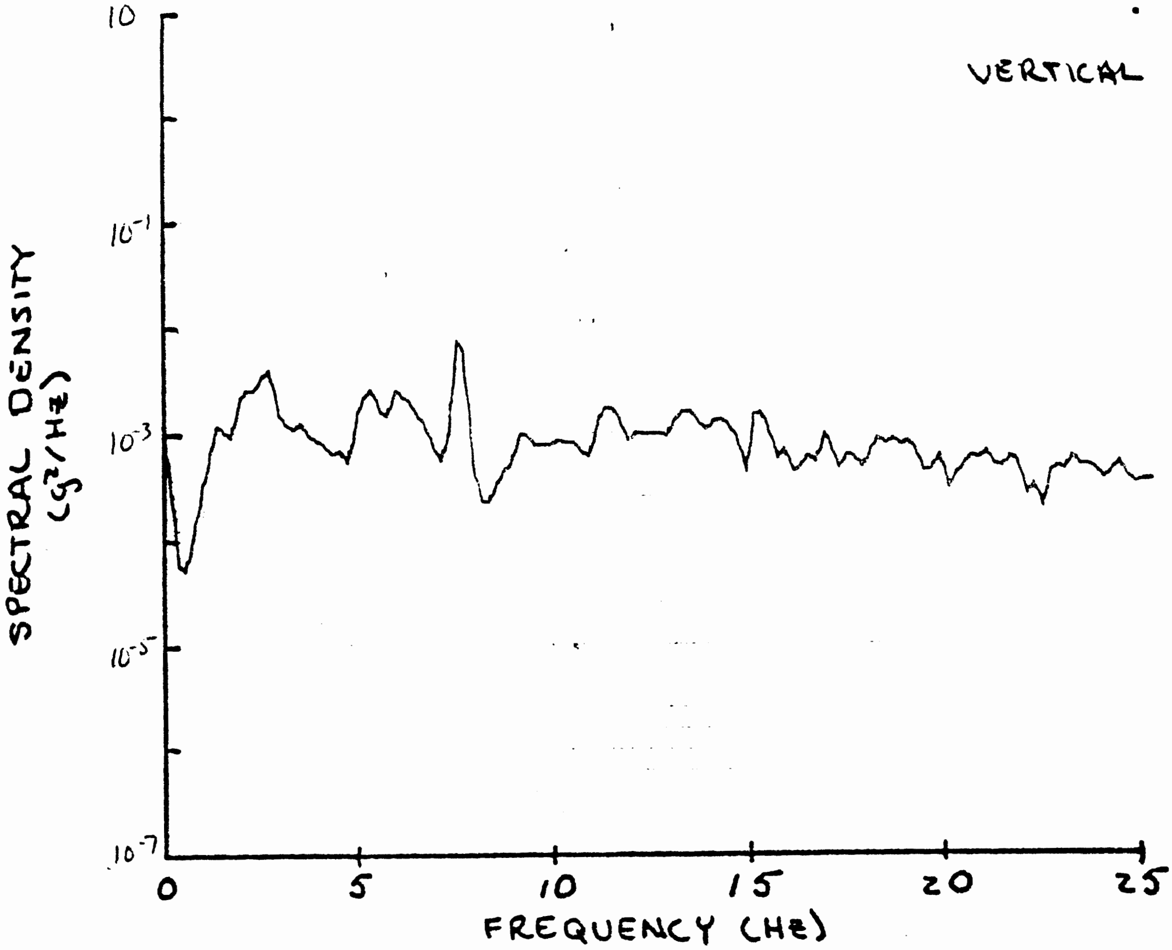


Figure VI.27. PSD's at seat, bobtail conventional tractor over site #3 at 45 mph.



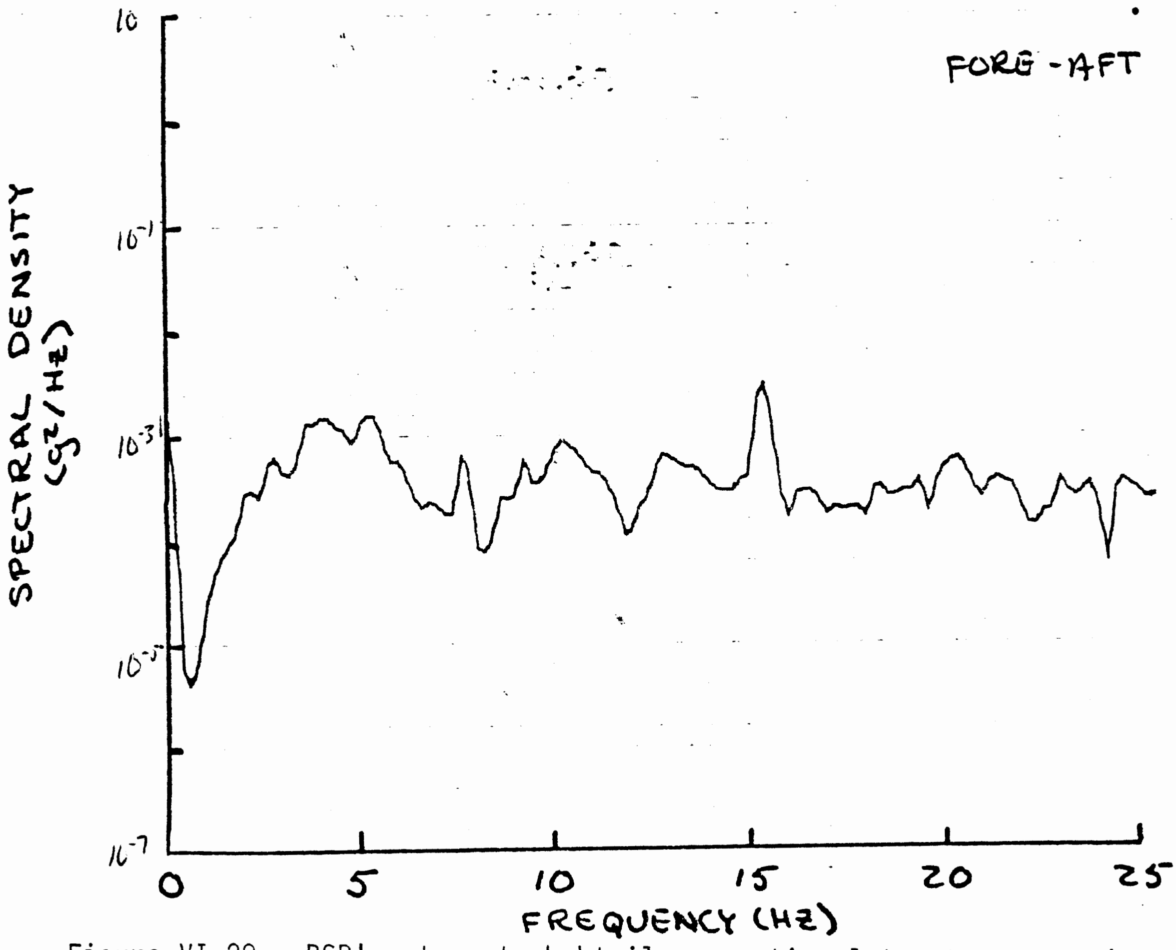
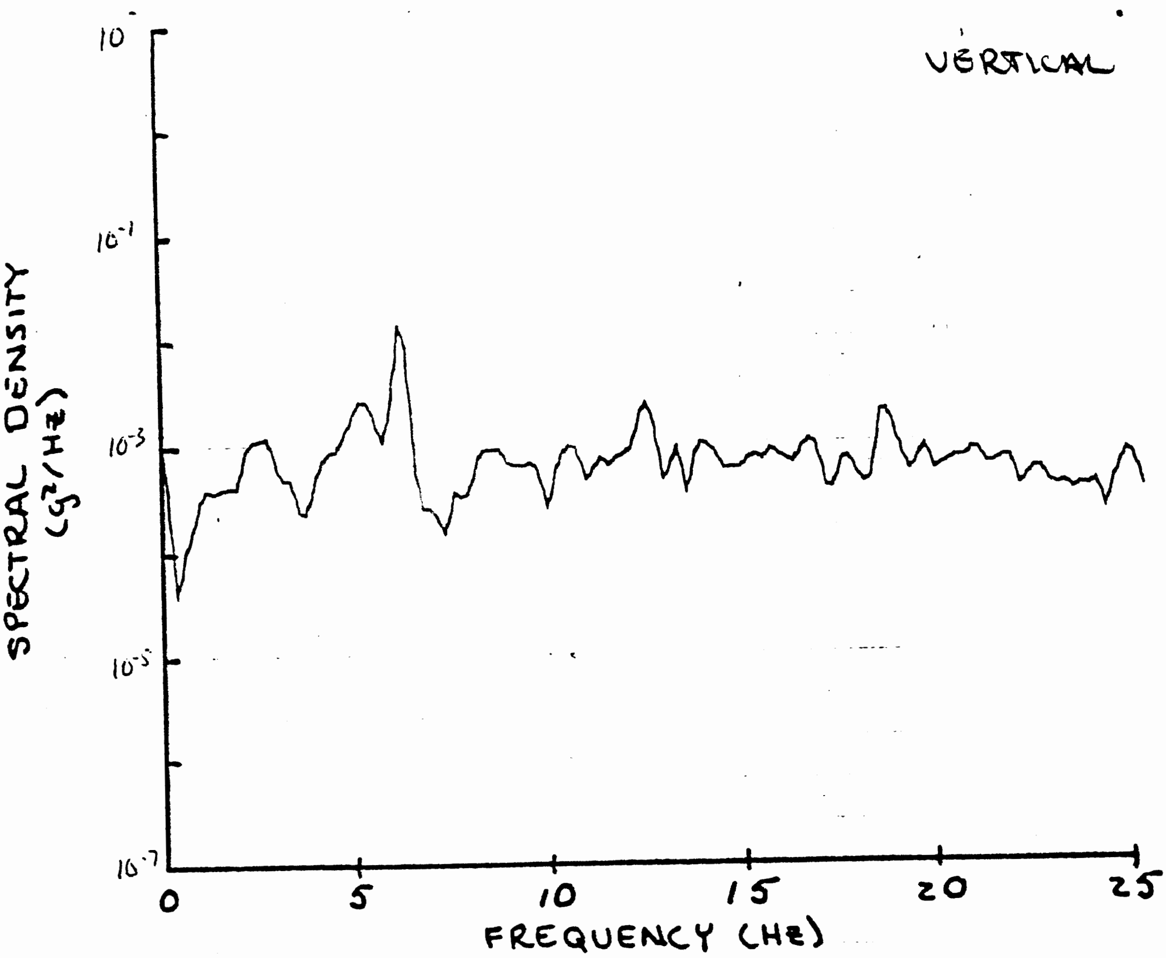


Figure VI.28. PSD's at seat, bobtail conventional tractor over site #4 at 55 mph.



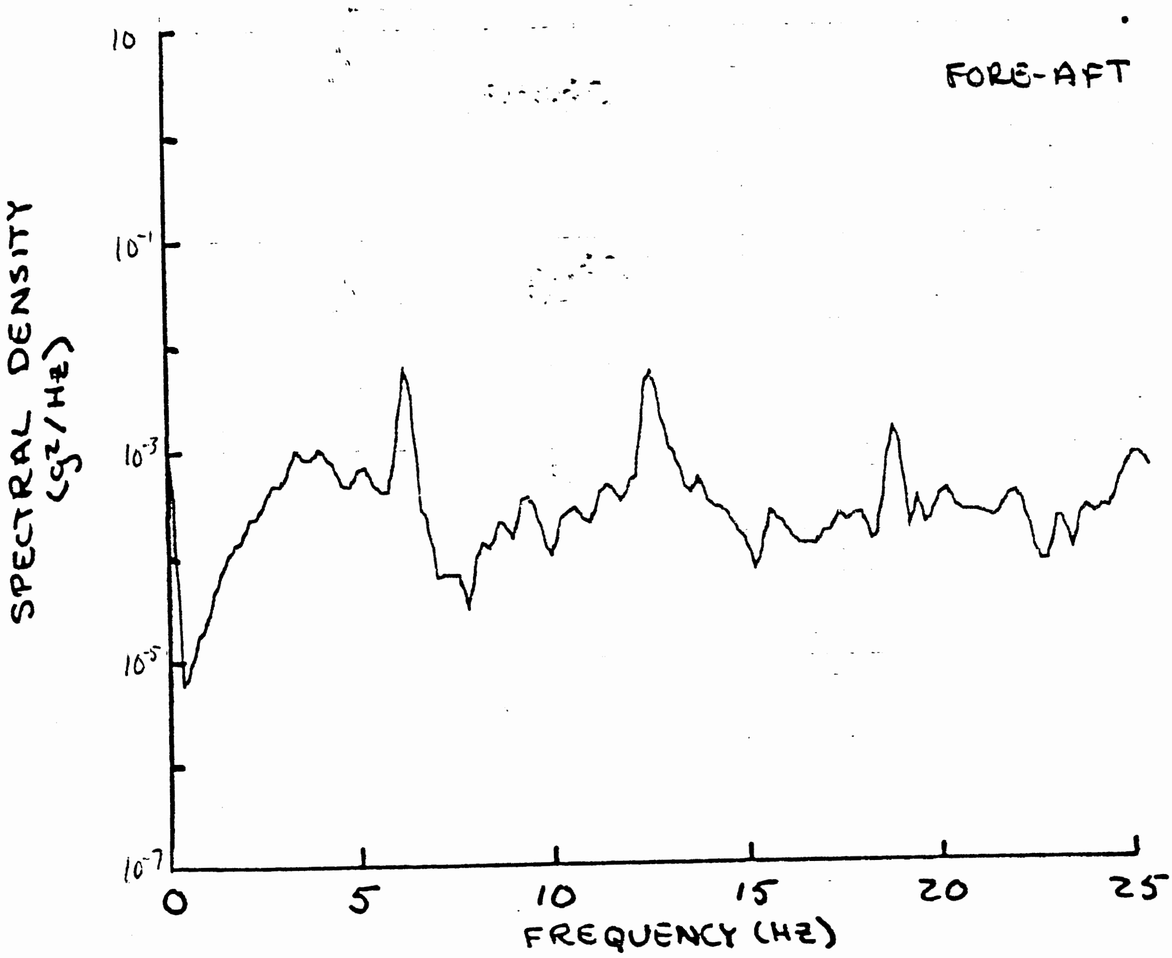


Figure VI.29. PSD's at seat, bobtail conventional tractor over site #4 at 45 mph.

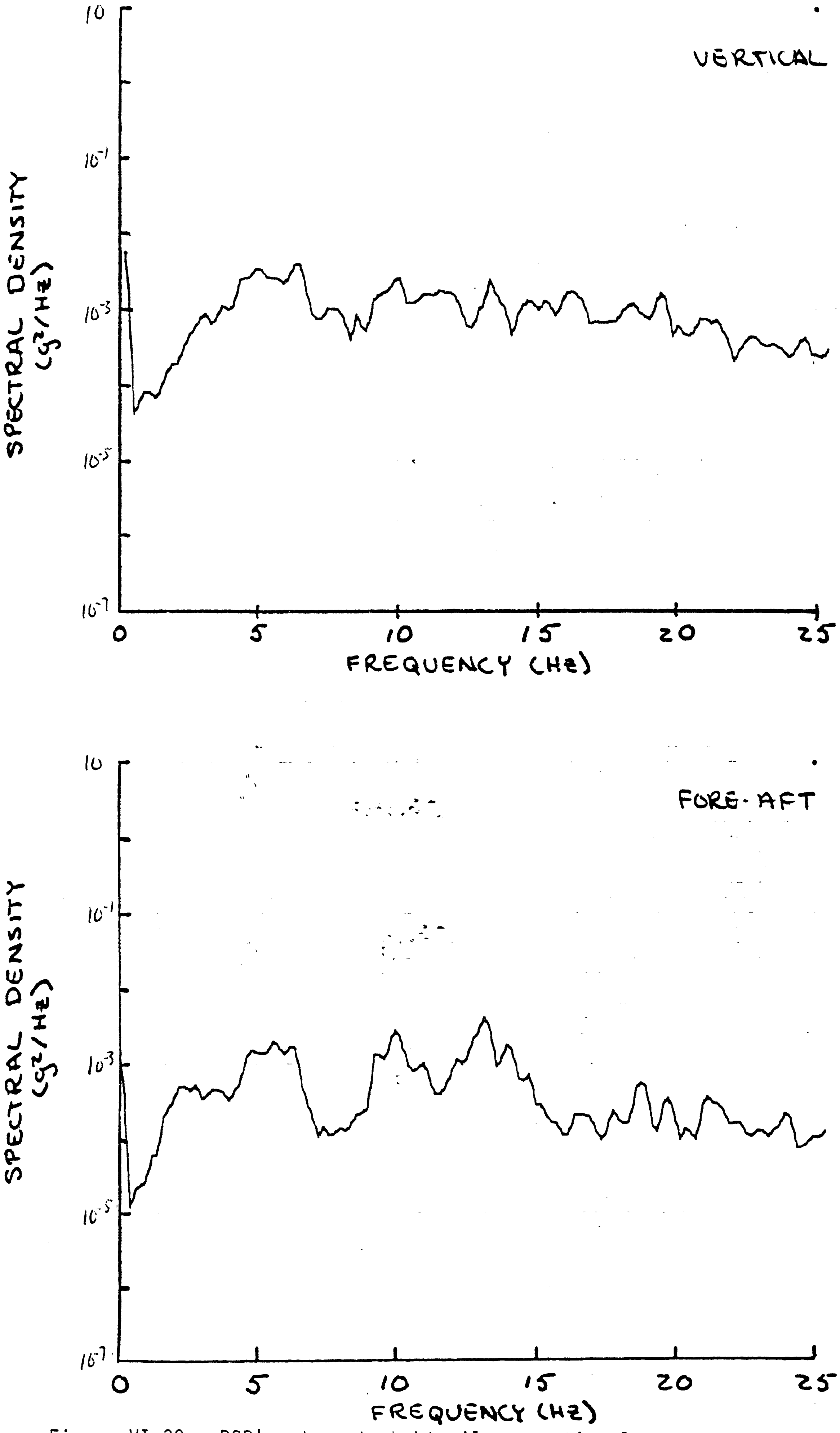
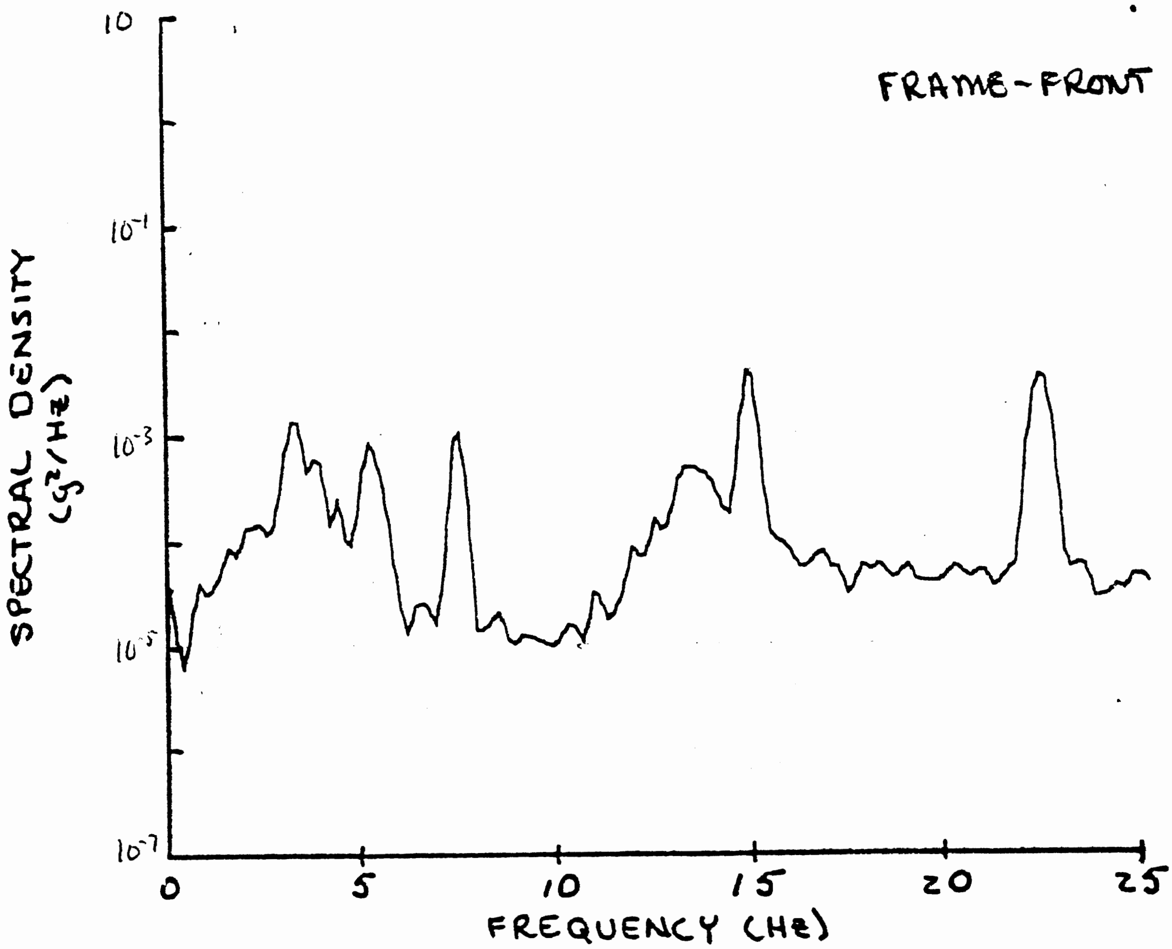


Figure VI.30. PSD's at seat, bobtrail conventional tractor over site #5 at 35 mph.



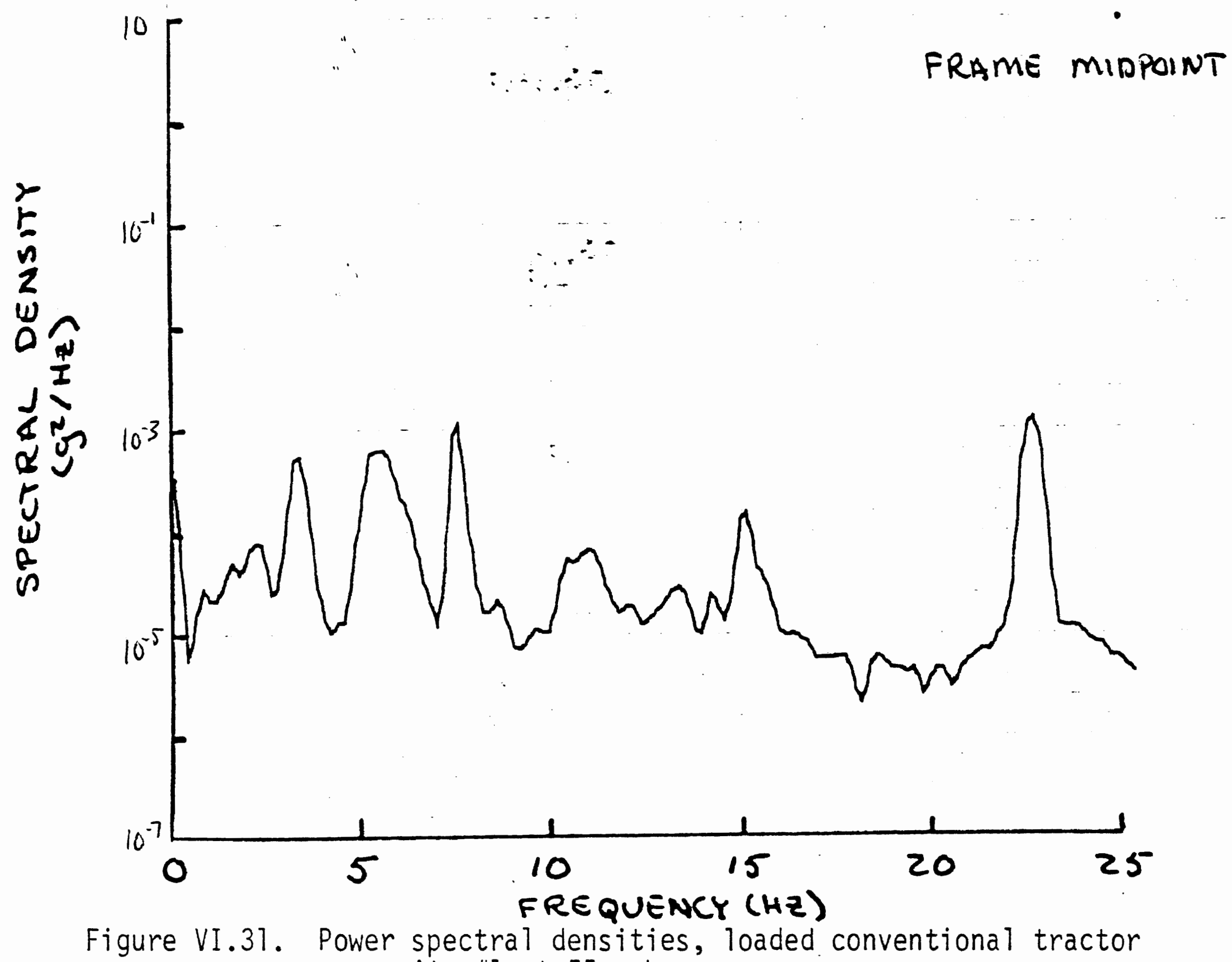
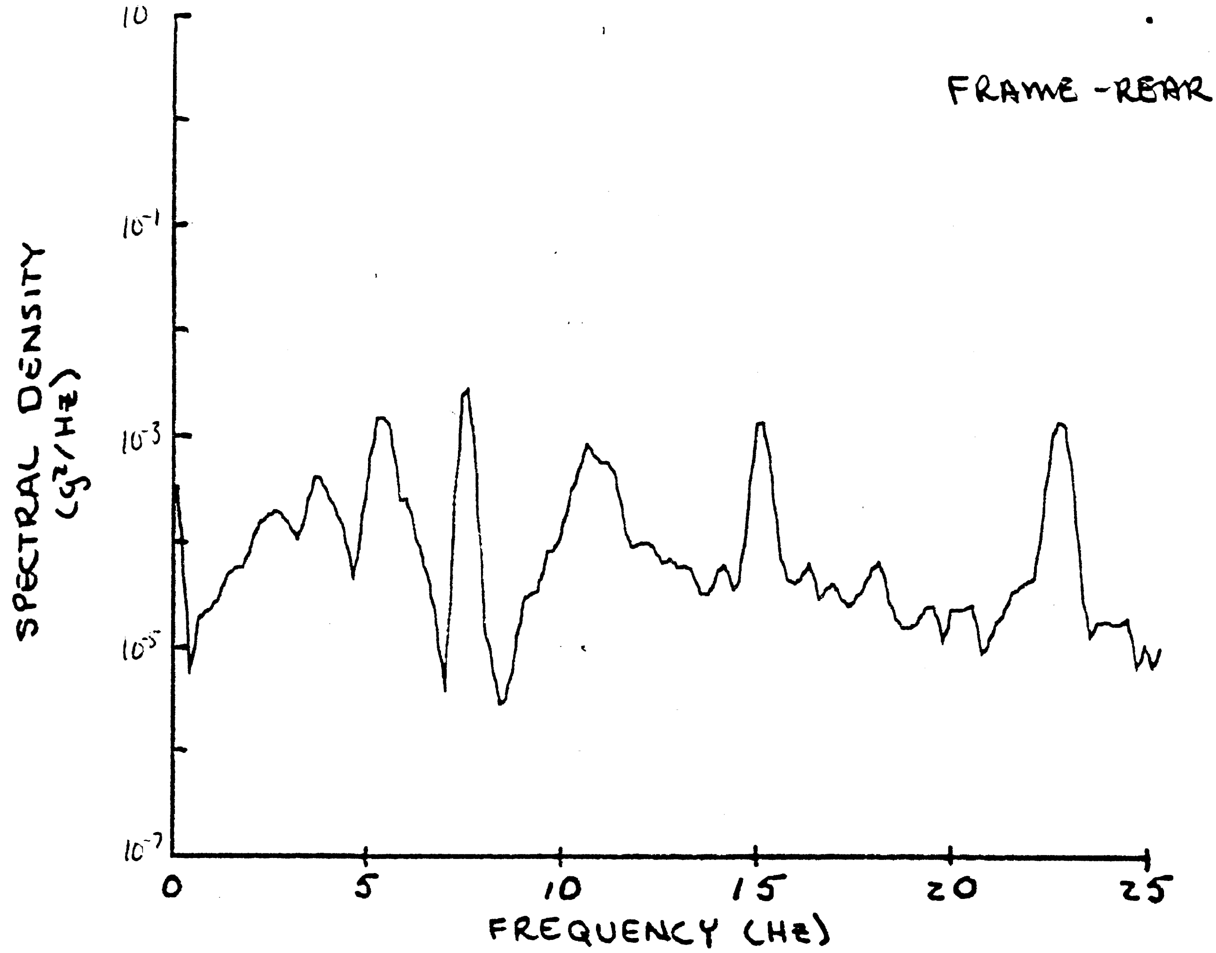


Figure VI.31. Power spectral densities, loaded conventional tractor over site #1 at 55 mph.



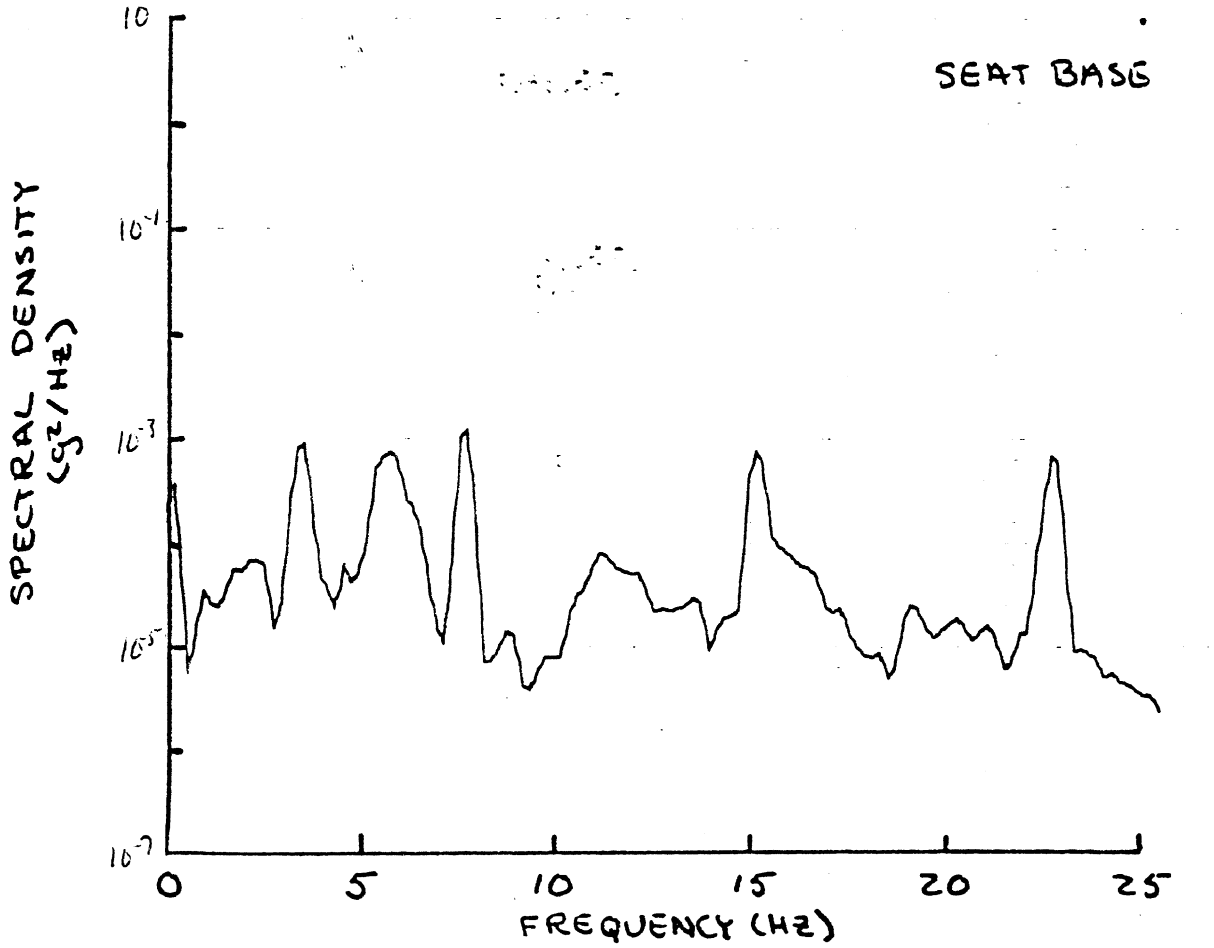
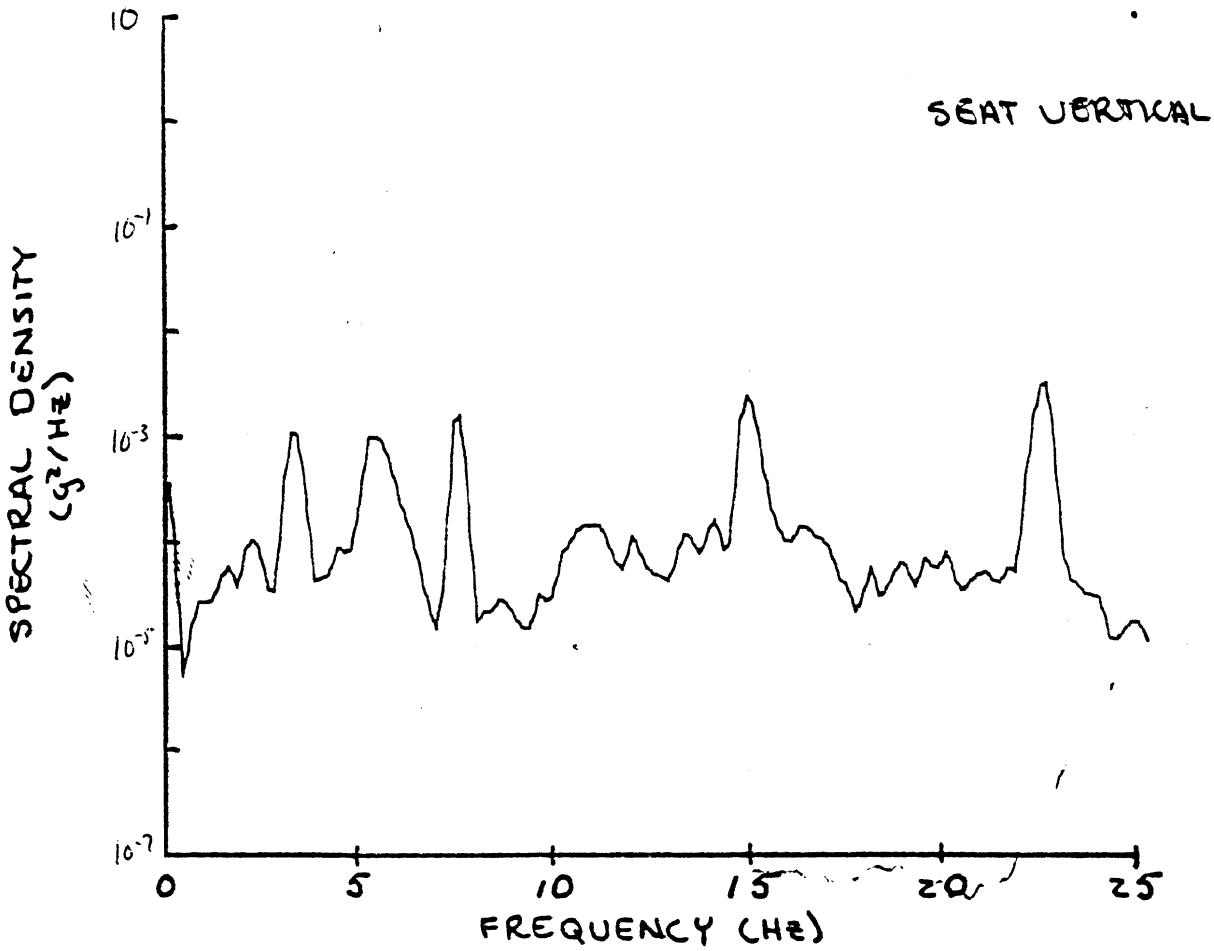
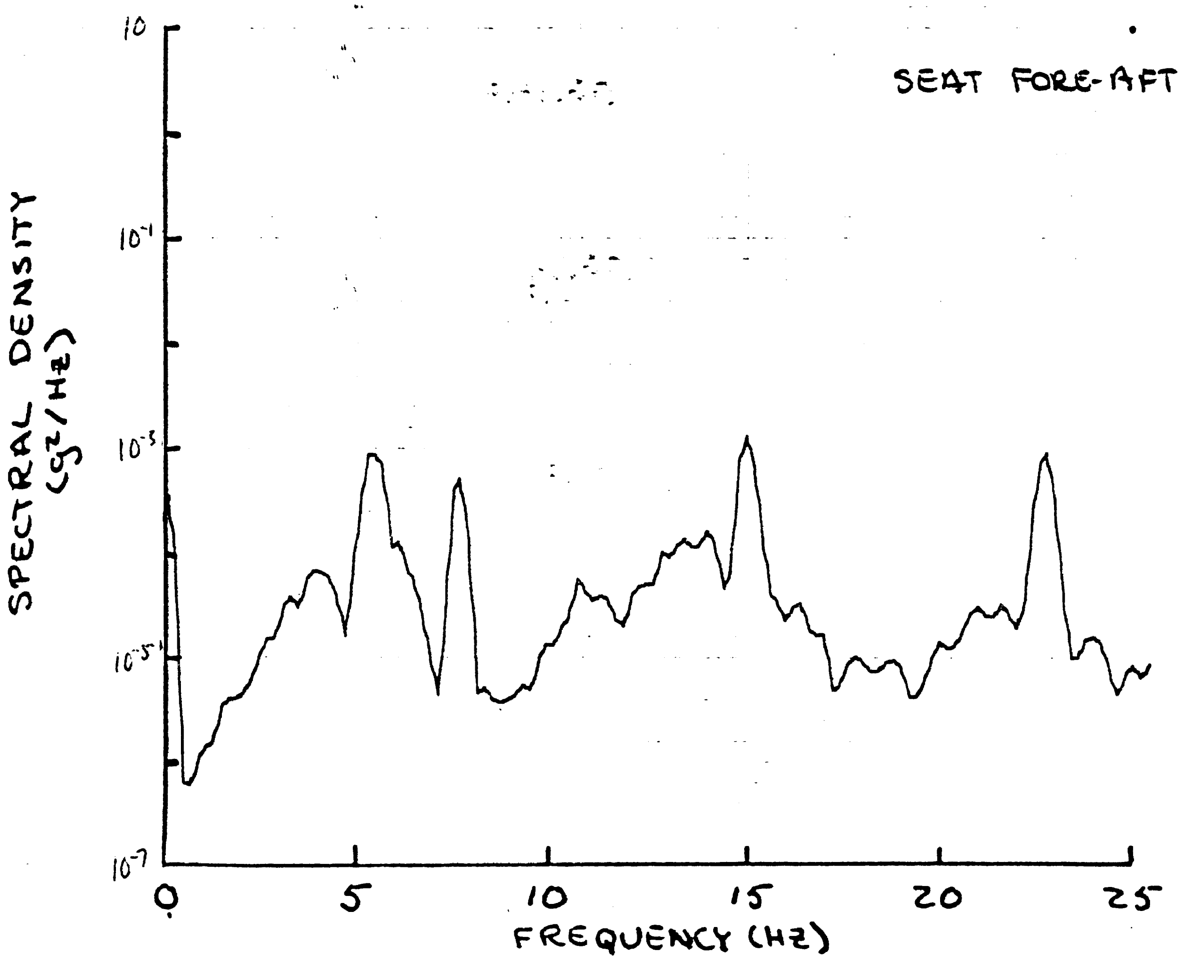


Figure VI.31 (Cont.)





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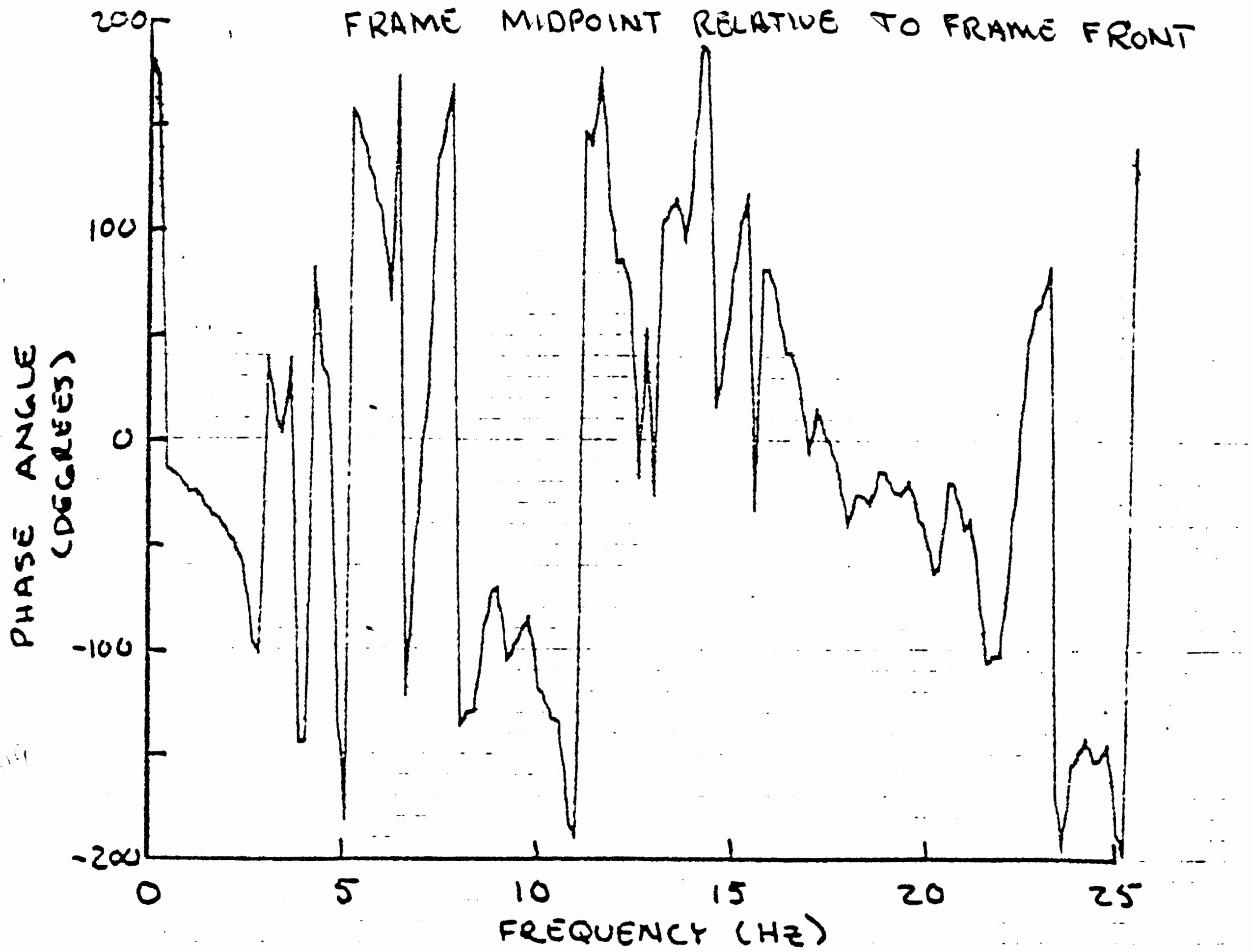


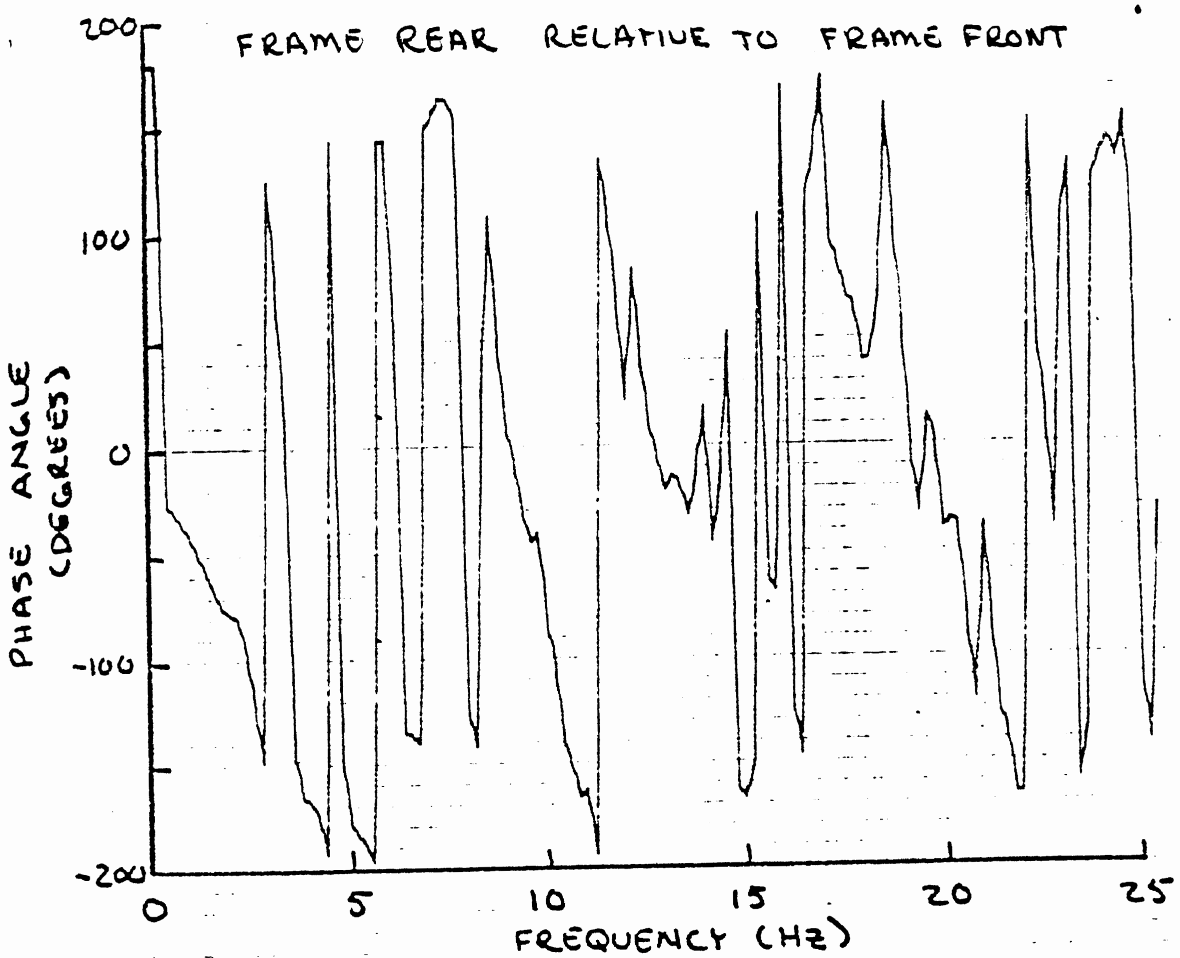
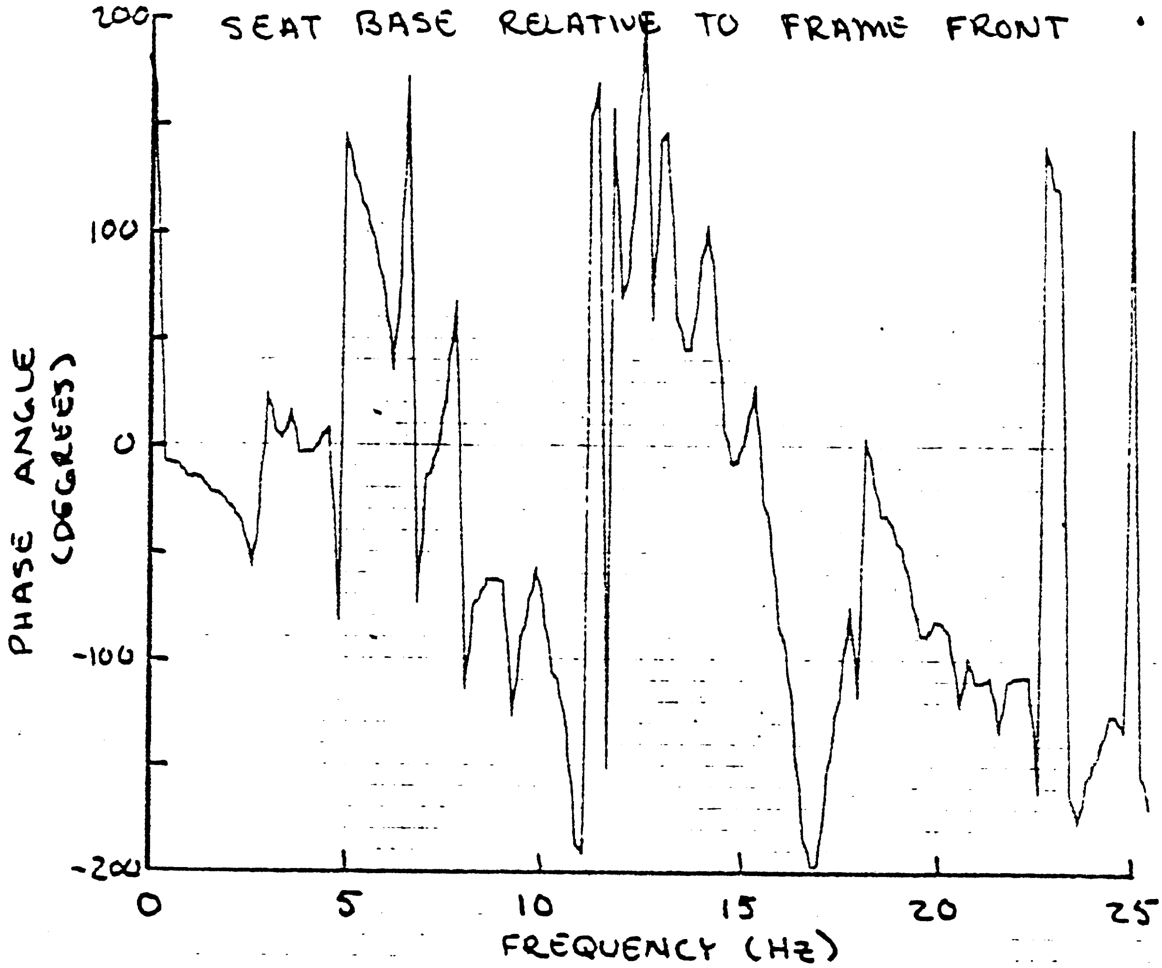
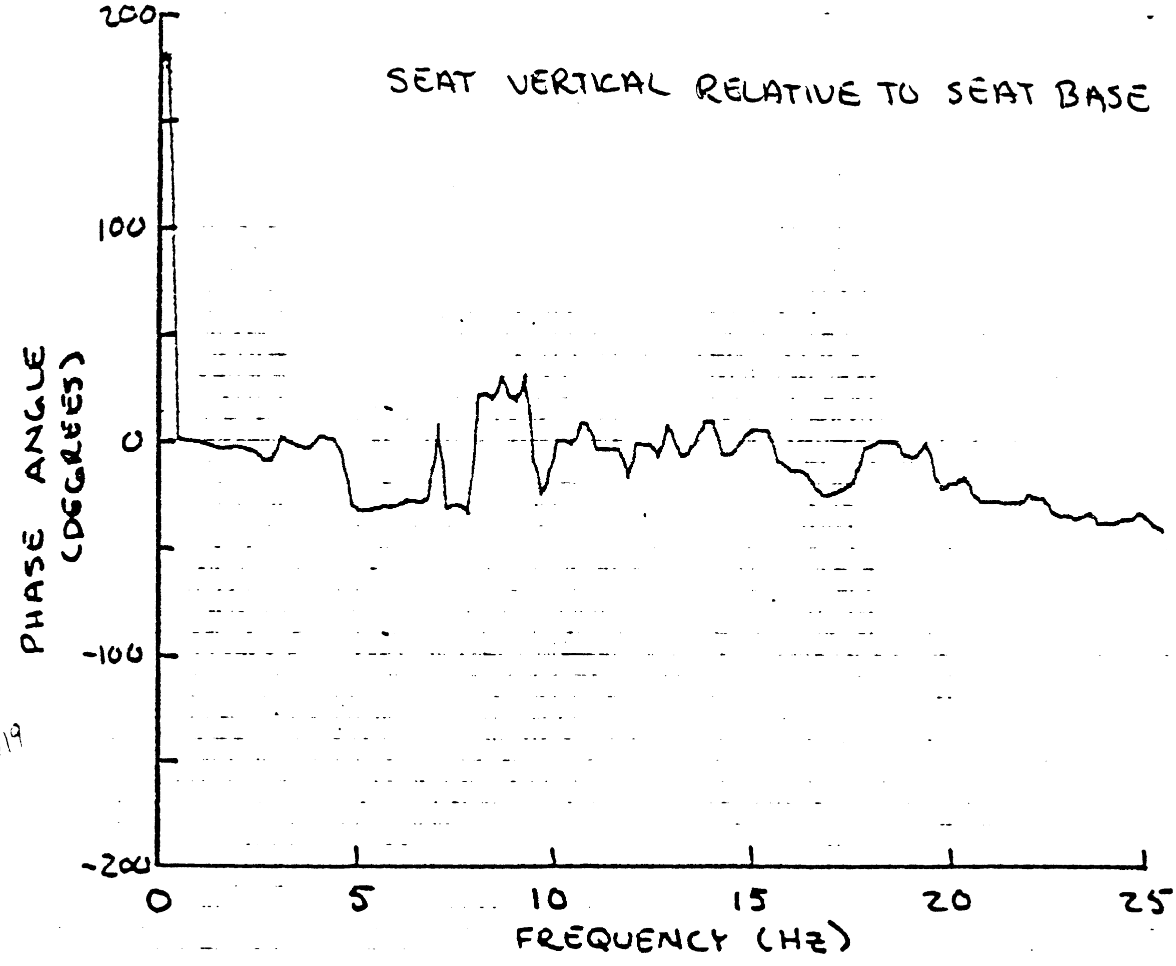


Figure VI.32. Phase relationships, loaded conventional tractor over site #1 at 55 mph.





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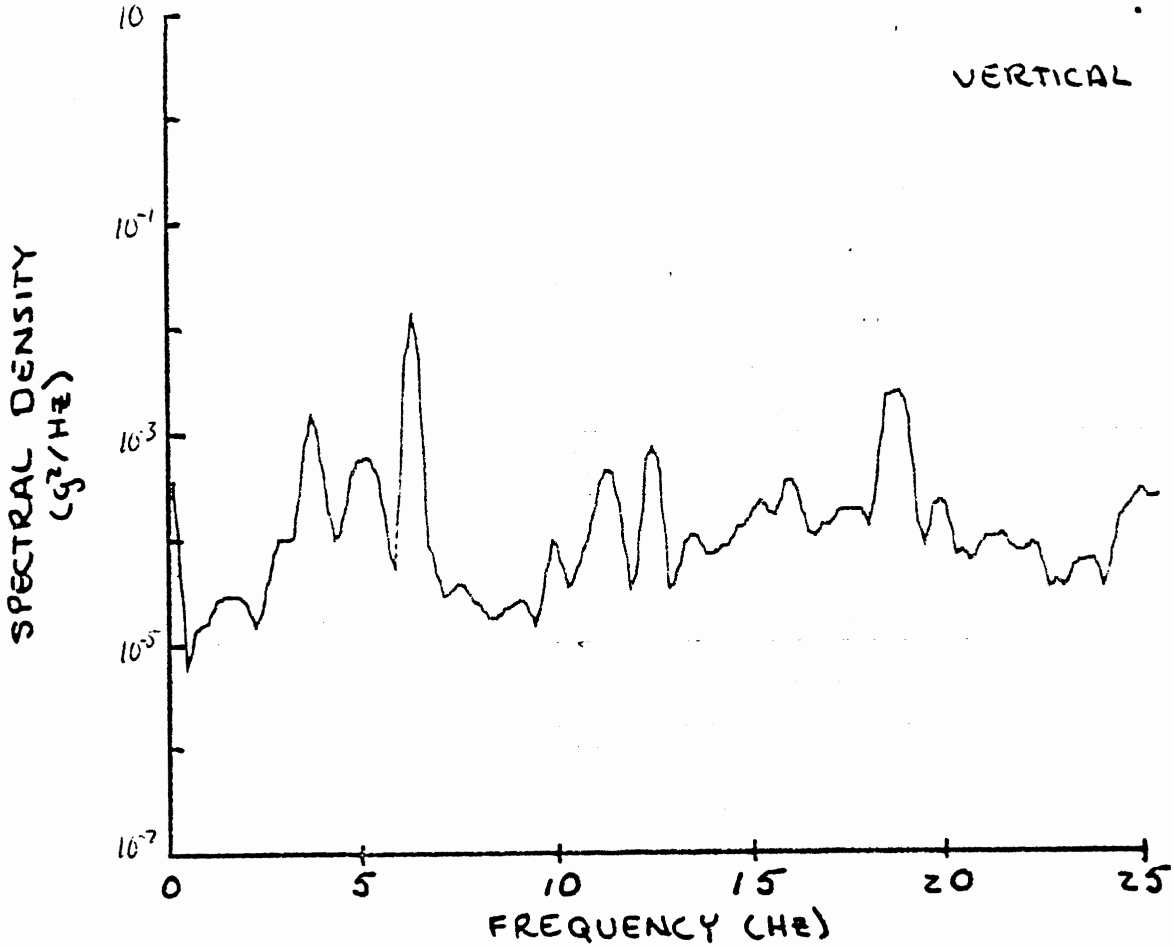


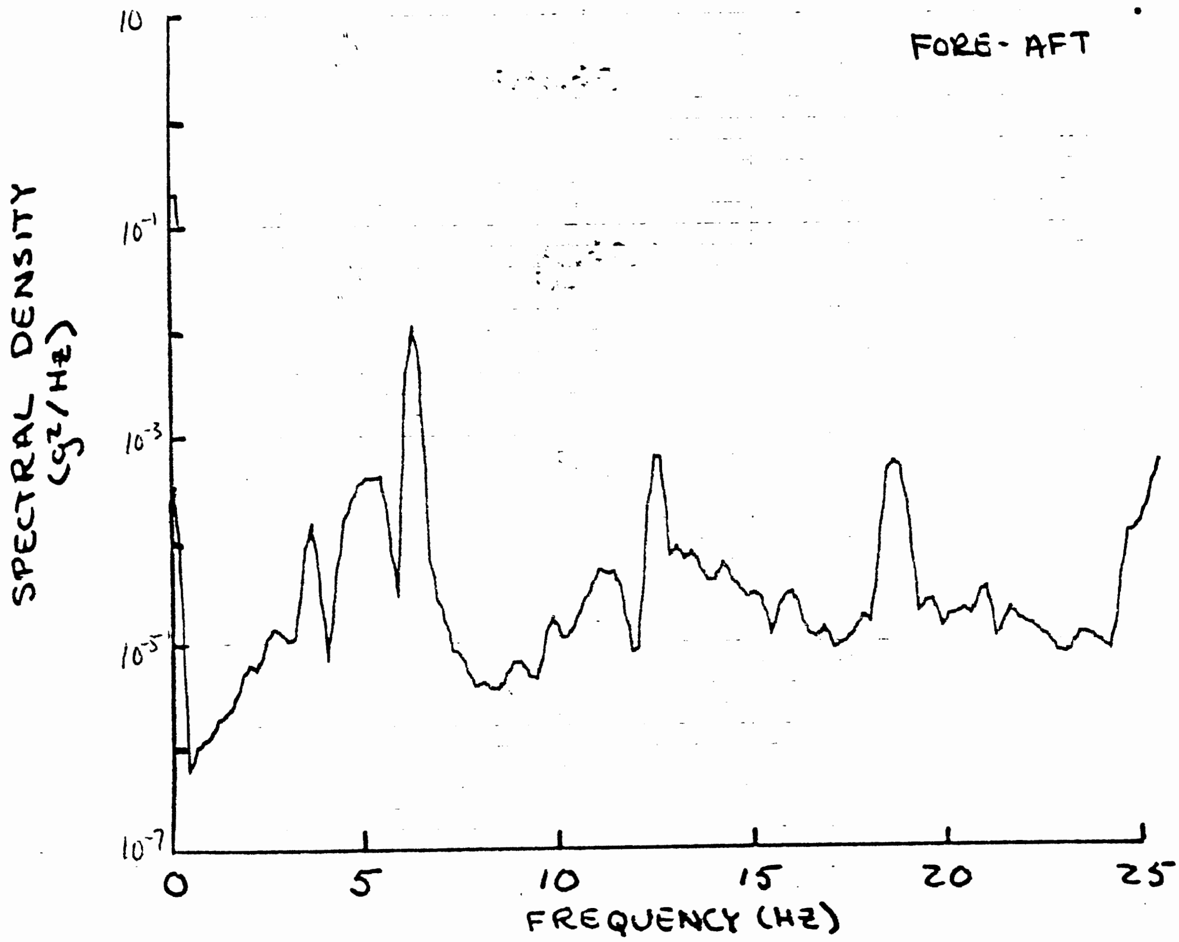
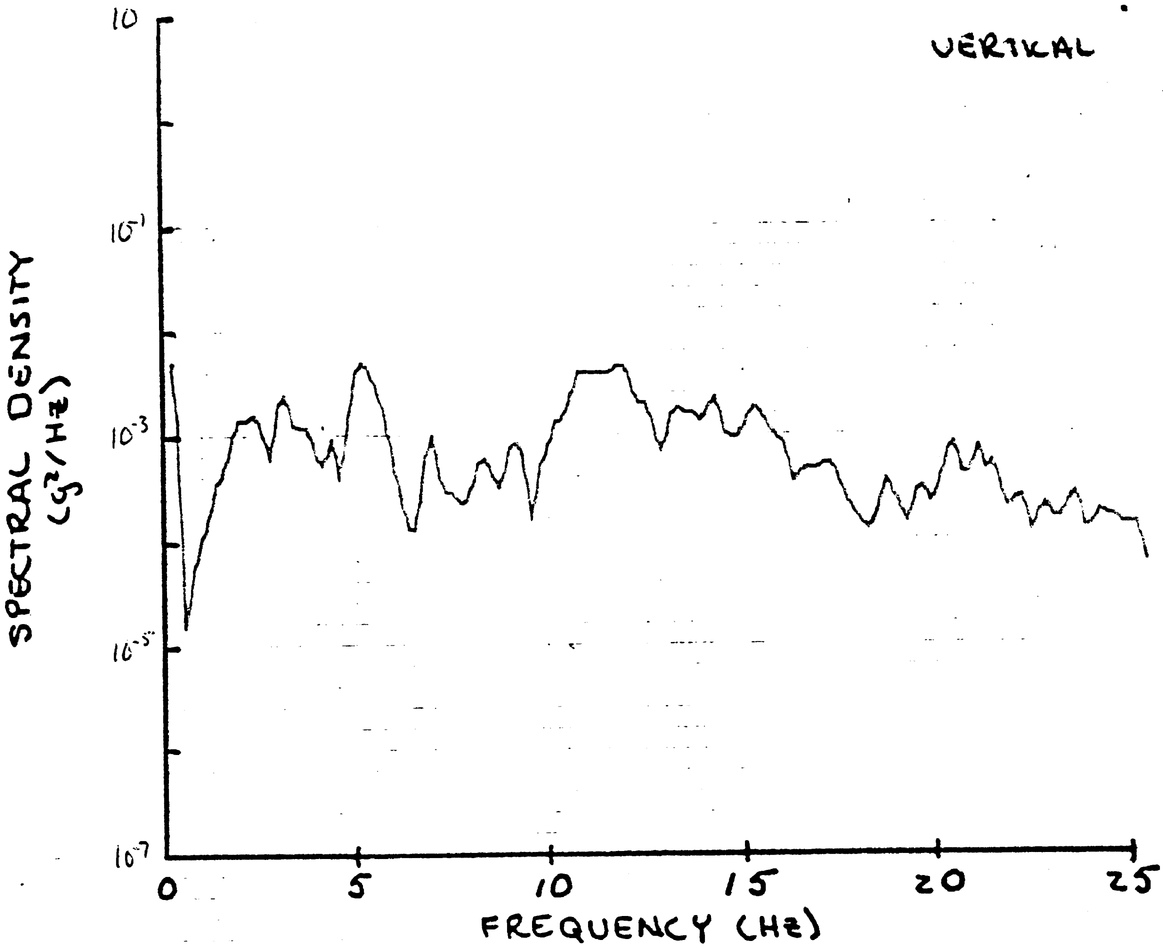


Figure VI.33. PSD's at seat, loaded conventional tractor over site #1 at 45 mph.



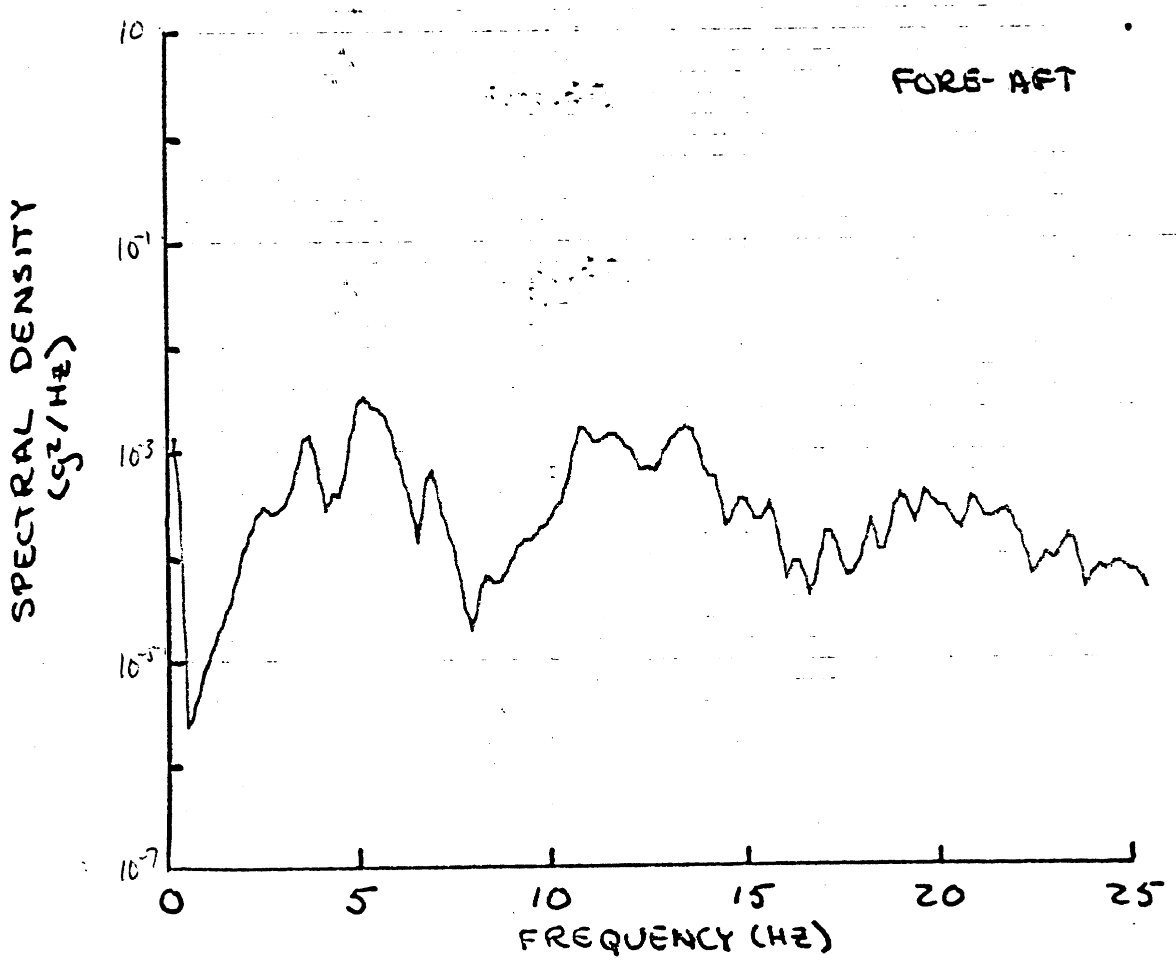
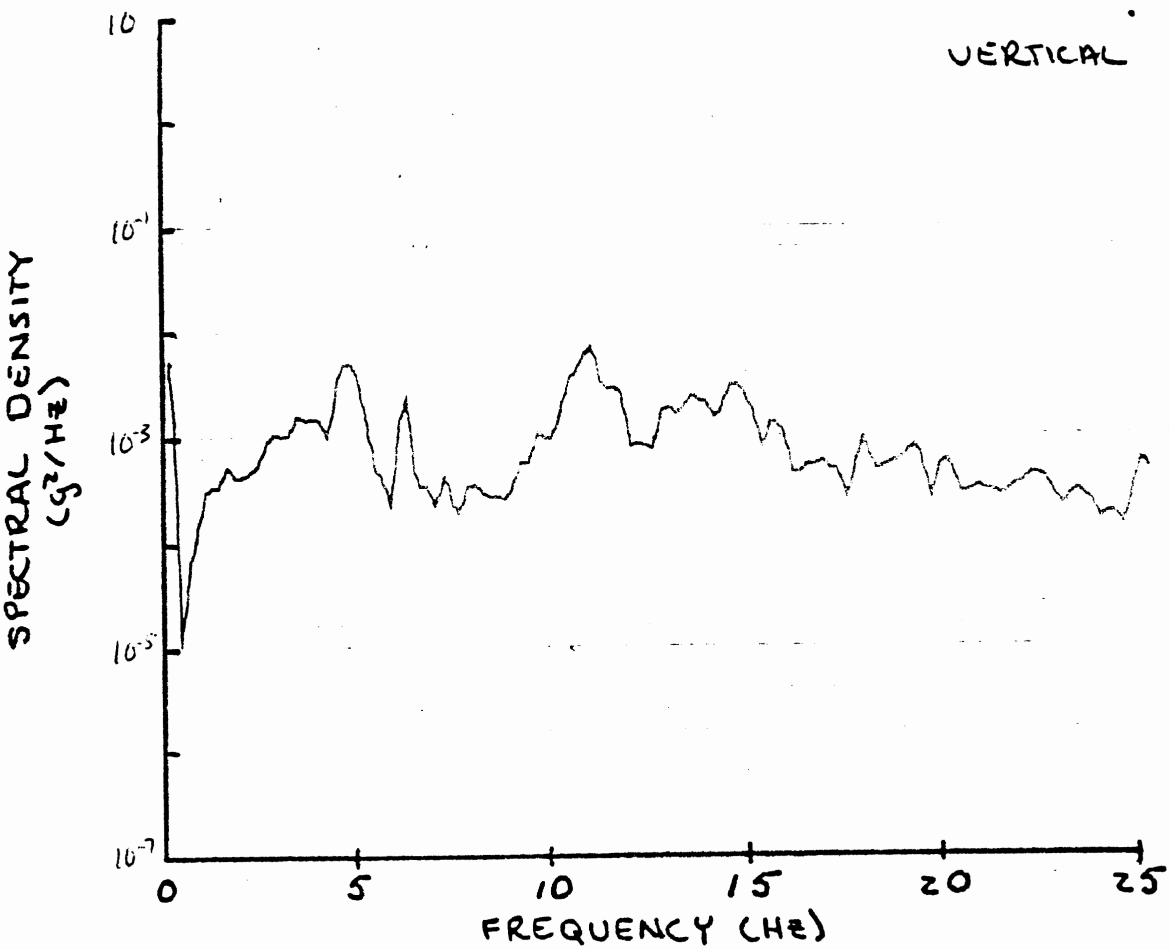


Figure VI.34. PSD's at seat, loaded conventional tractor over site #2 at 55 mph.



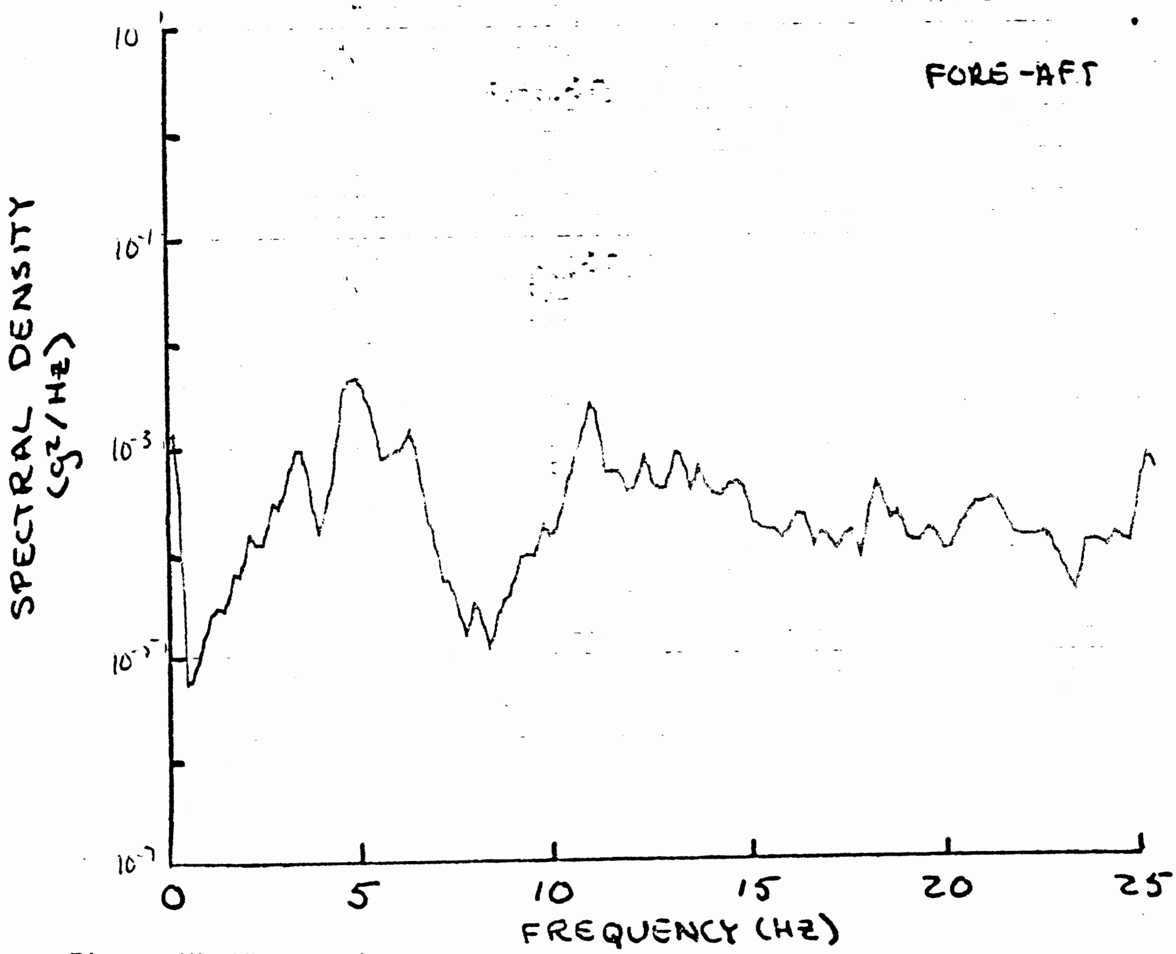
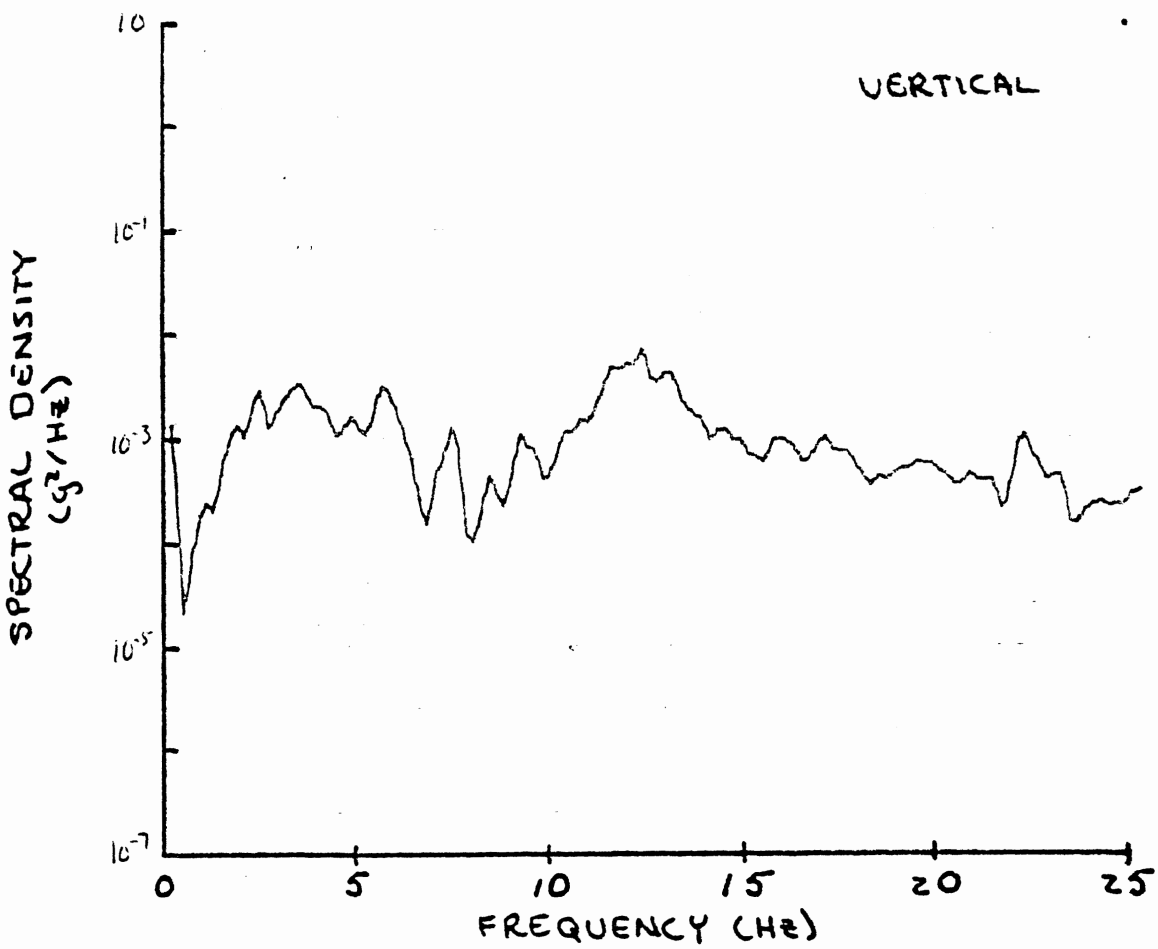


Figure VI.35. PSD's at seat, loaded conventional tractor over site #2 at 45 mph.

On Sites #3 and 4 the situation is similar with bounce, pitch and tire rotational frequencies contributing to seat vertical motions at 55 mph; the bounce mode becoming less significant at 45 mph. Fore/aft vibration is again dominated by the pitch resonances and the tire rotational disturbance (Figures VI.36-39).

The 3.5 Hz pitch mode and the 5 Hz pitch mode coupled with the tire rotational input dominate the vertical seat vibration on Site #5 (Figure VI.40). The coinciding pitch and tire rotational frequency at 5 Hz completely dominates the seat longitudinal vibration.



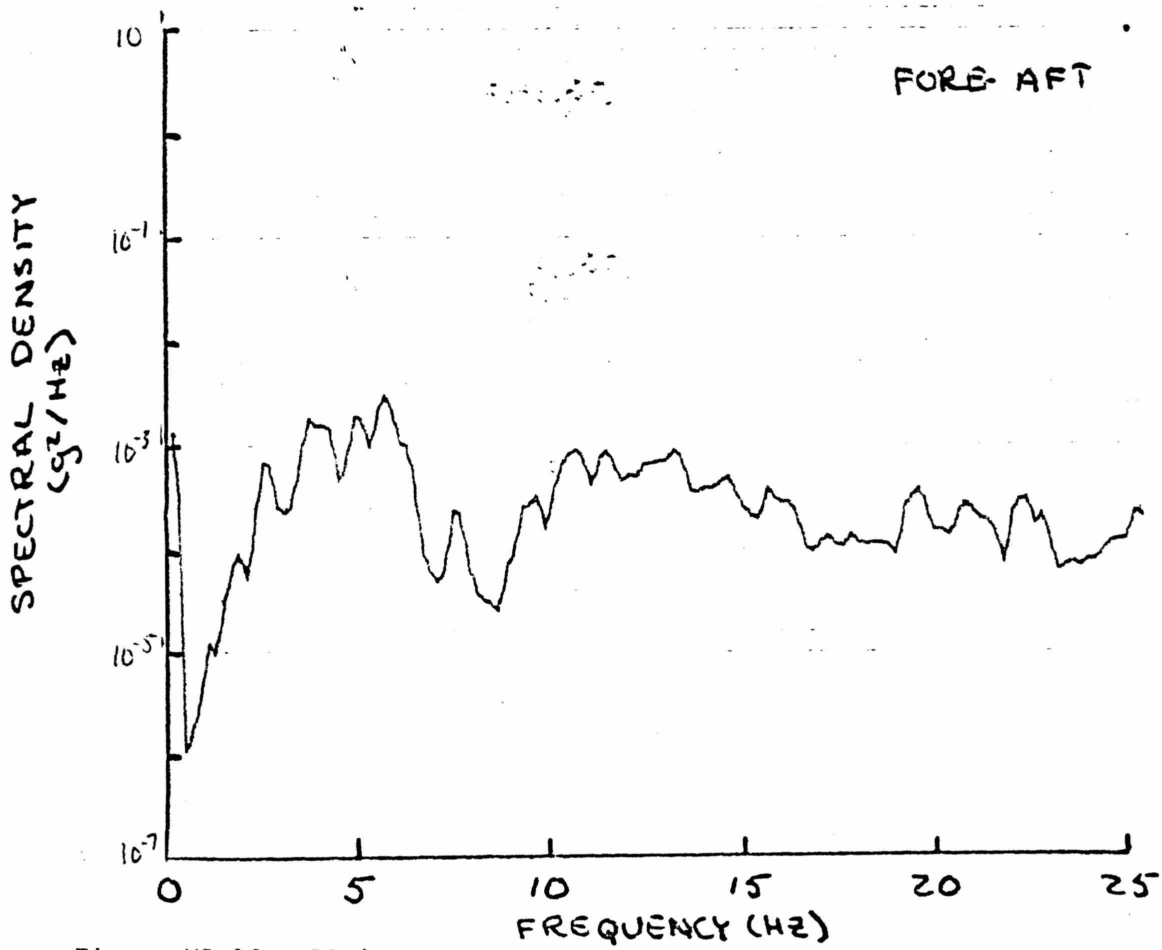
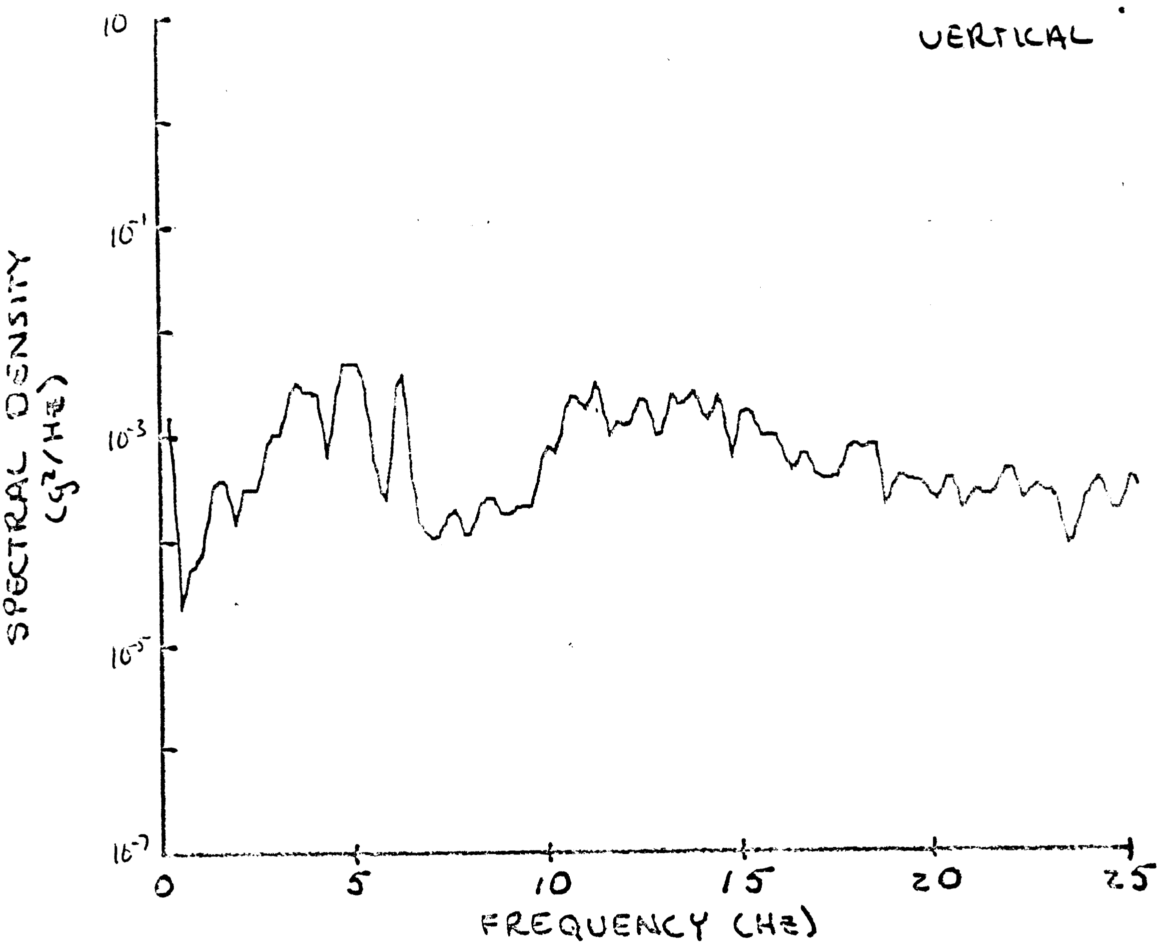


Figure VI.36. PSD's at seat, loaded conventional tractor over site #3 at 55 mph.



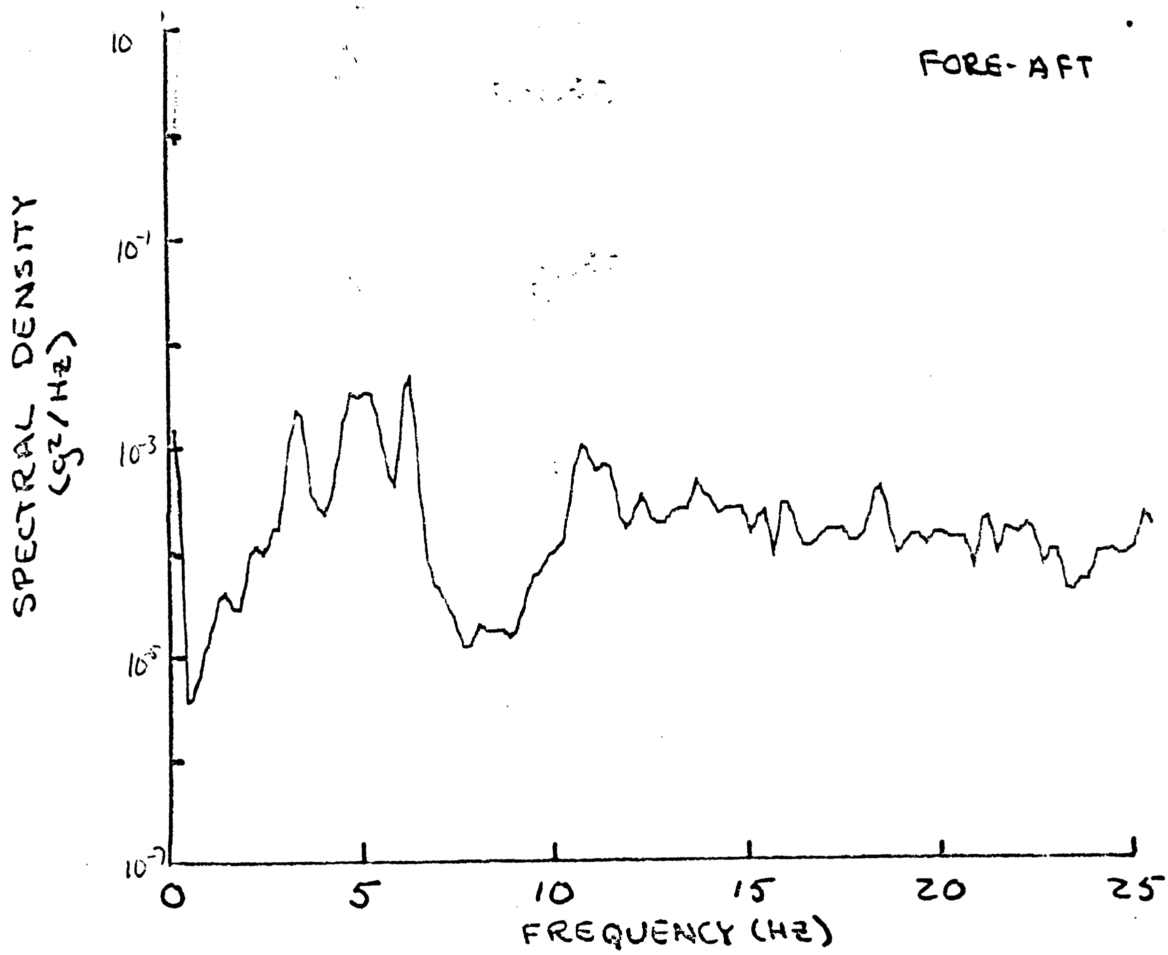
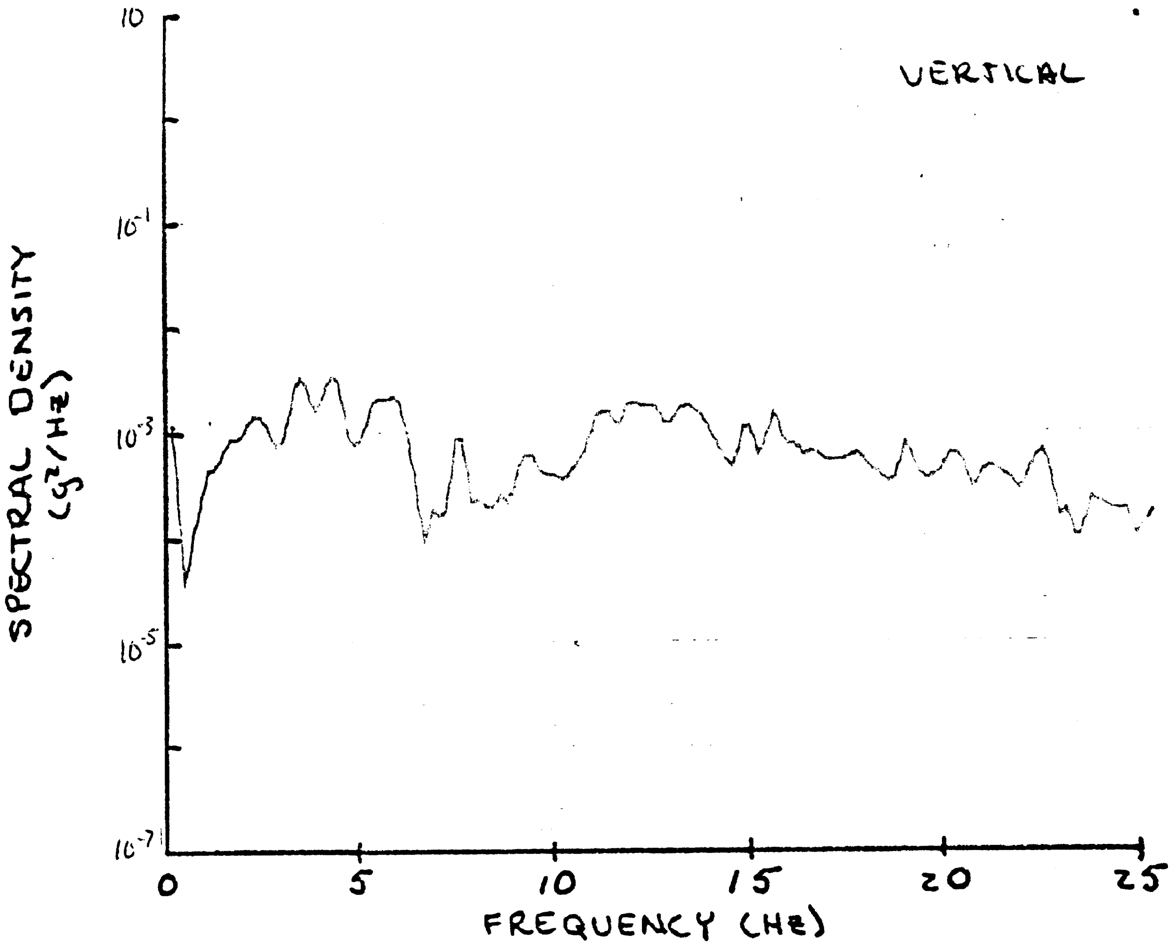


Figure VI.37. PSD's at seat, loaded conventional tractor over site #3 at 45 mph.



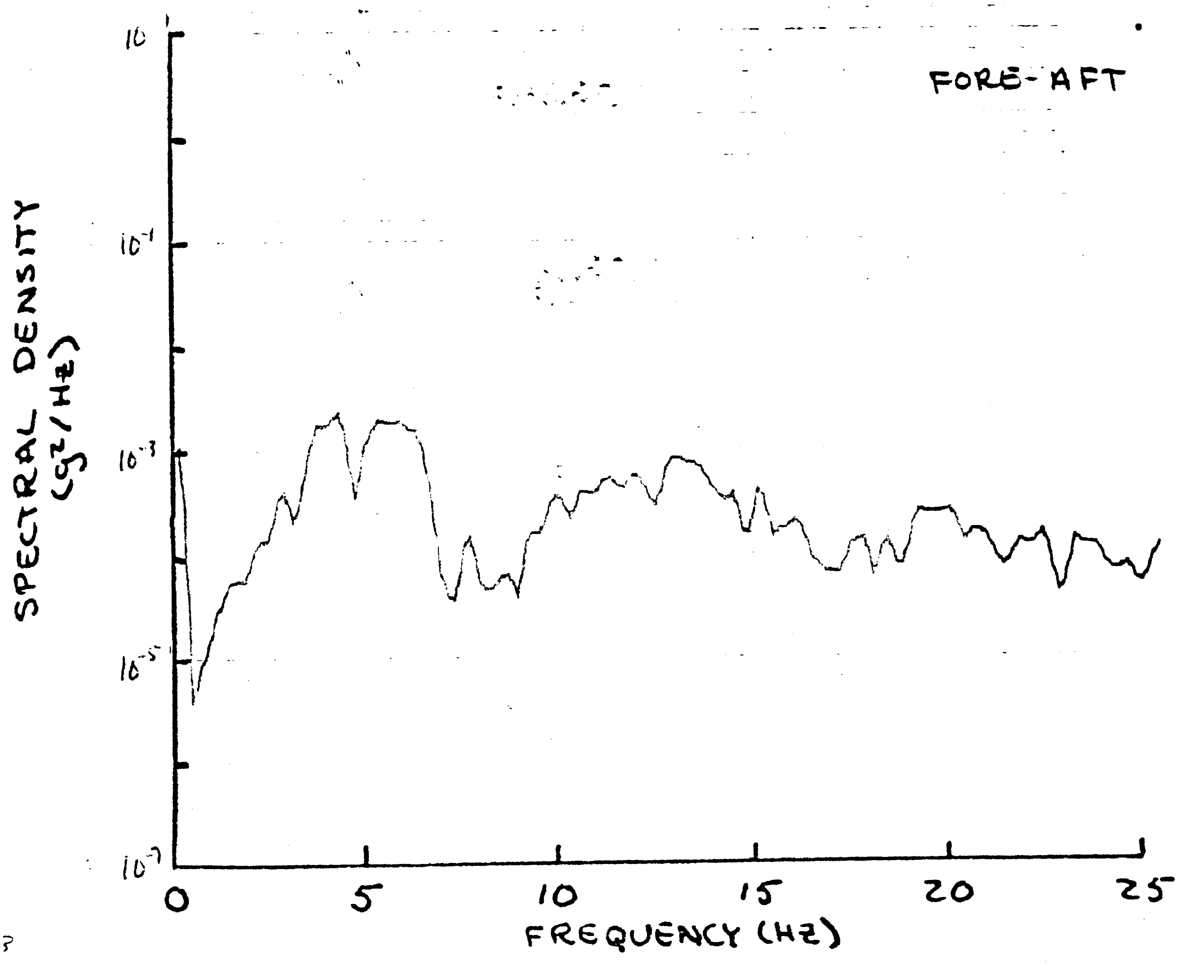


Figure VI.36. PSD's at seat, loaded conventional tractor over site #4 at 55 mph.

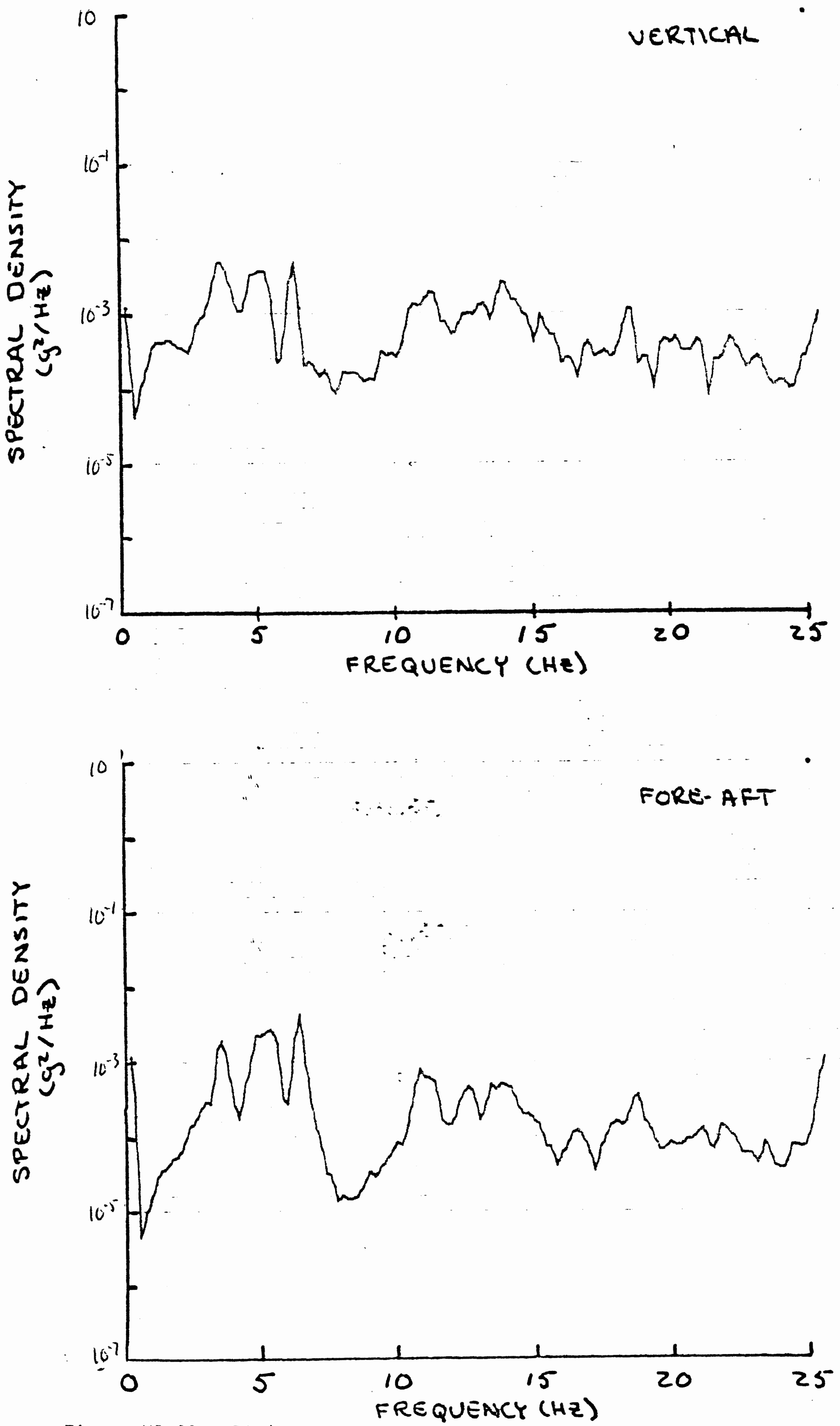
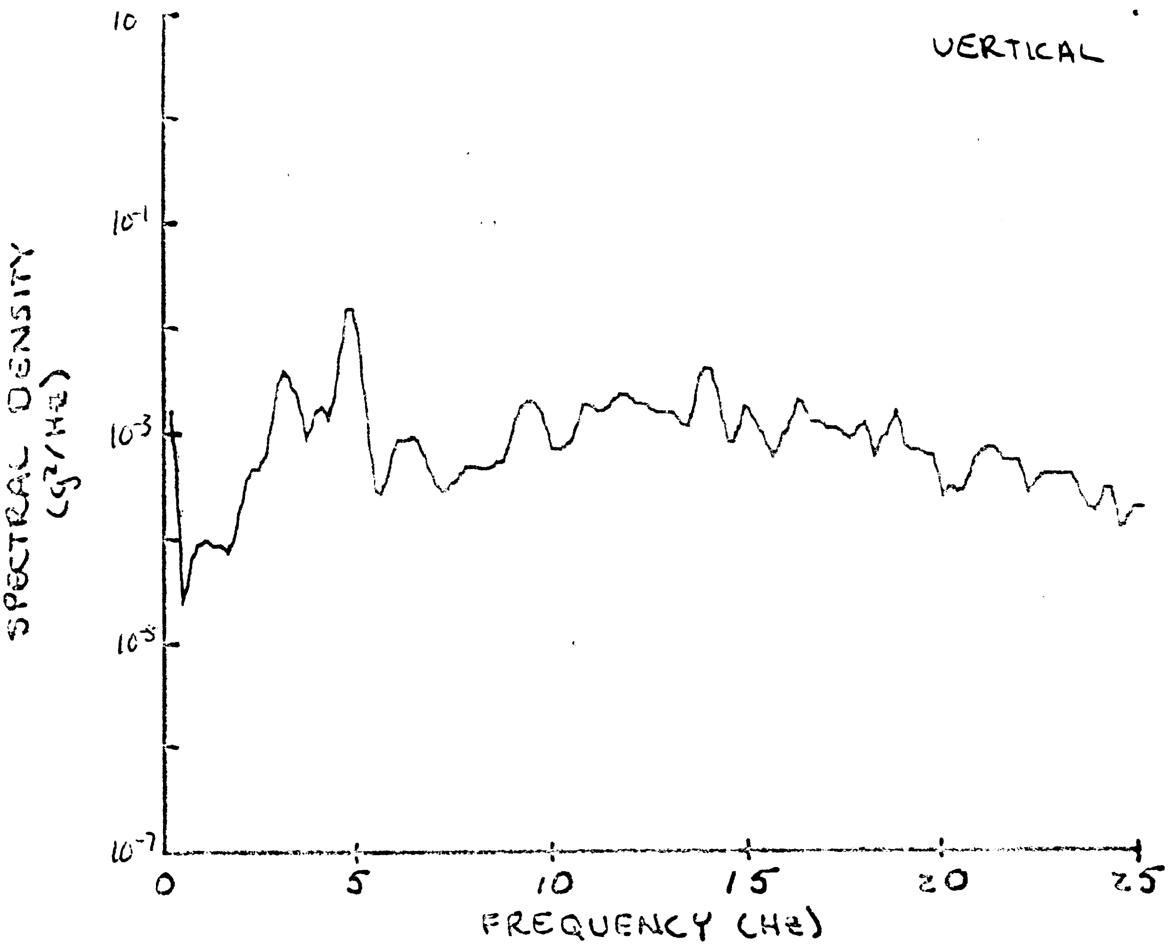


Figure VI.39. PSD's at seat, loaded conventional tractor over site #4 at 45 mph.



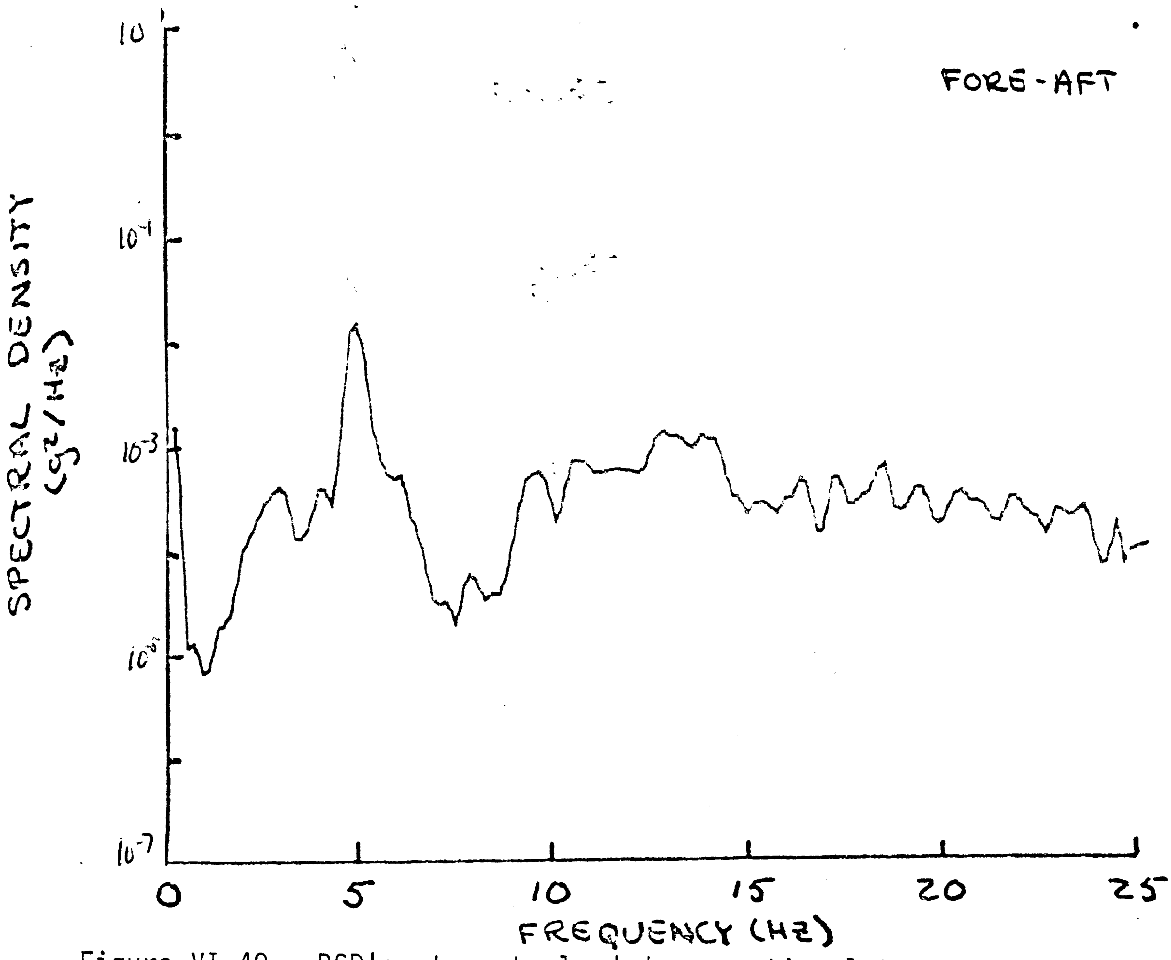
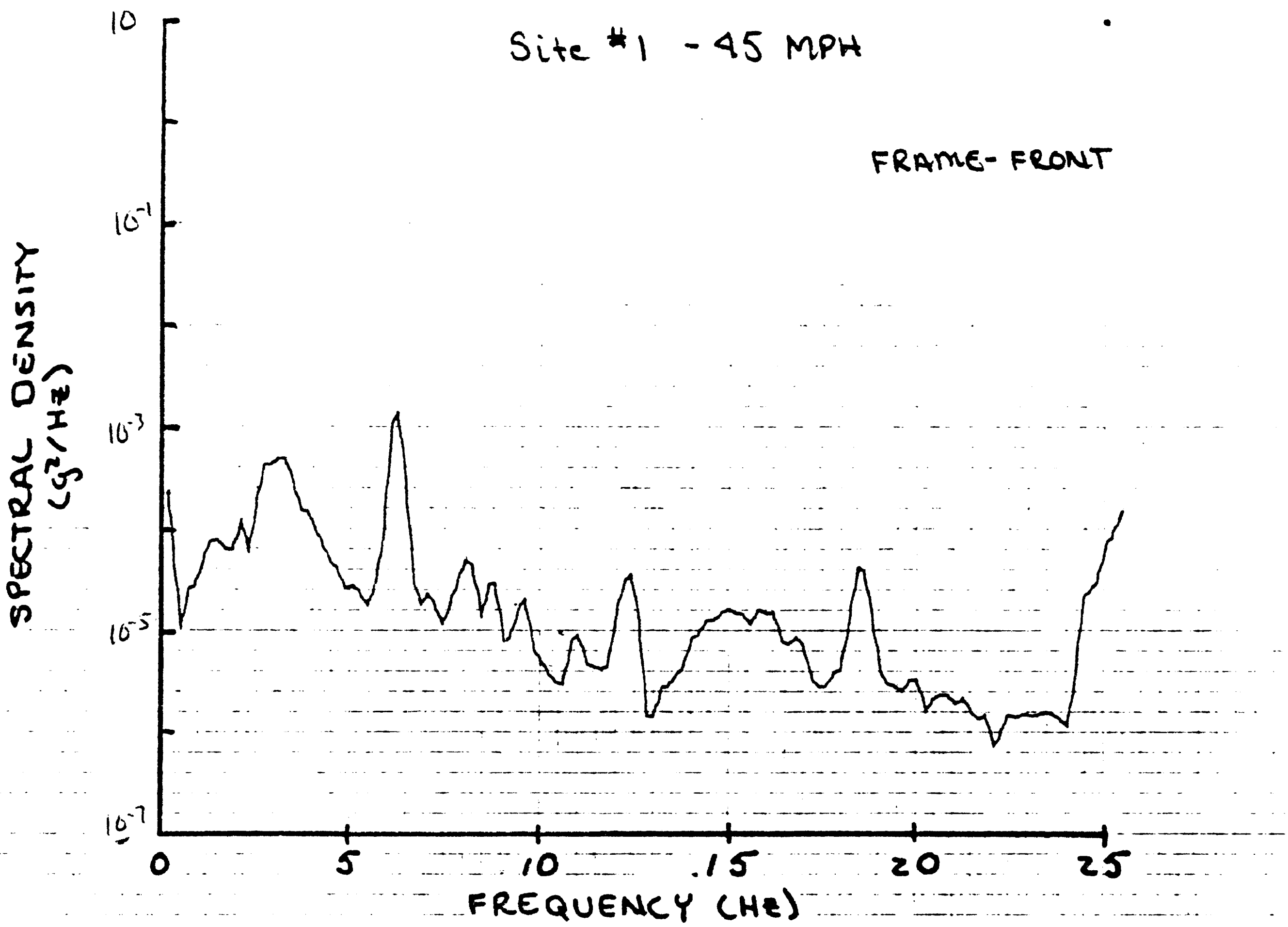


Figure VI.40. PSD's at seat, loaded conventional tractor over site #5 at 35 mph.

VI.2 Additional Ride Response Data

This section contains power spectra information not presented in Section VI.1. All test vehicles and sites are covered. The data are arranged by vehicle configuration, i.e., bobtail COE tractor, loaded COE tractor, bobtail conventional tractor, and loaded conventional tractor. Test sites are numbered according to the site designations presented at the beginning of Appendix VI.



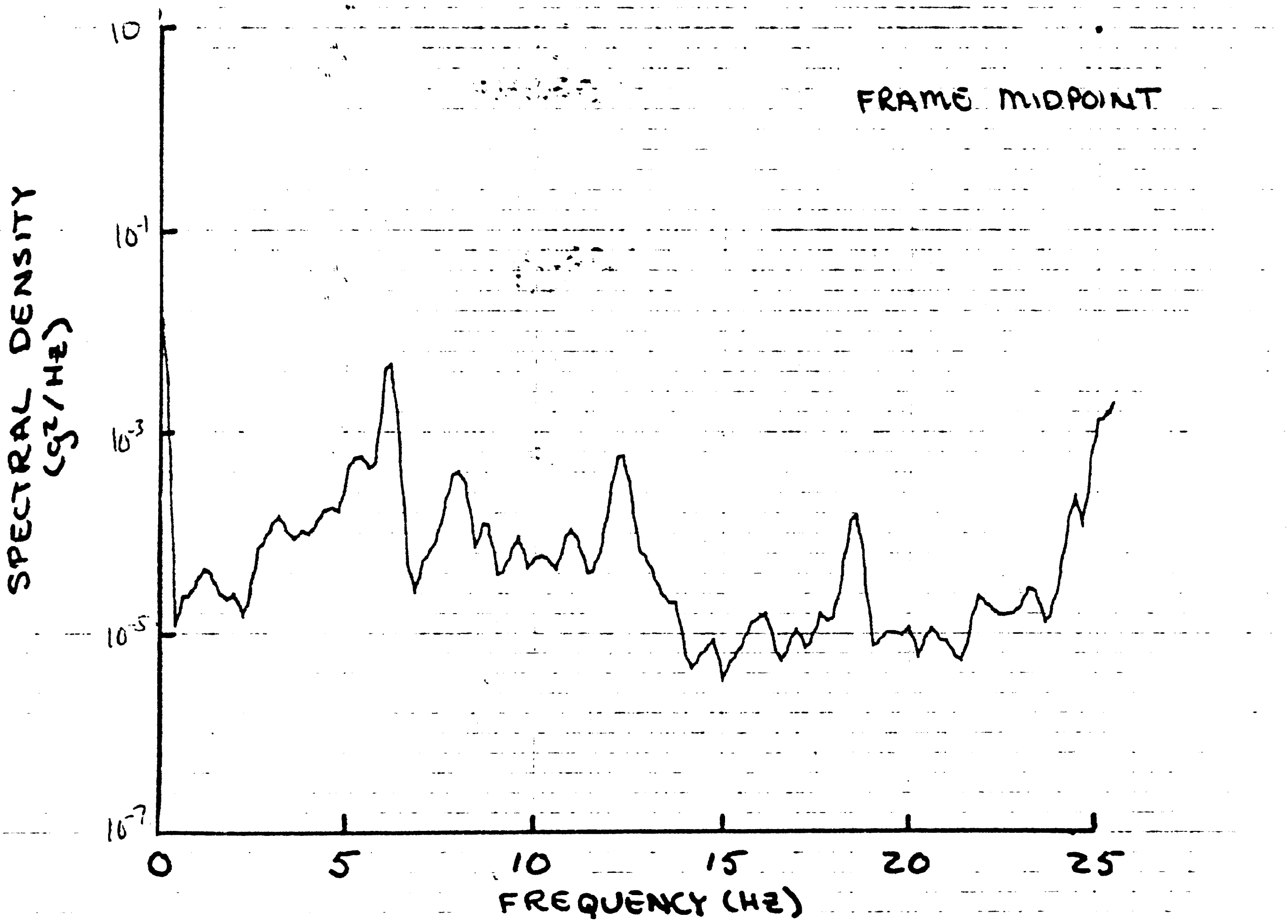
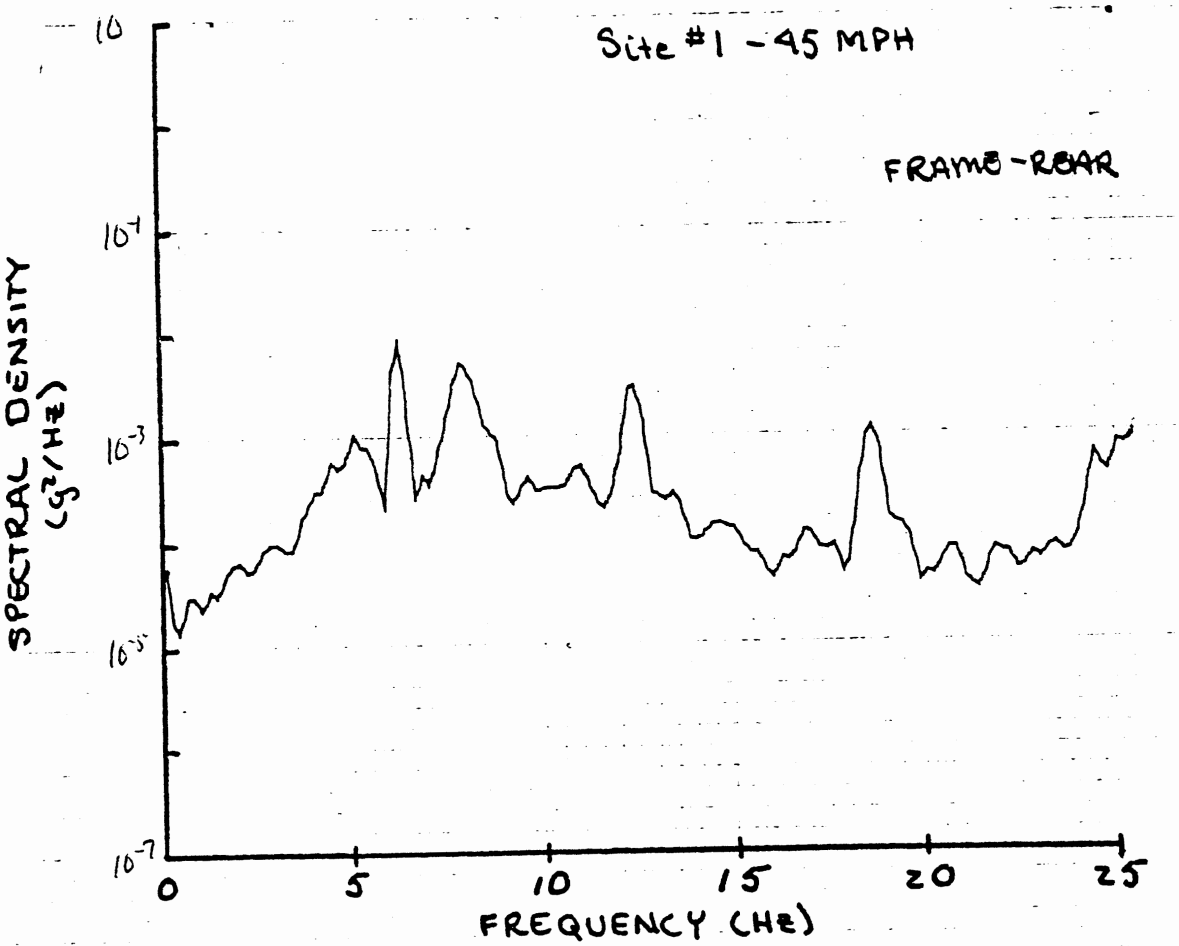
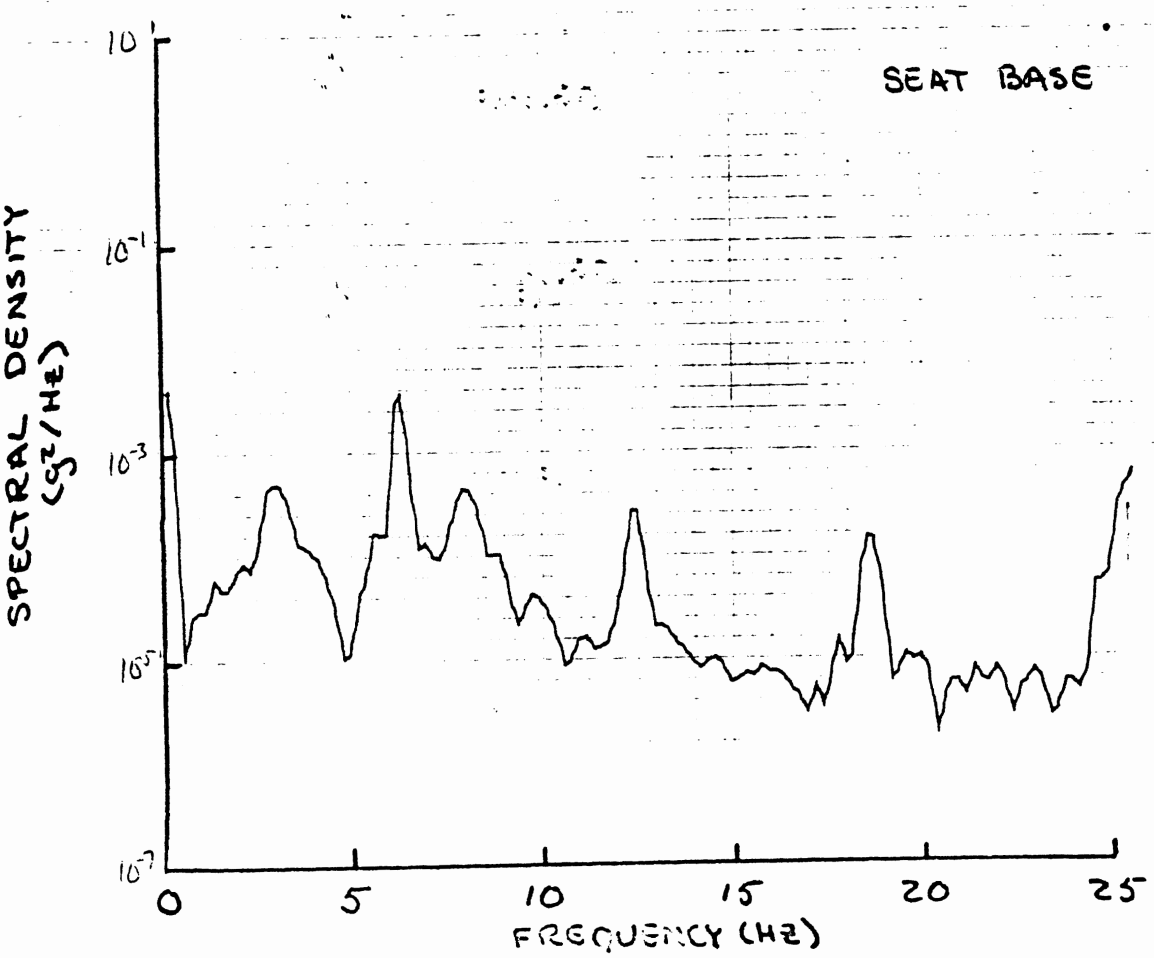


Figure VI.2.1. Bobtail cab-over-engine tractor.





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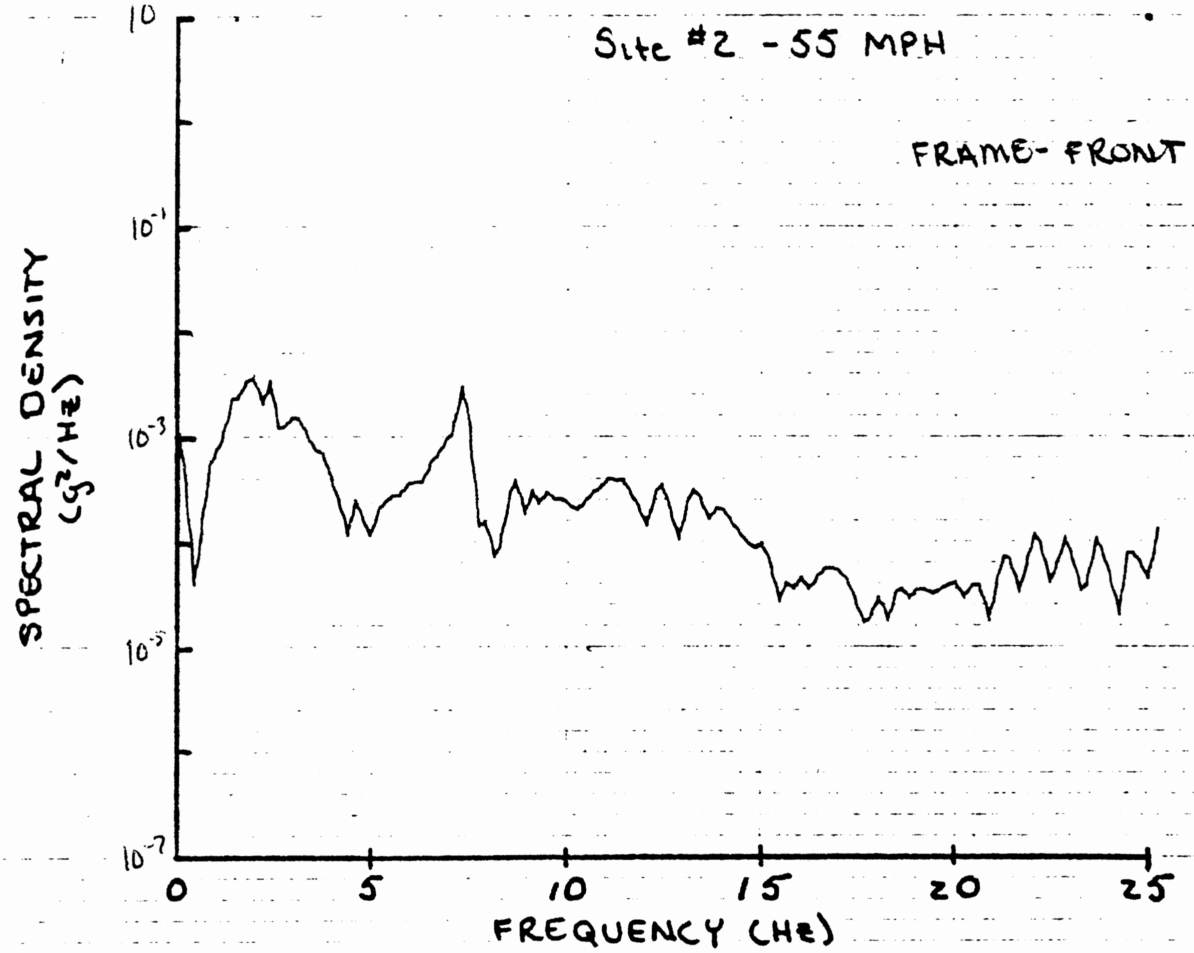

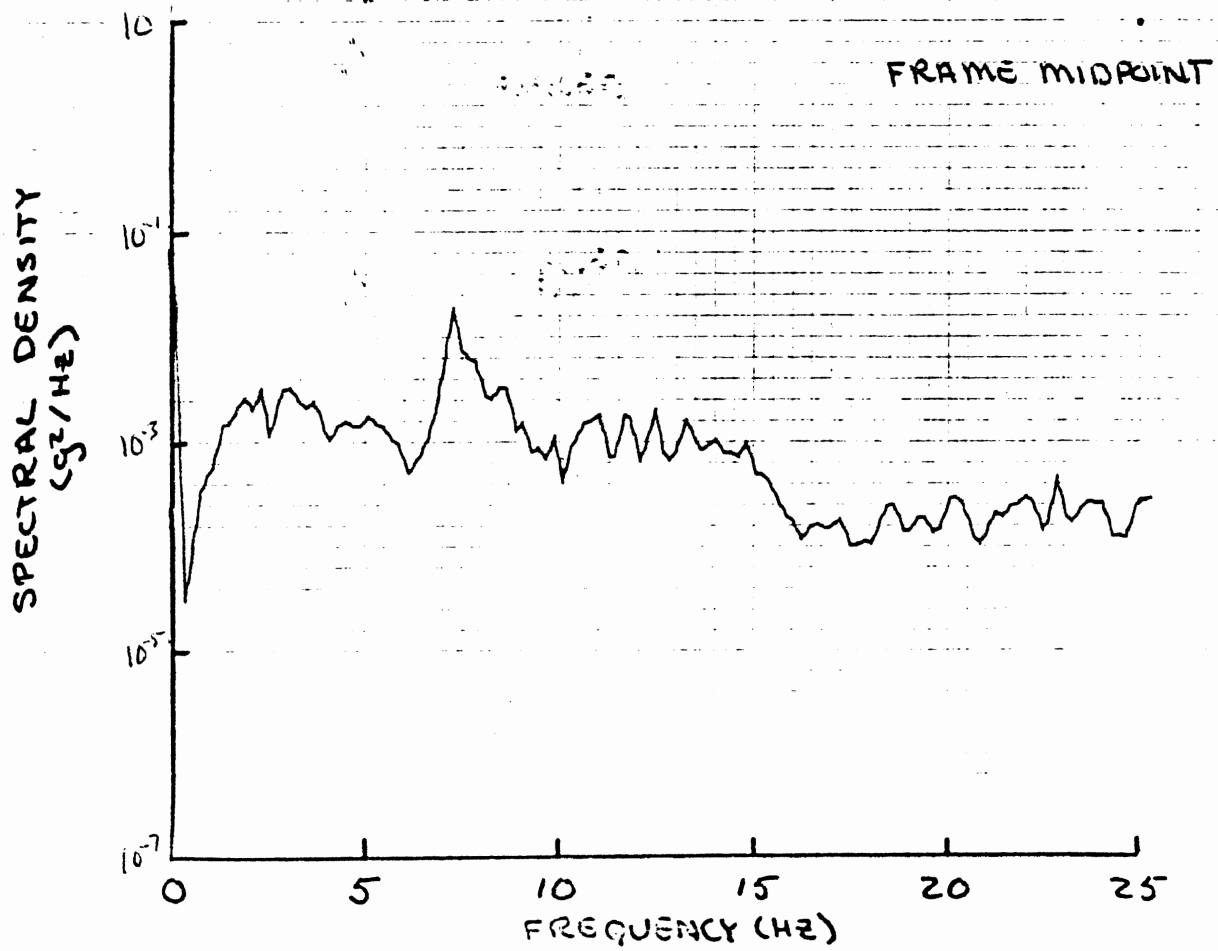

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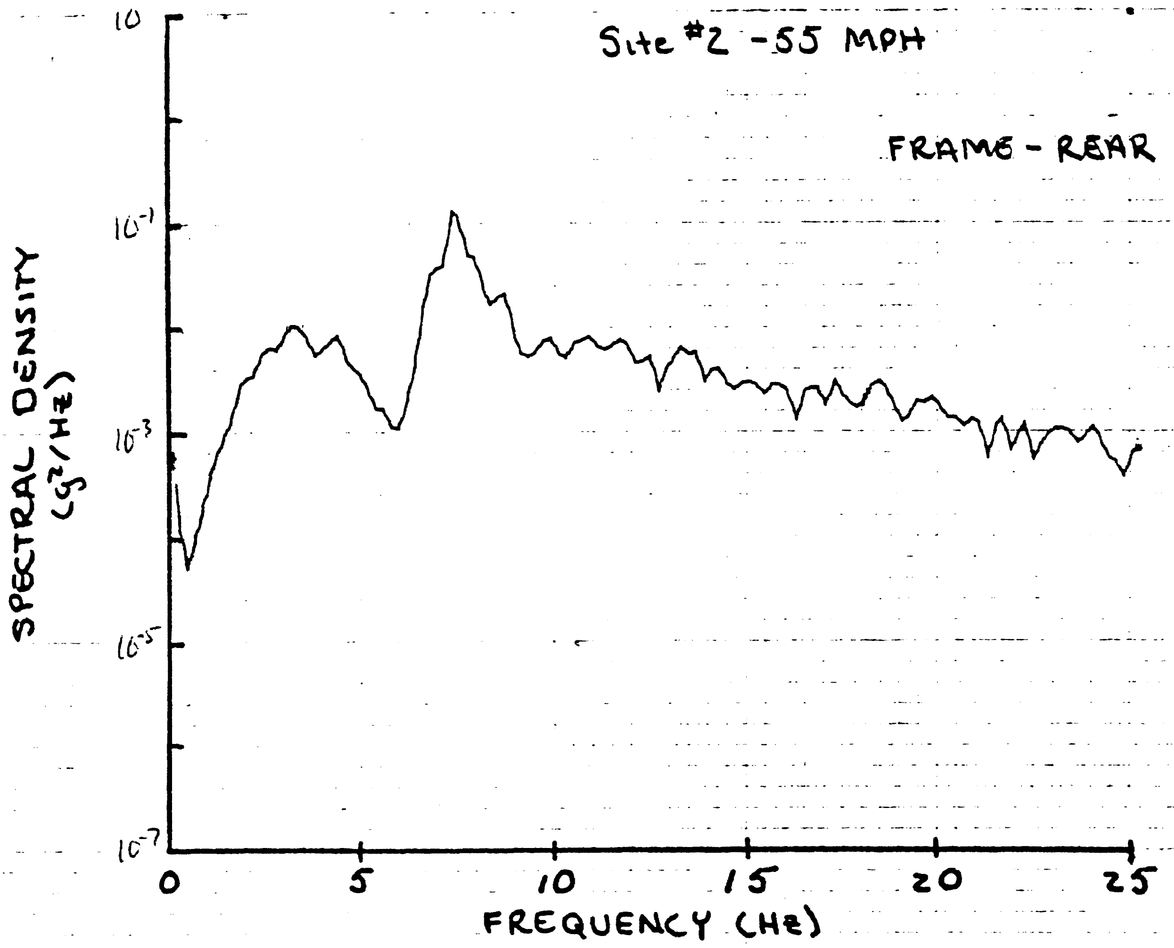

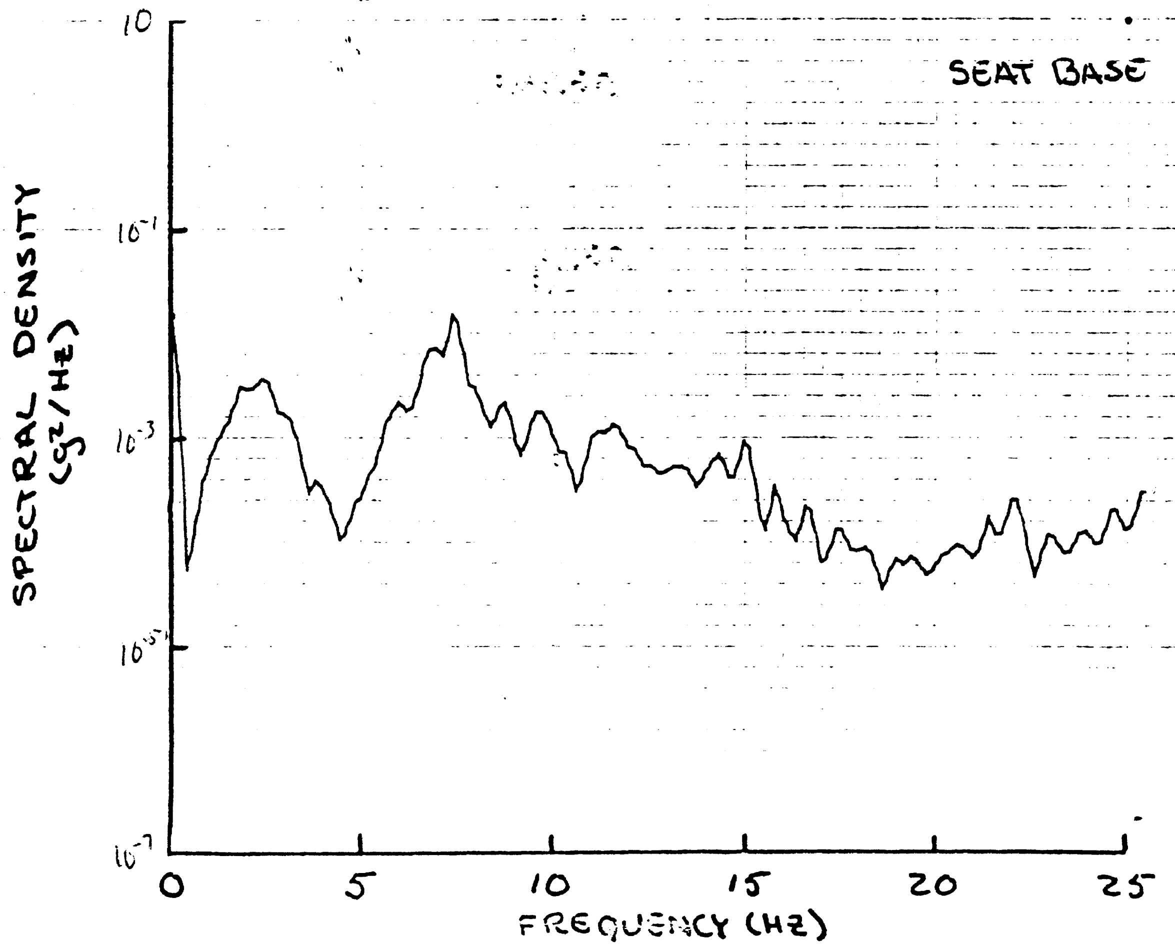

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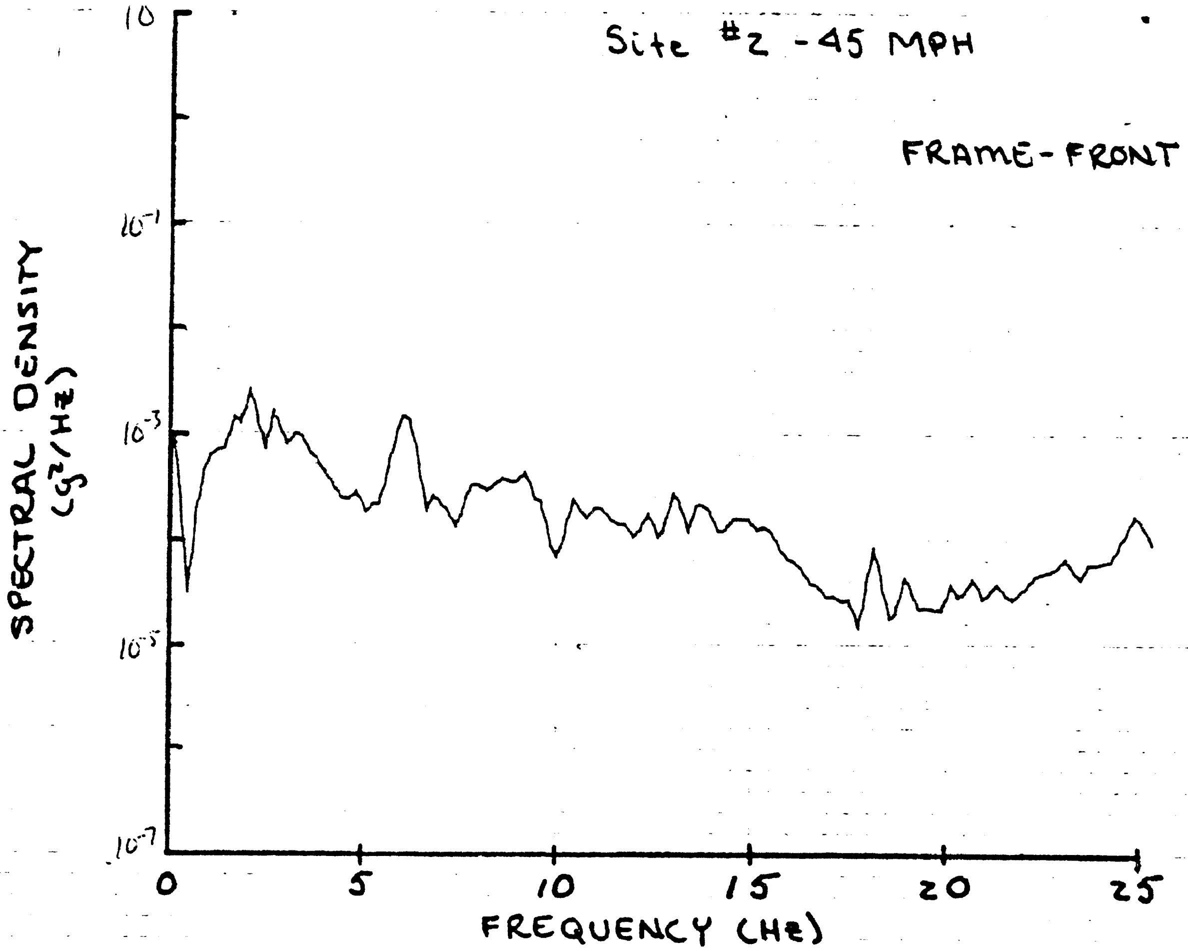

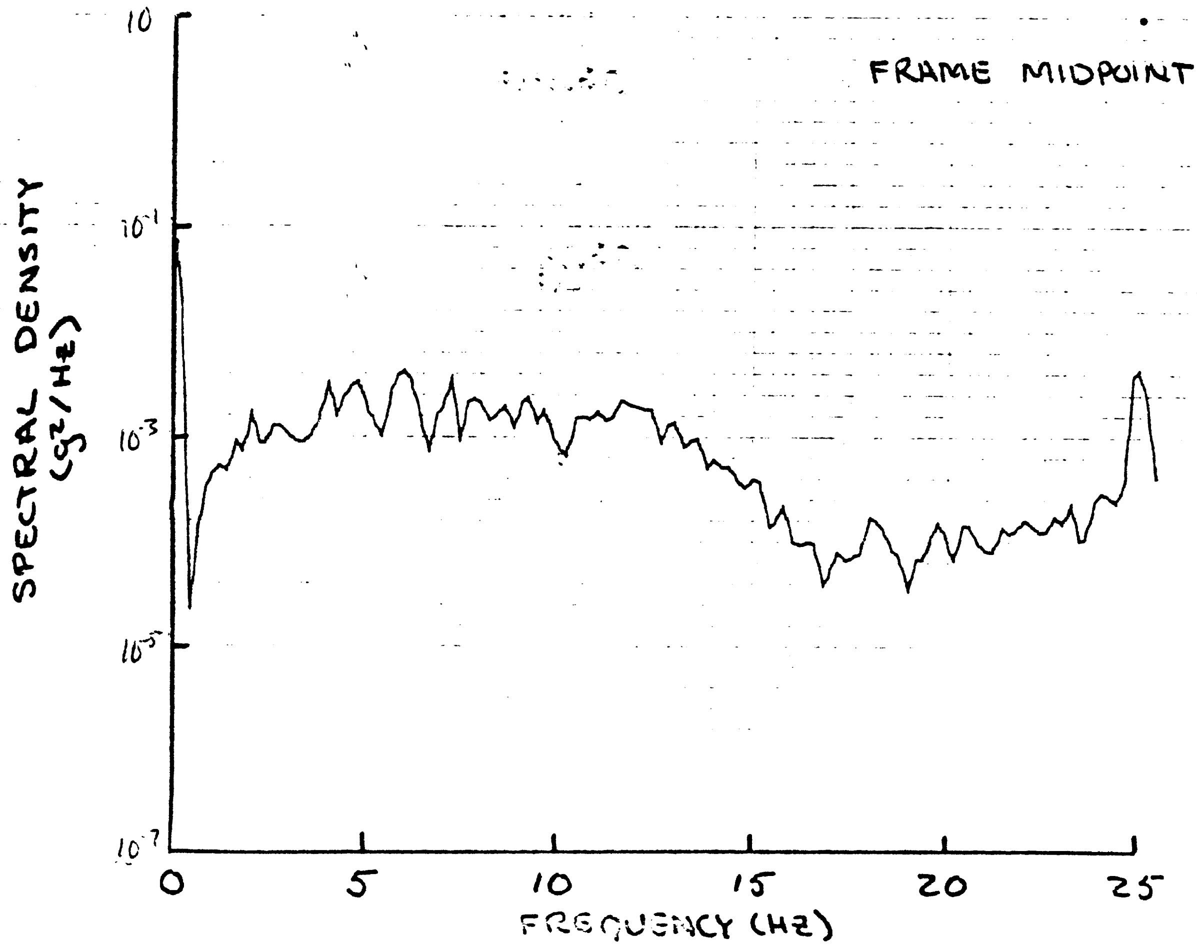

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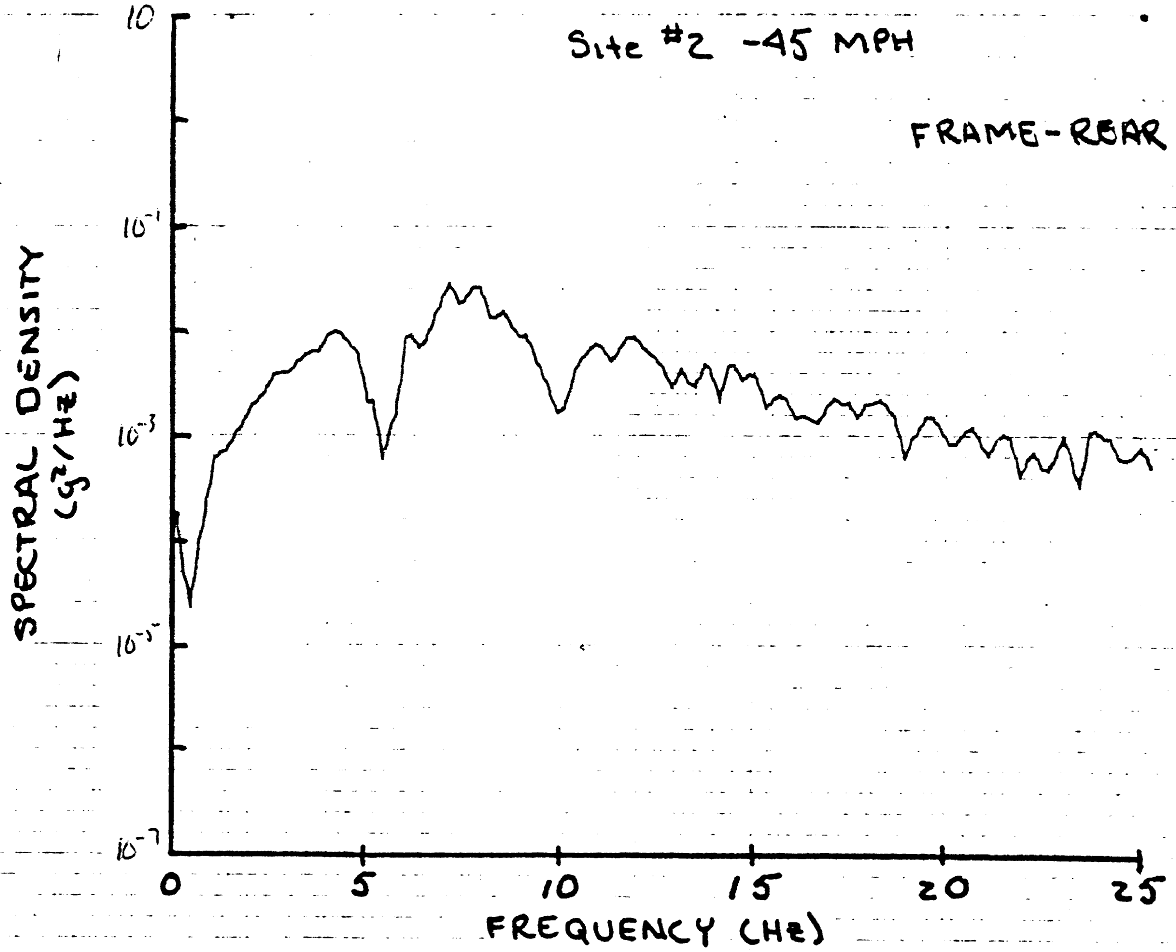

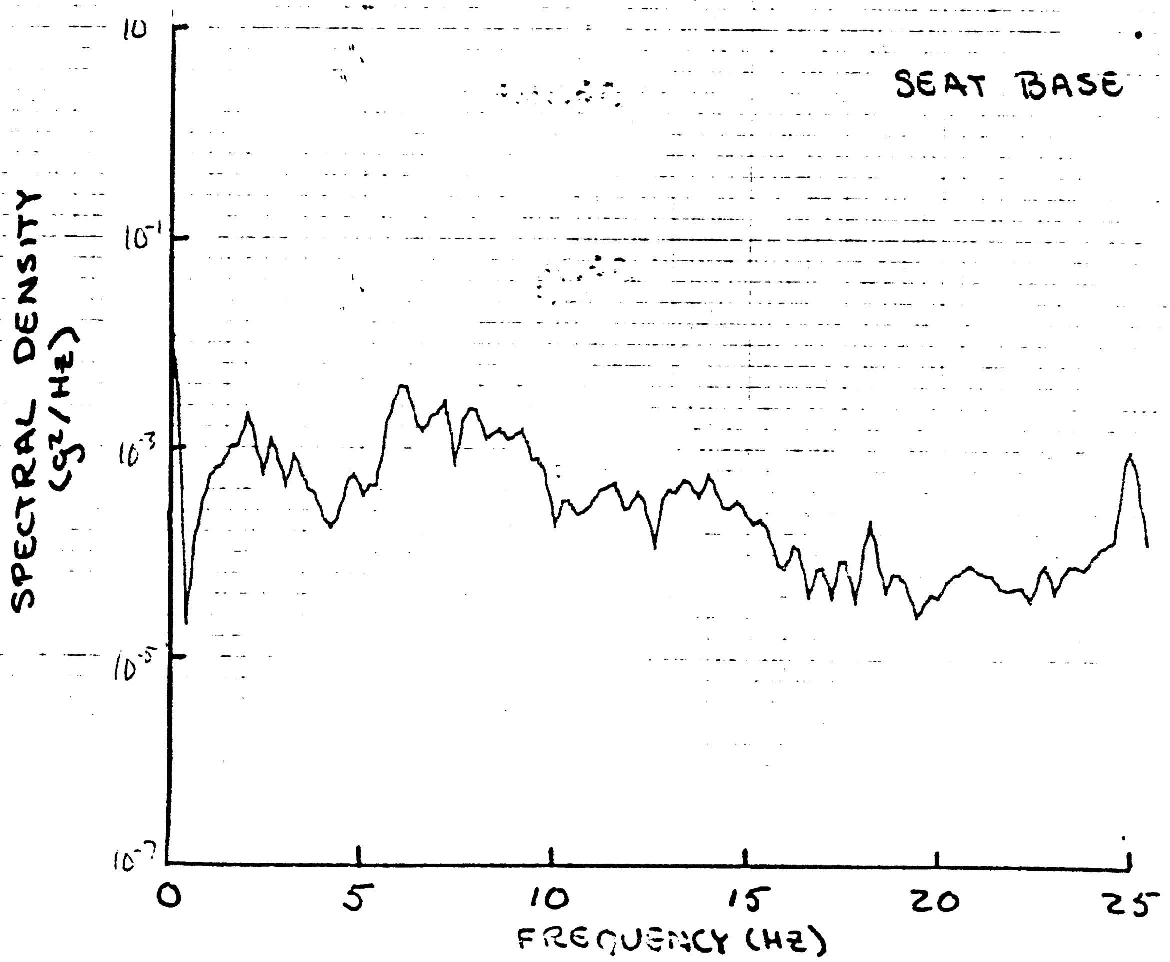

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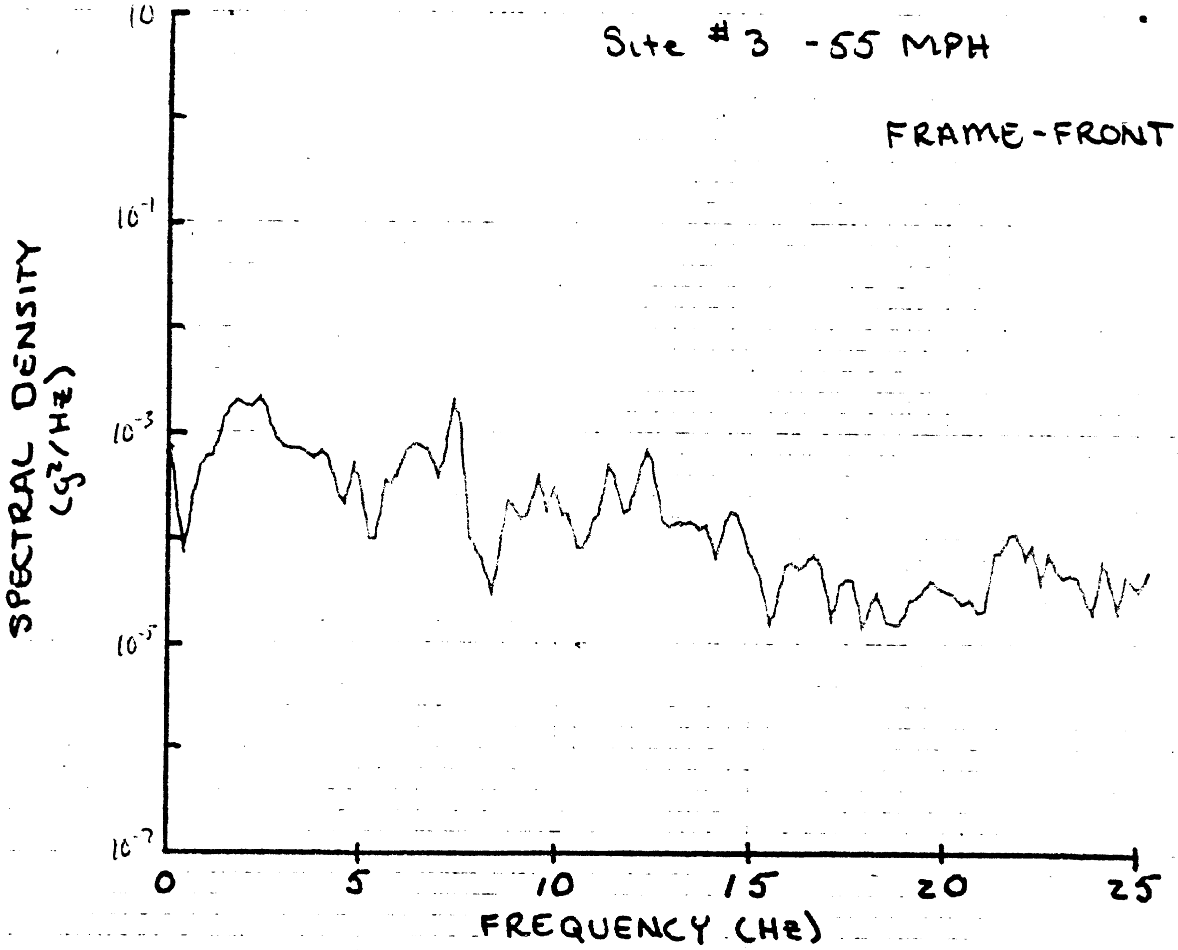

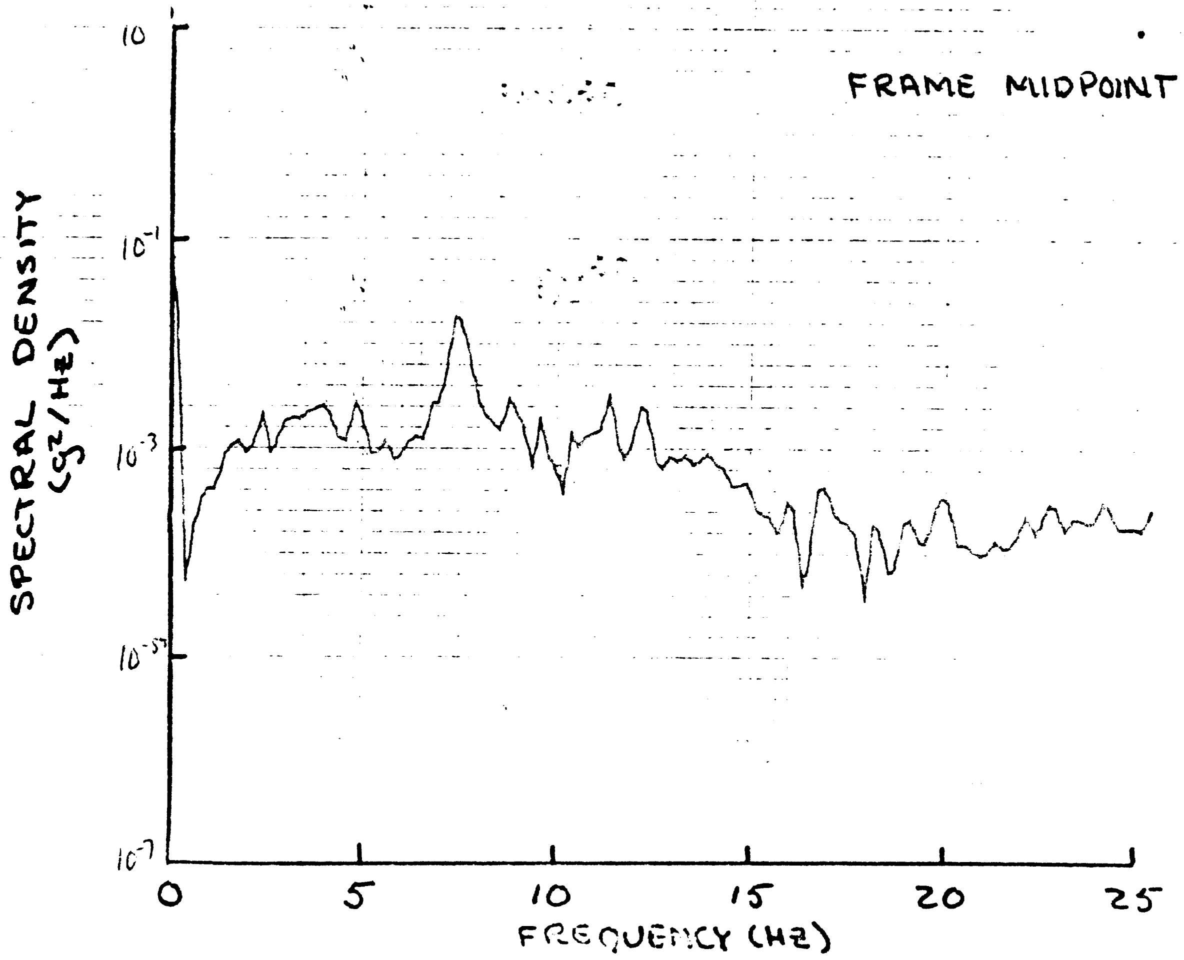

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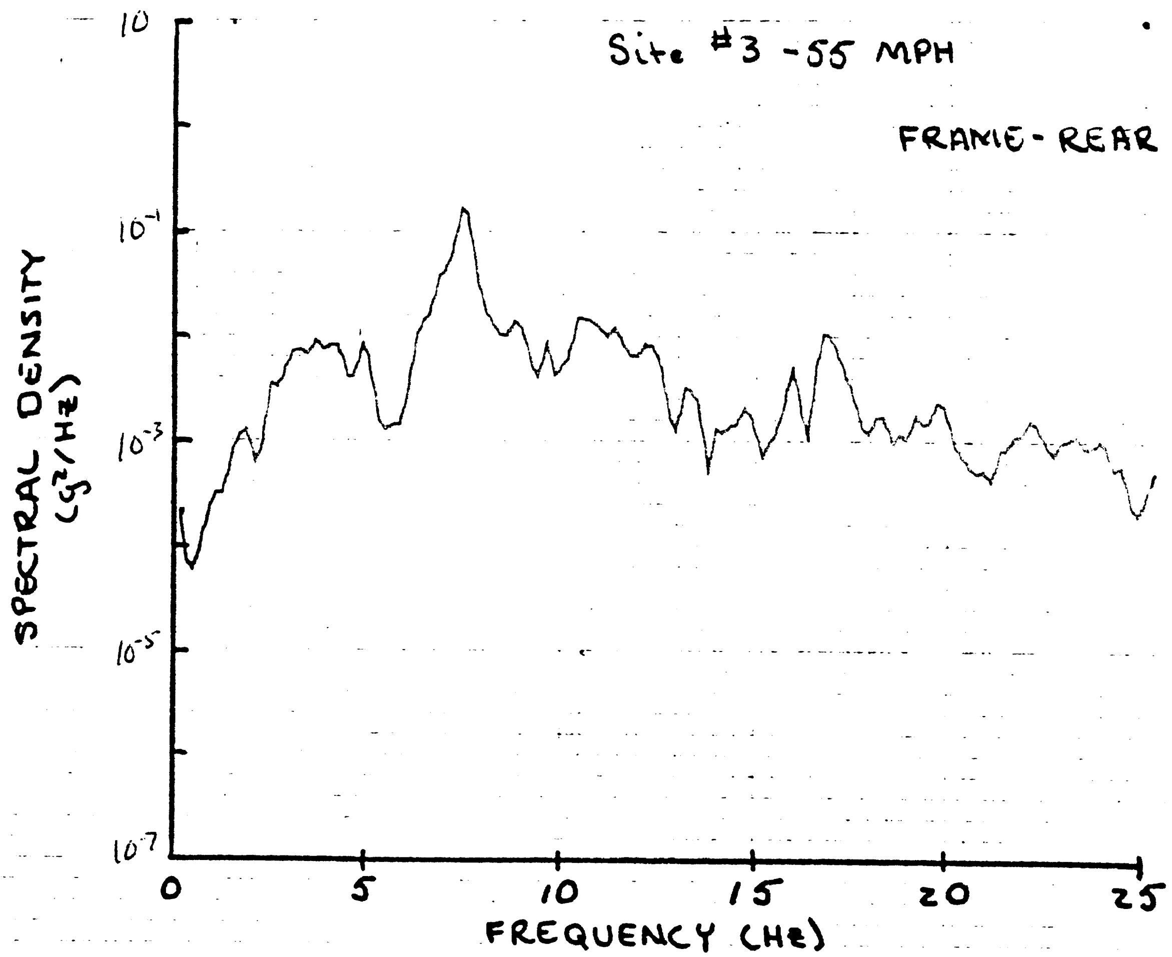

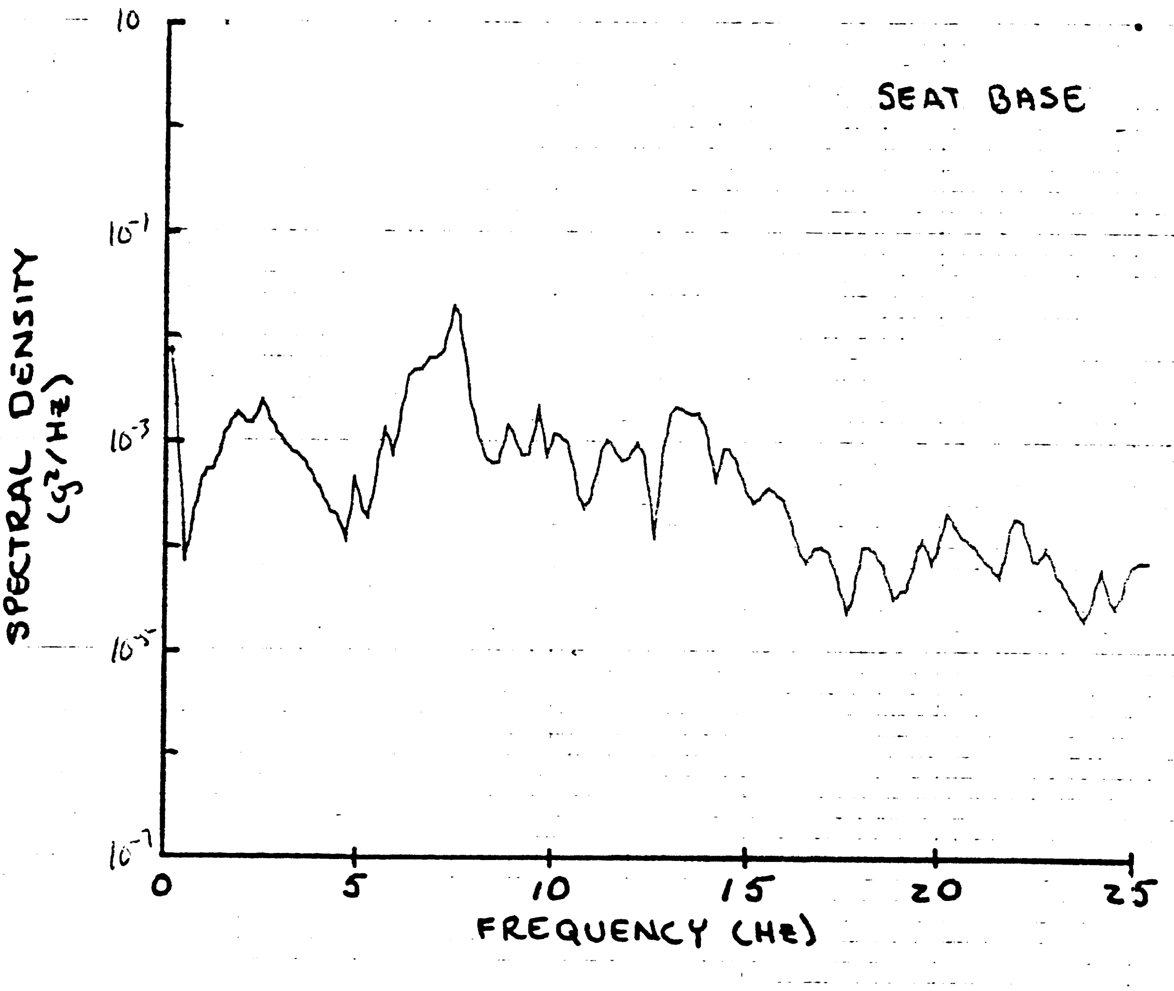

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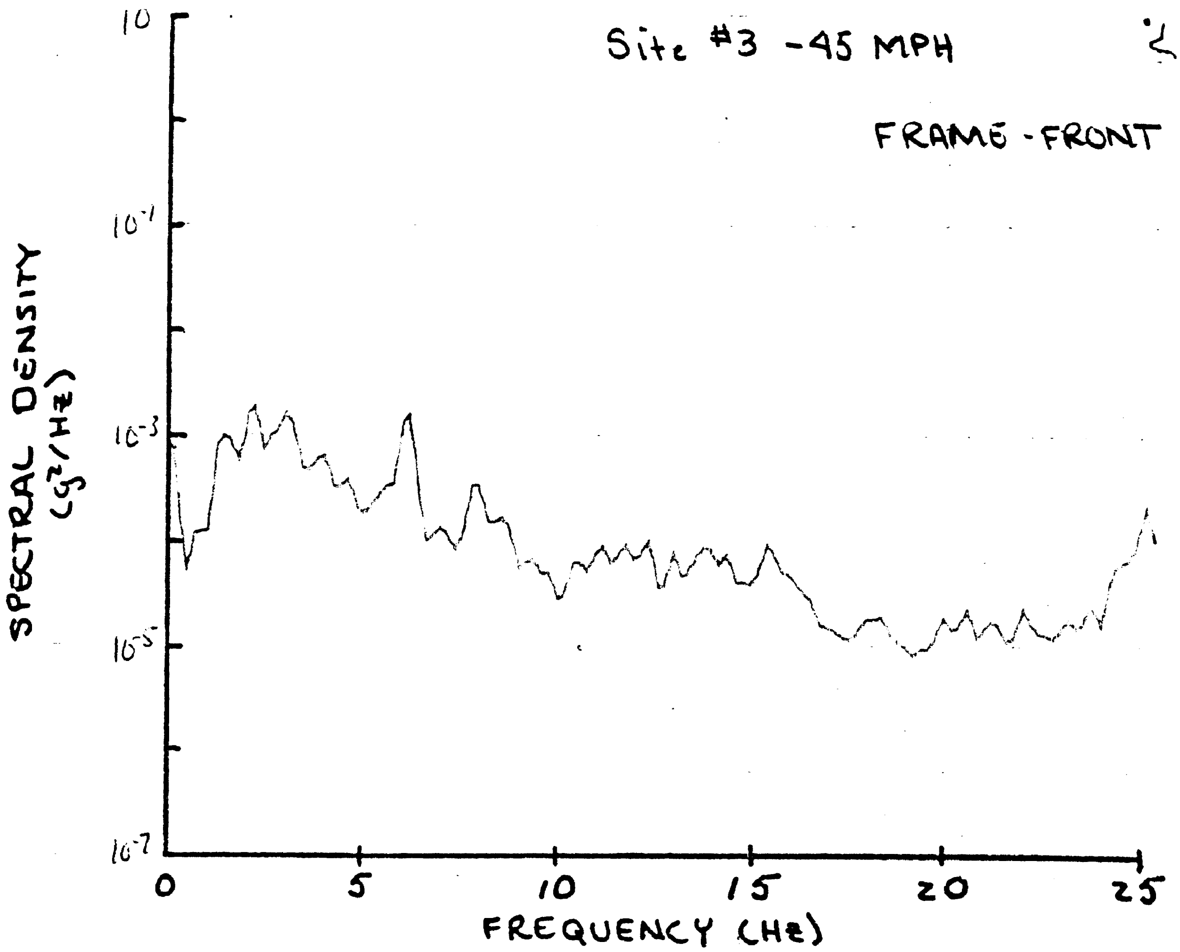

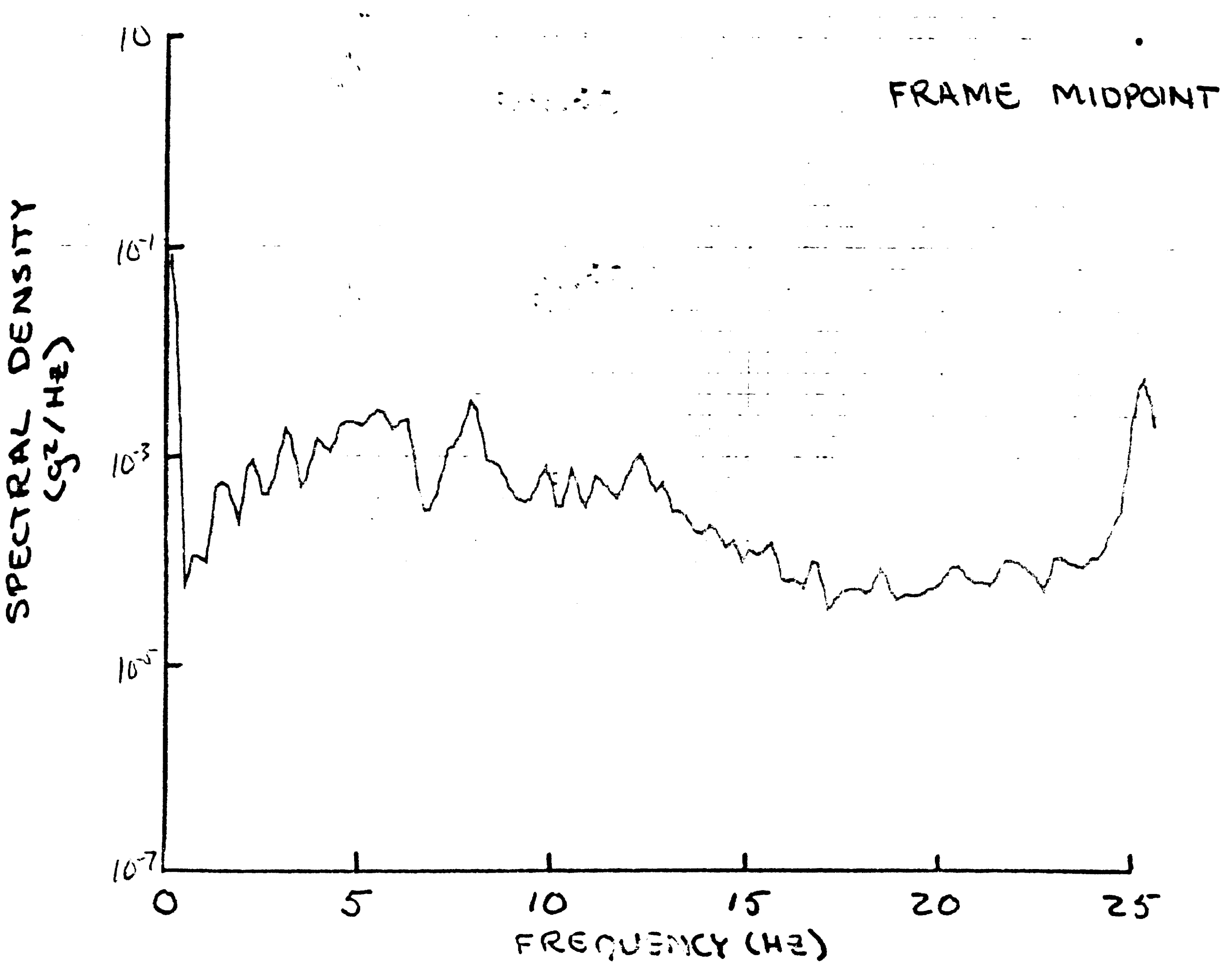

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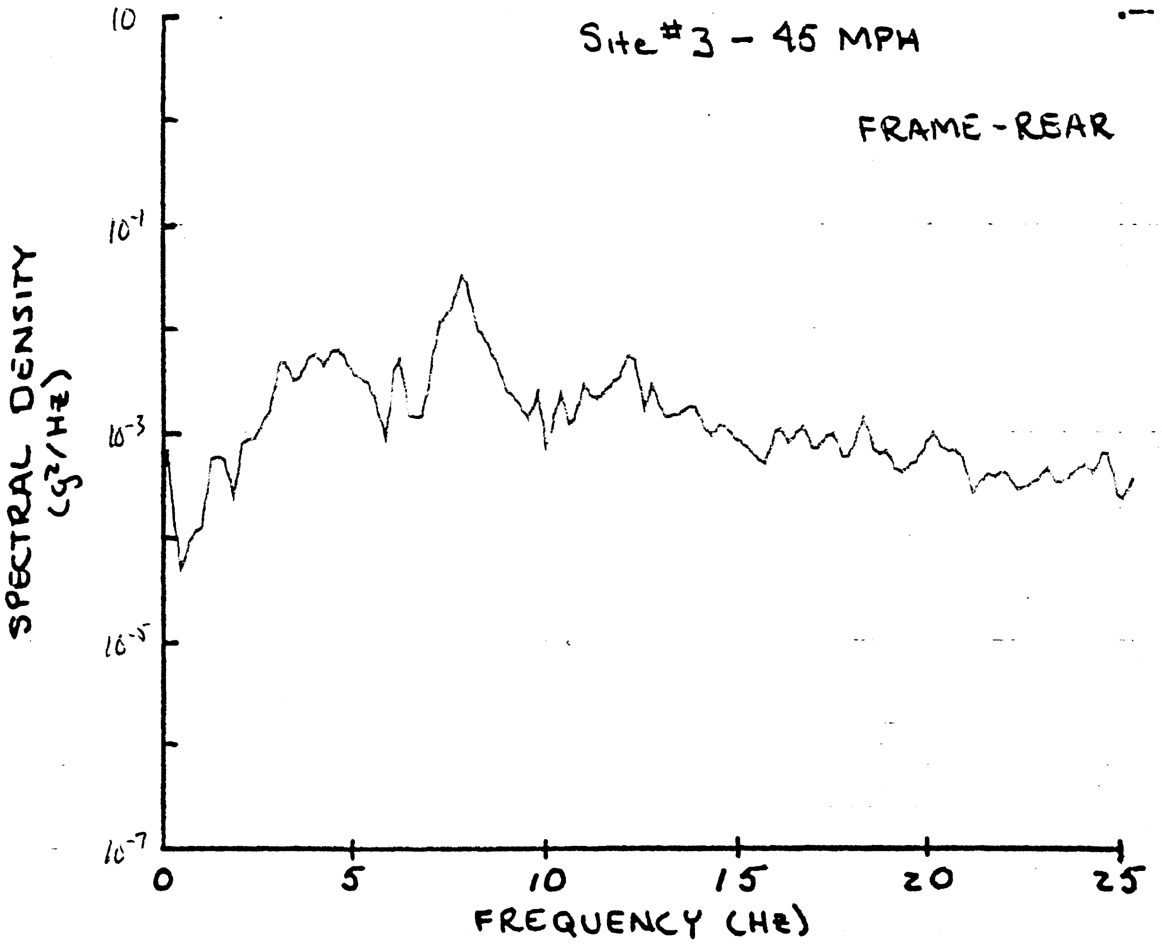

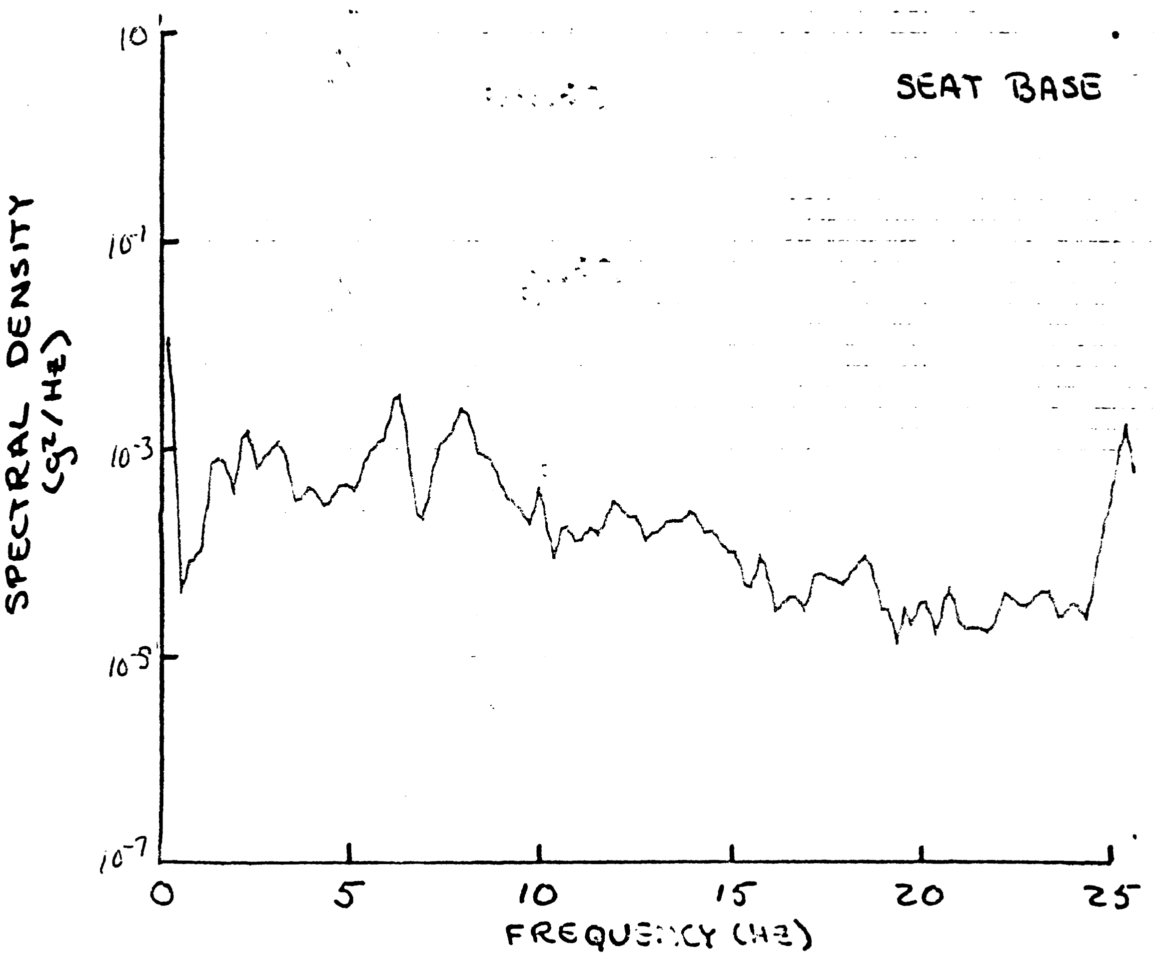

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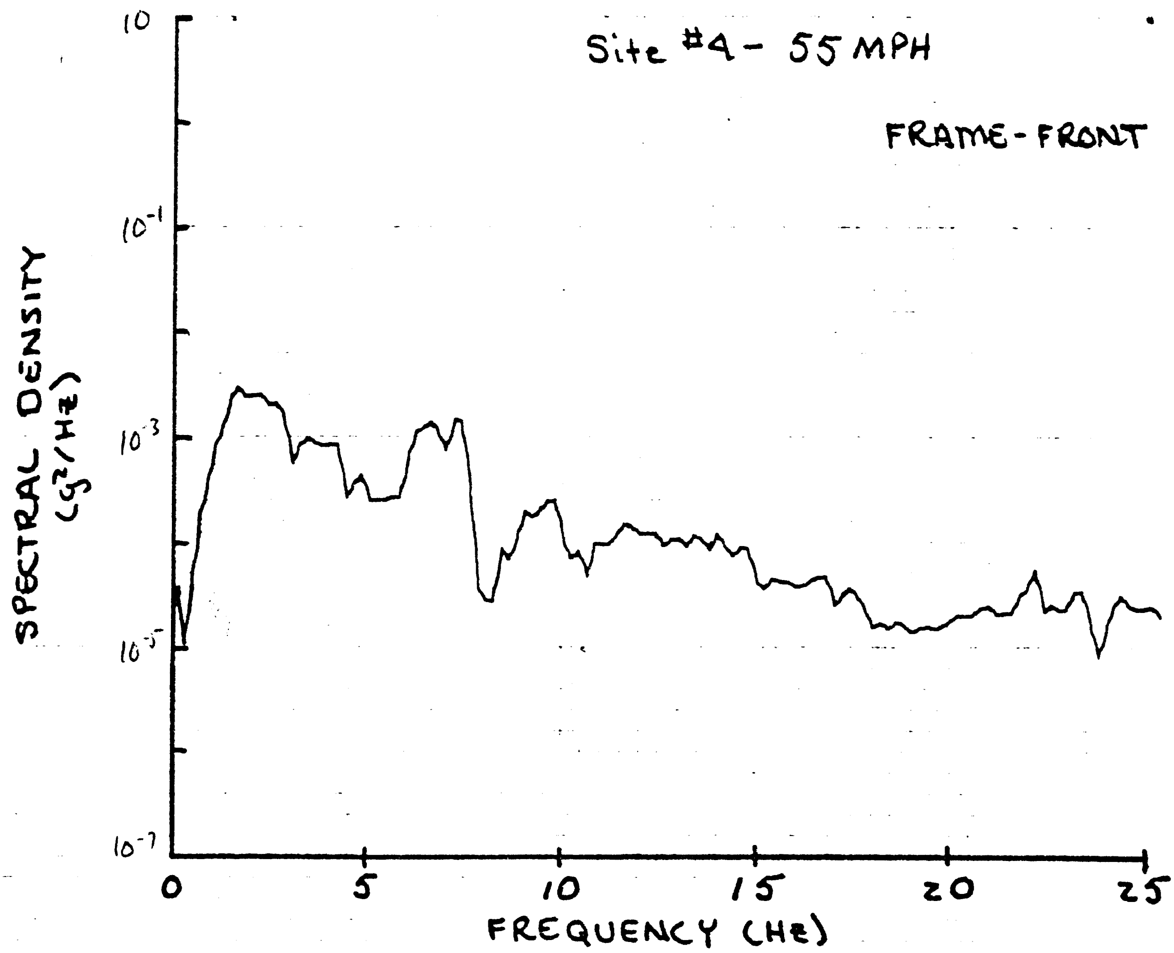

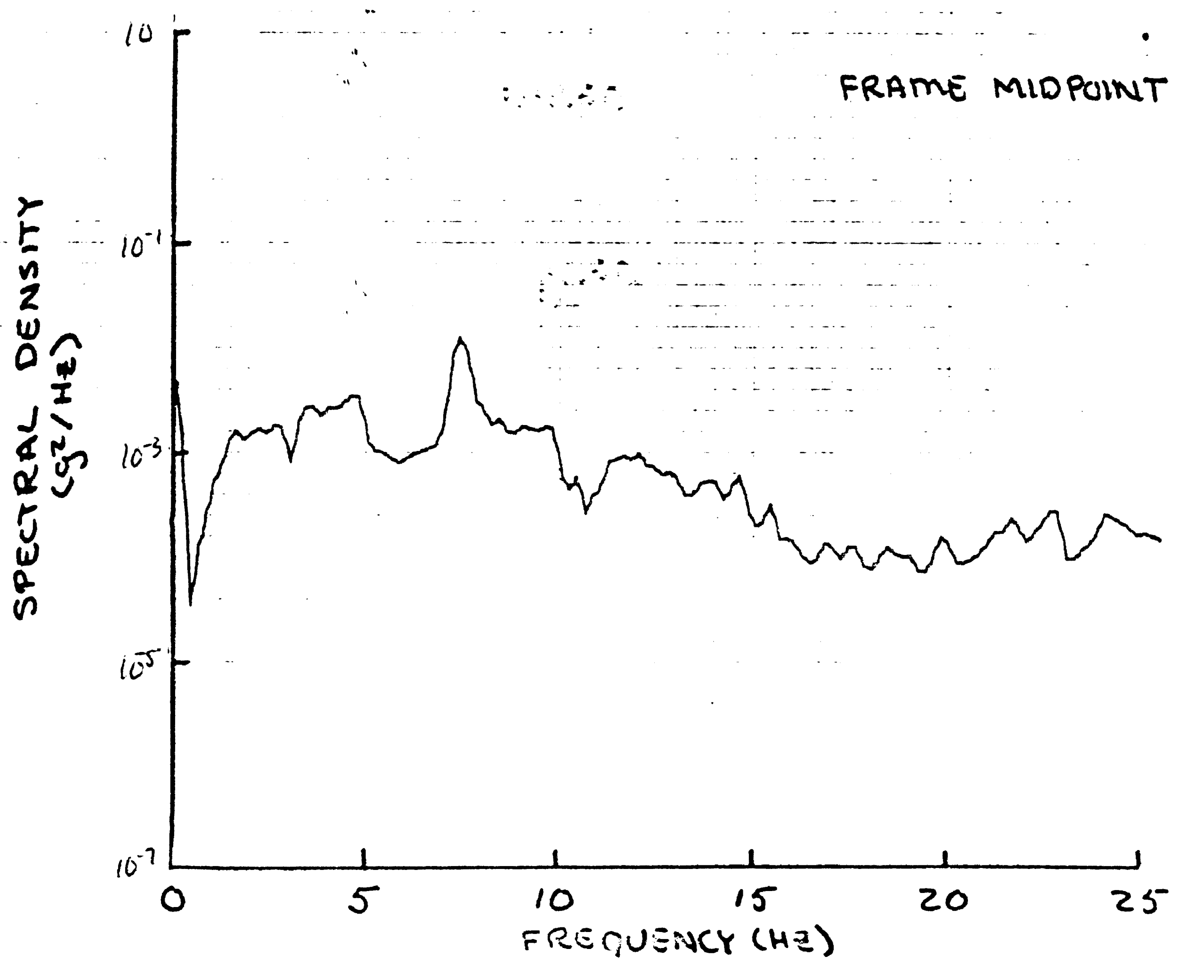

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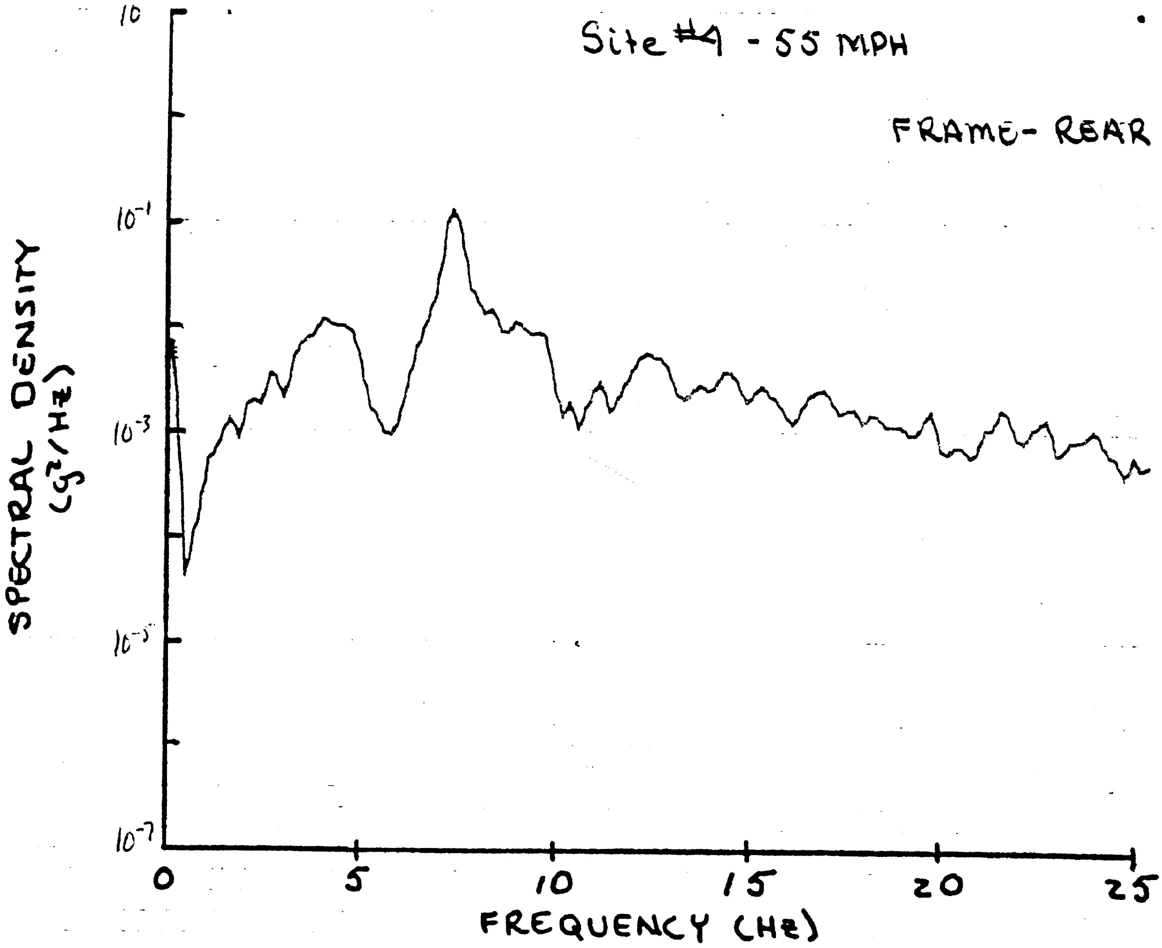

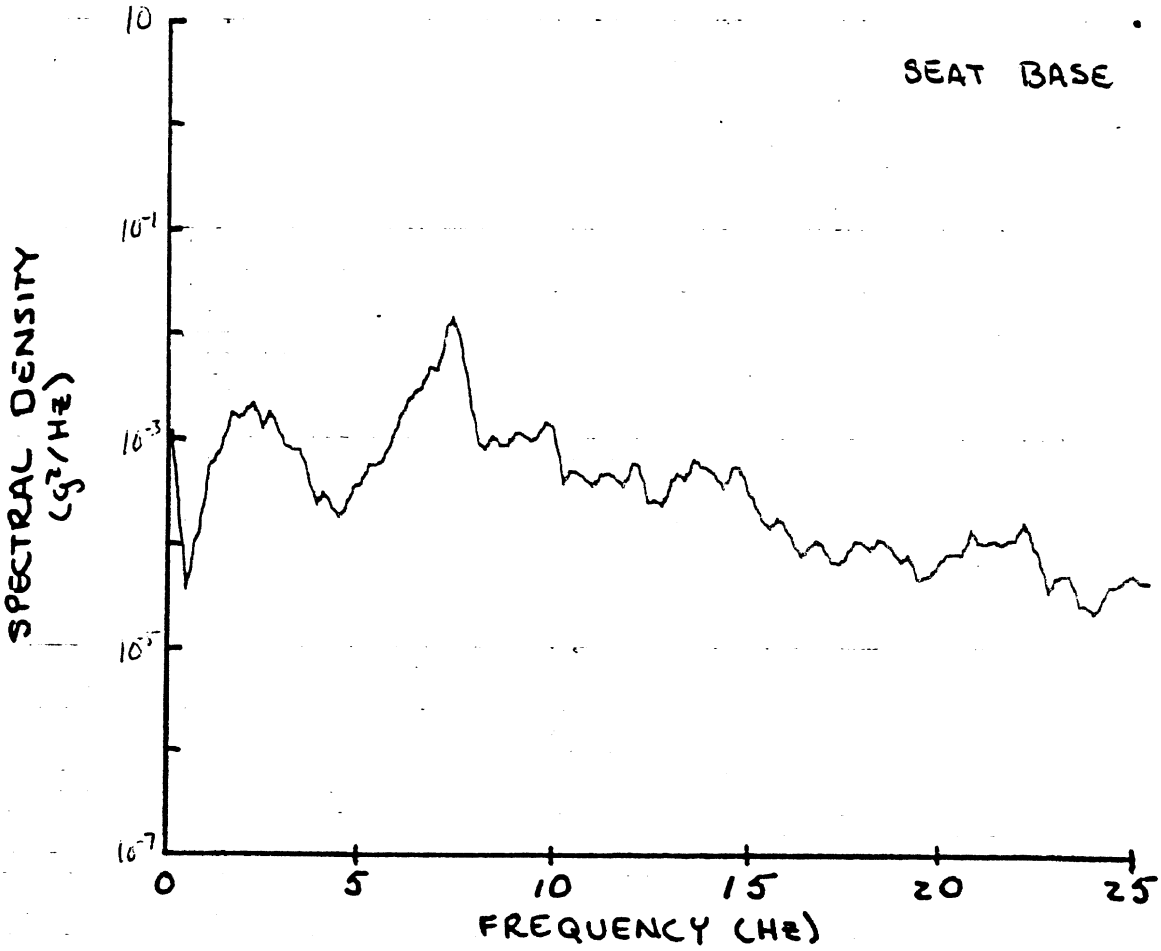

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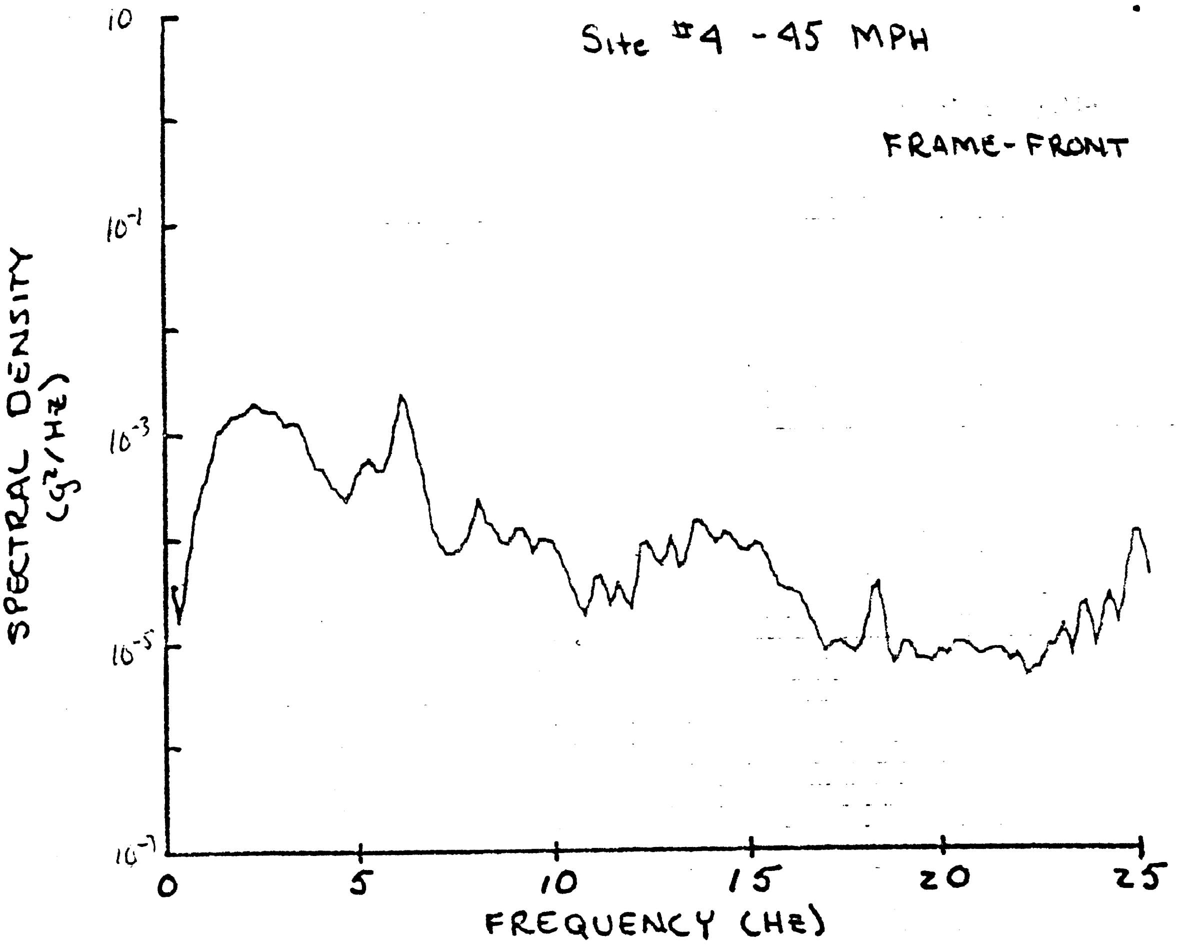

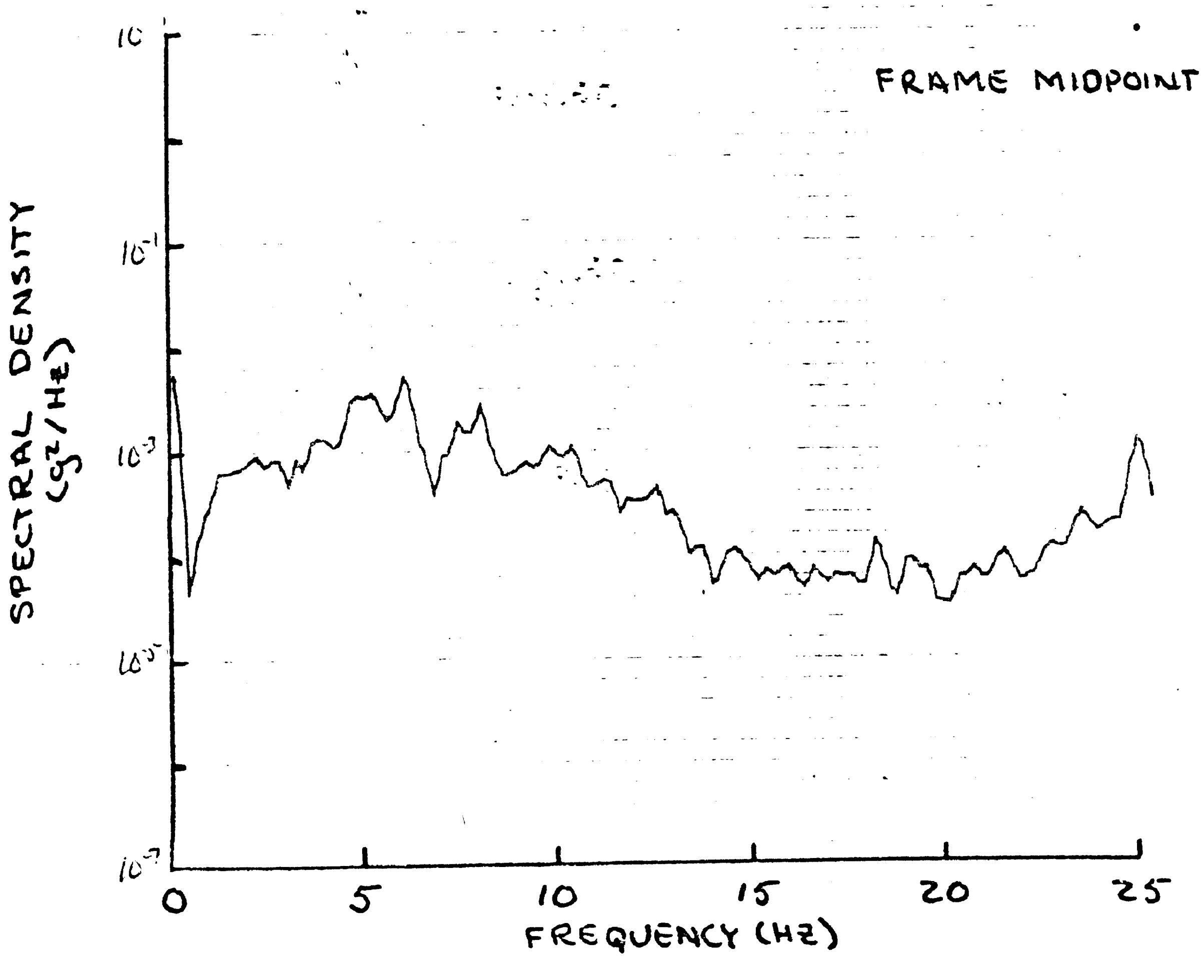

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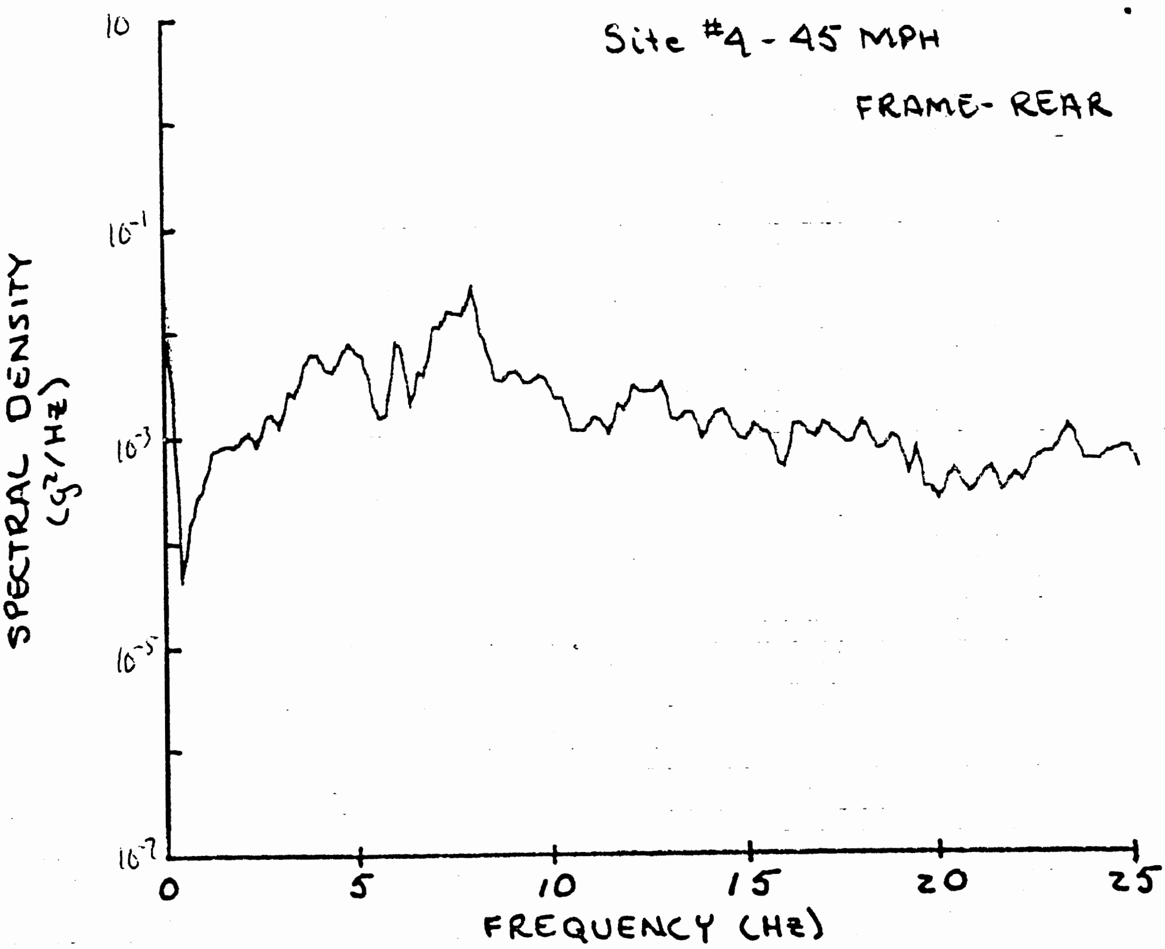

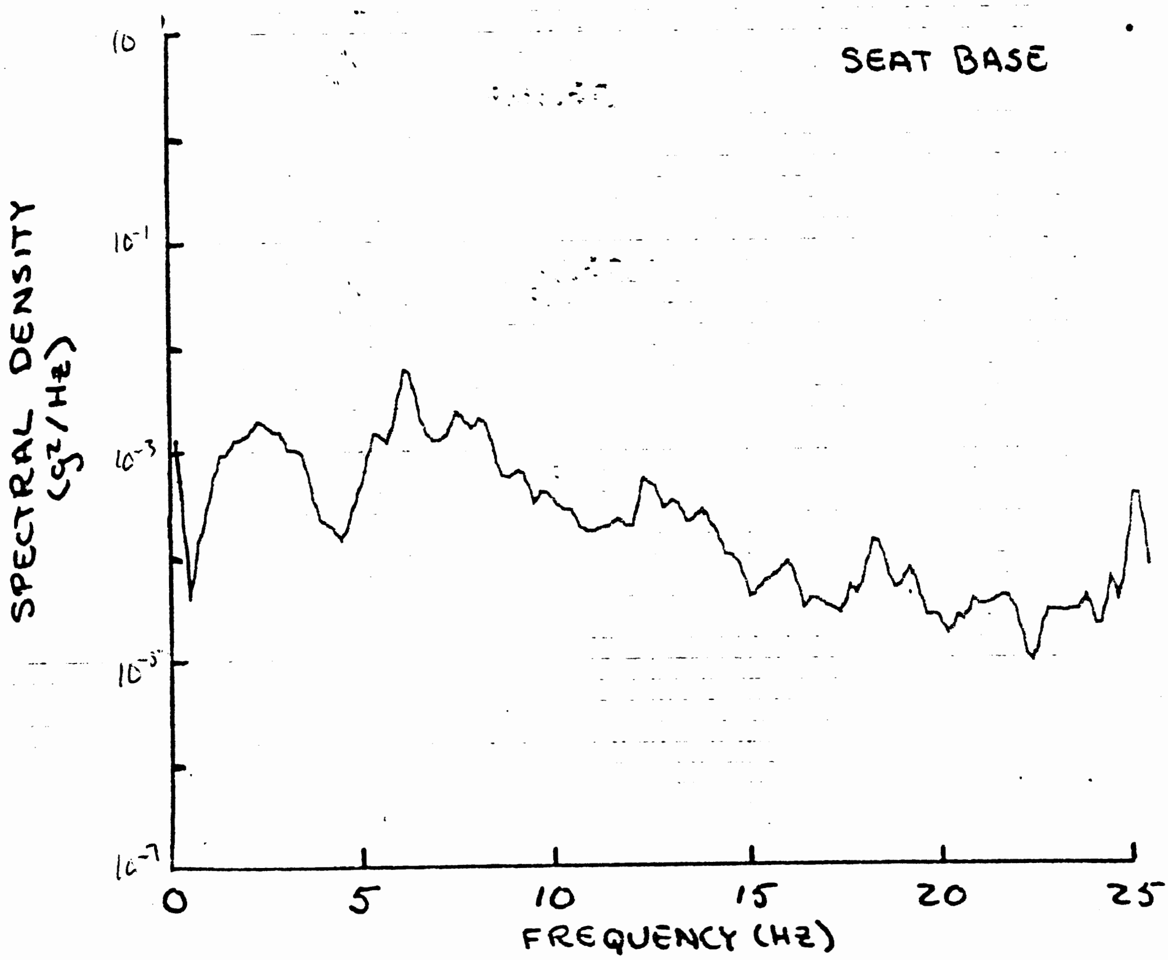

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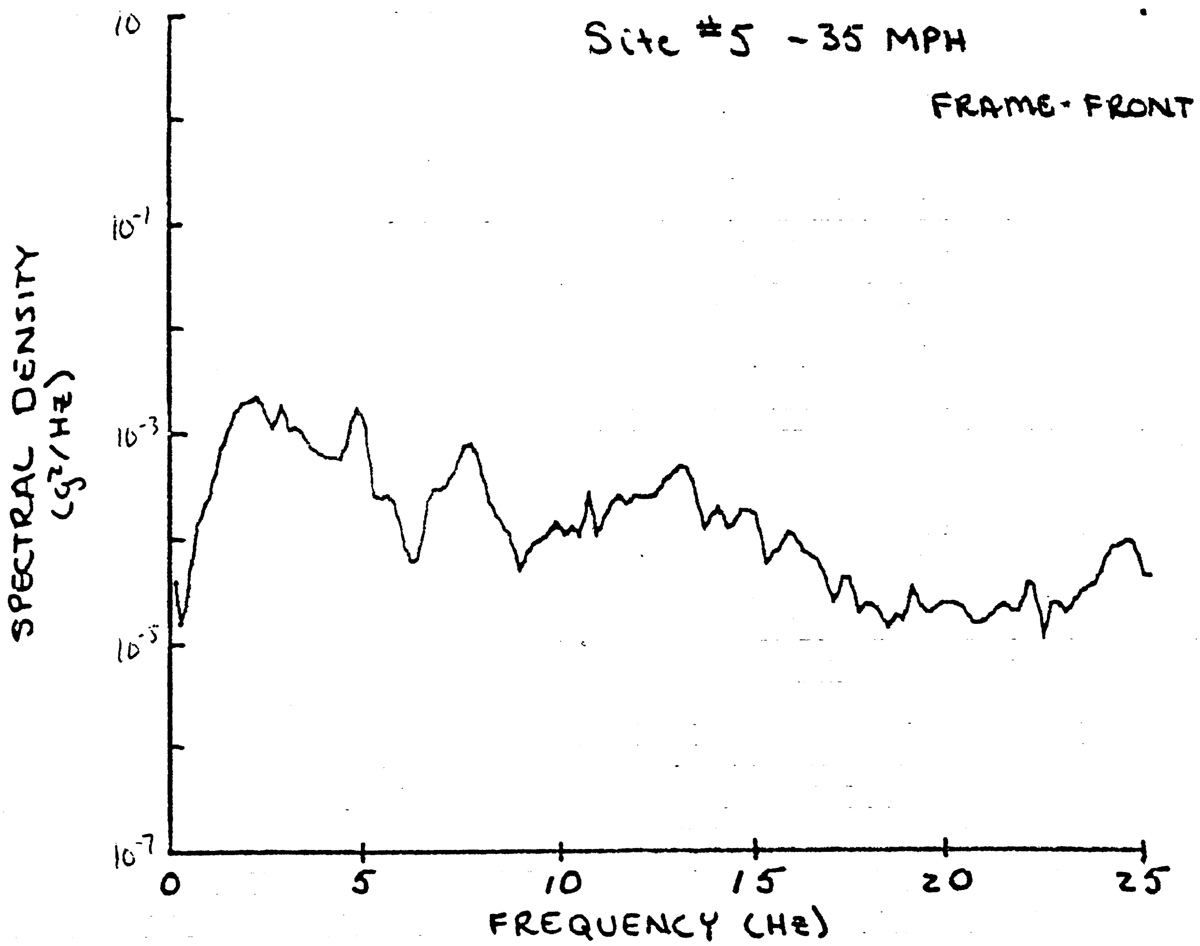

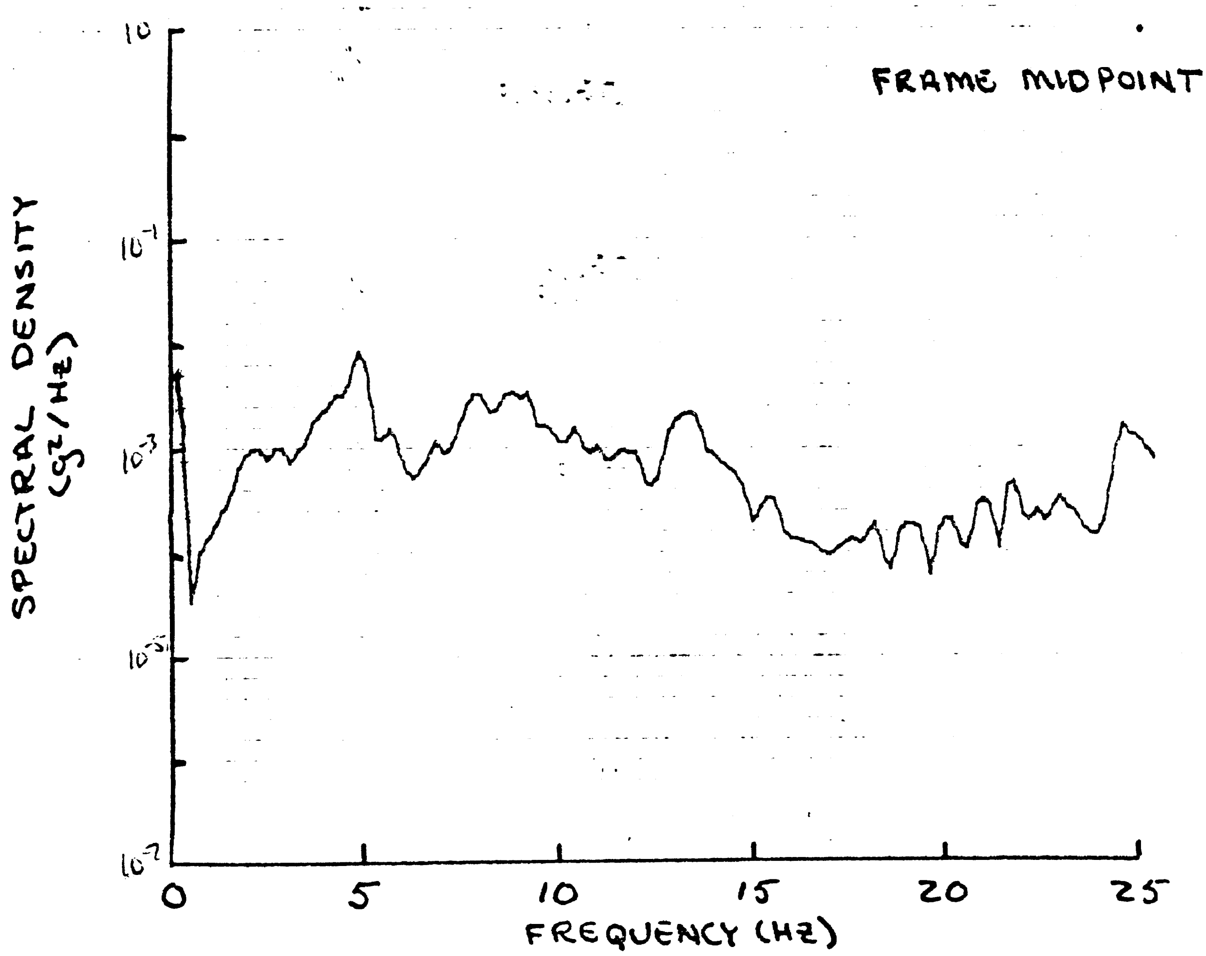

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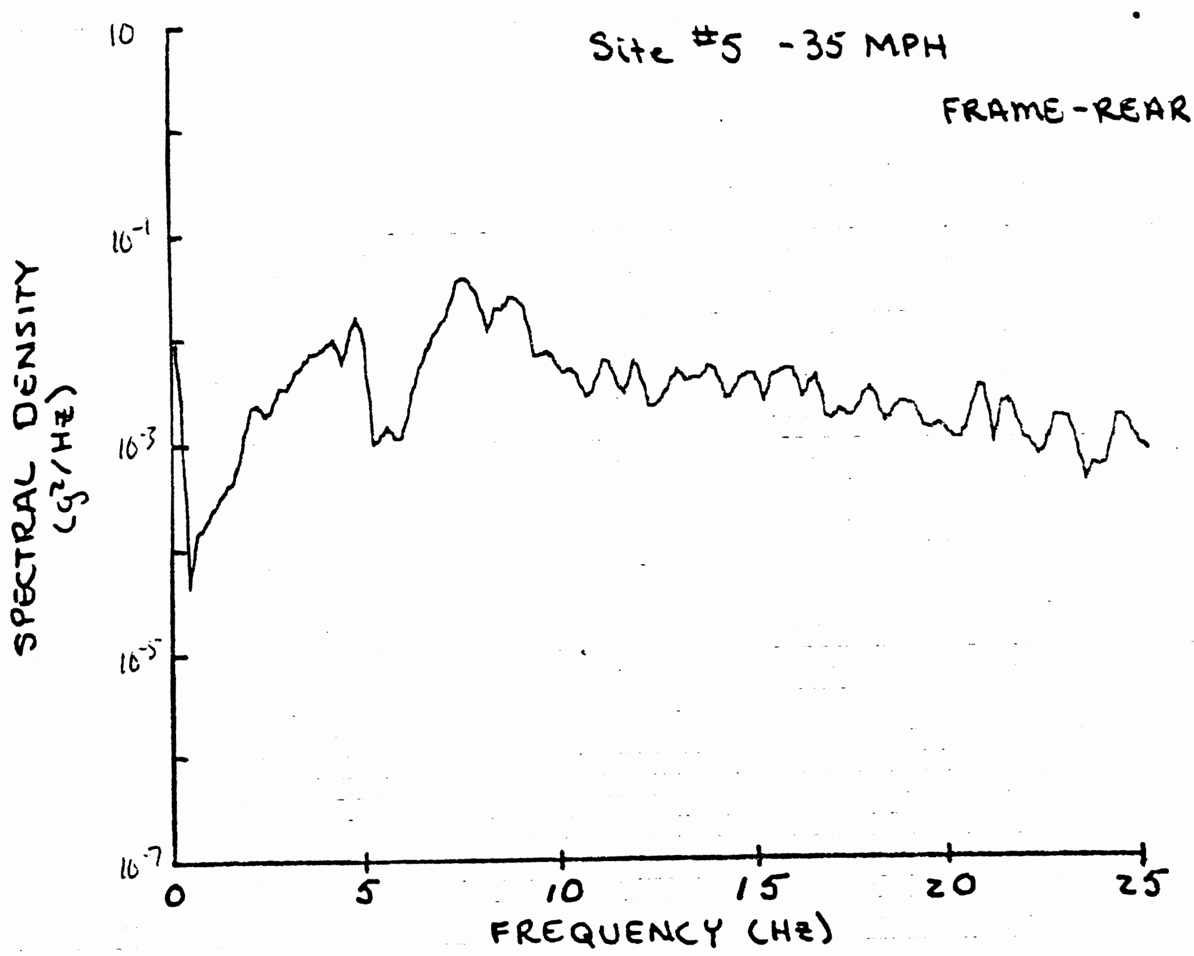

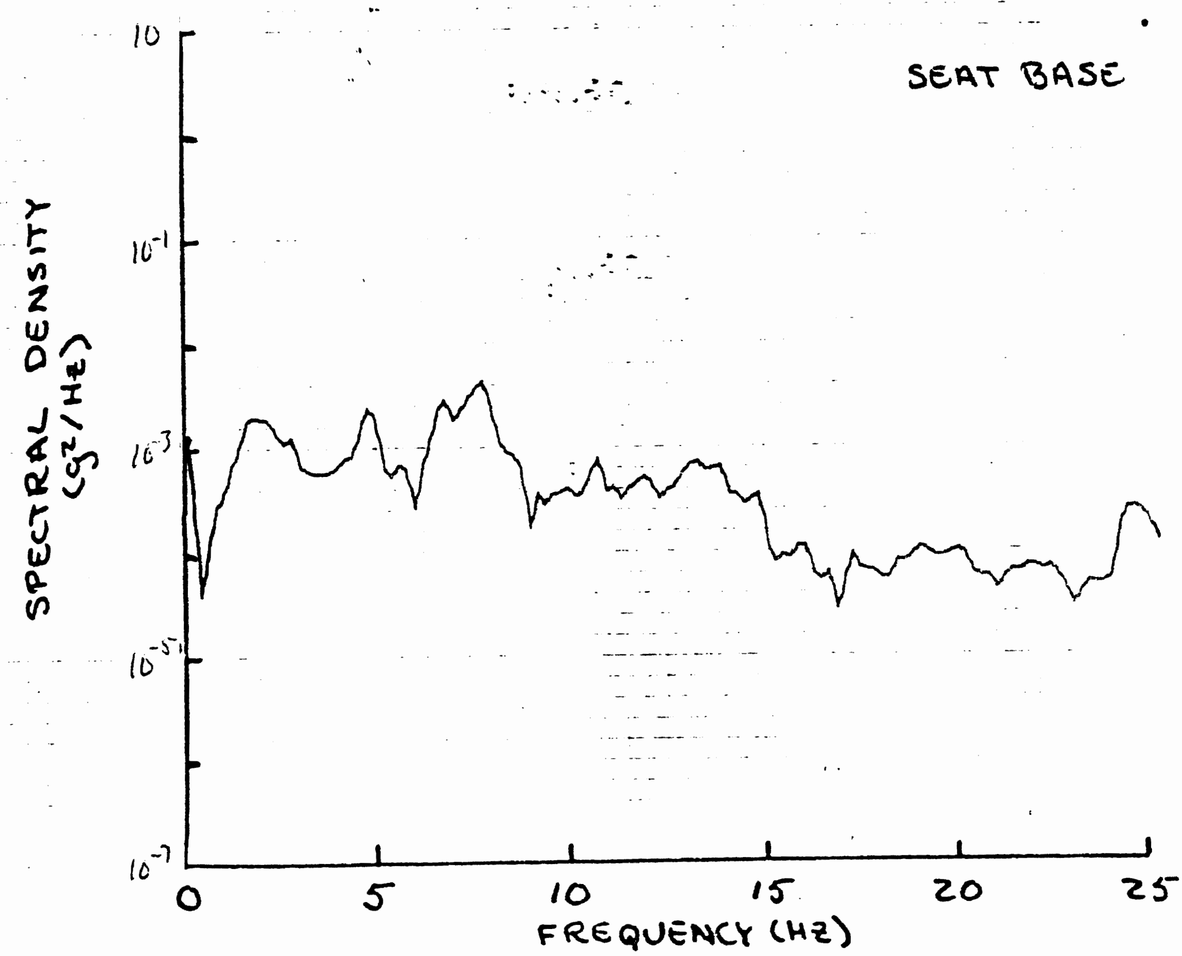

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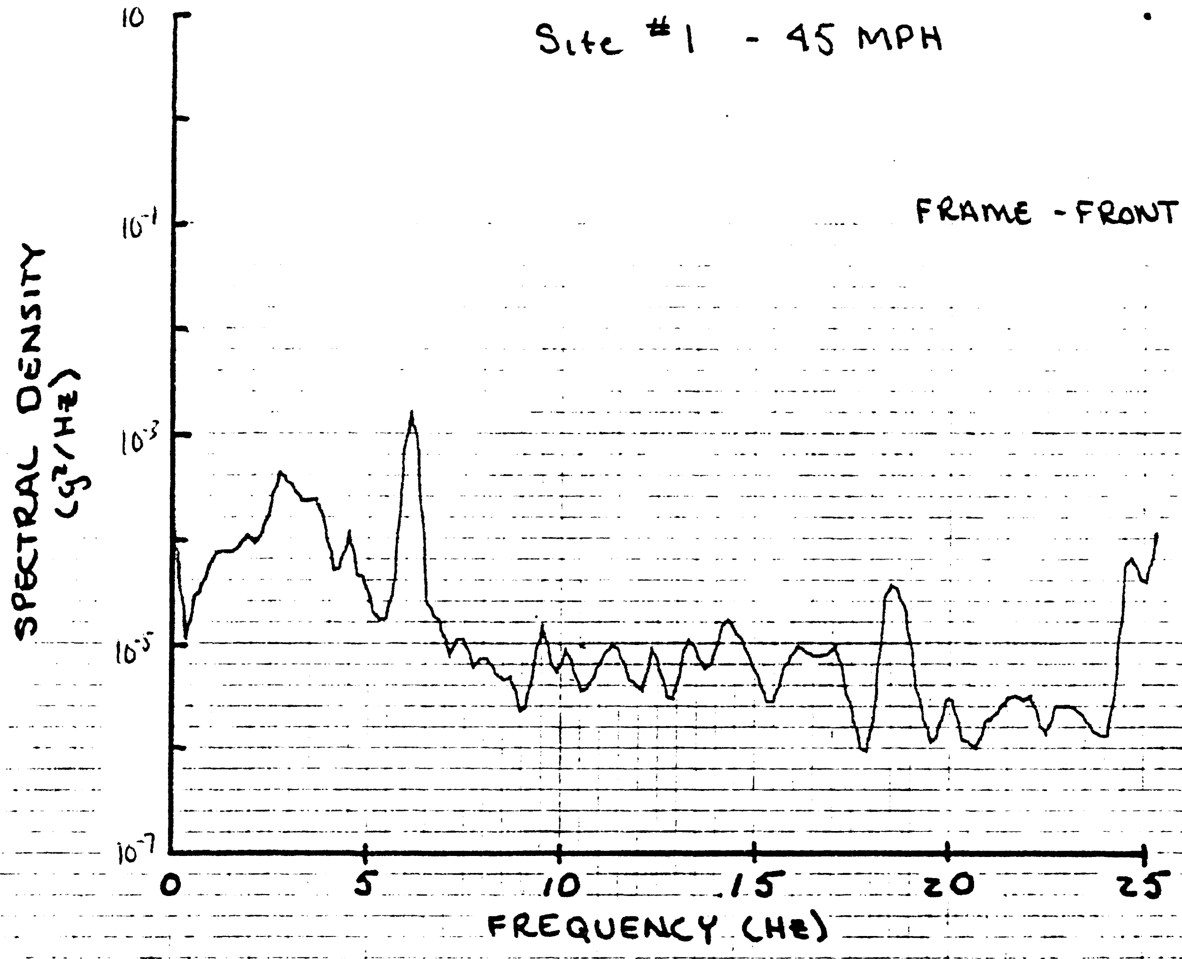


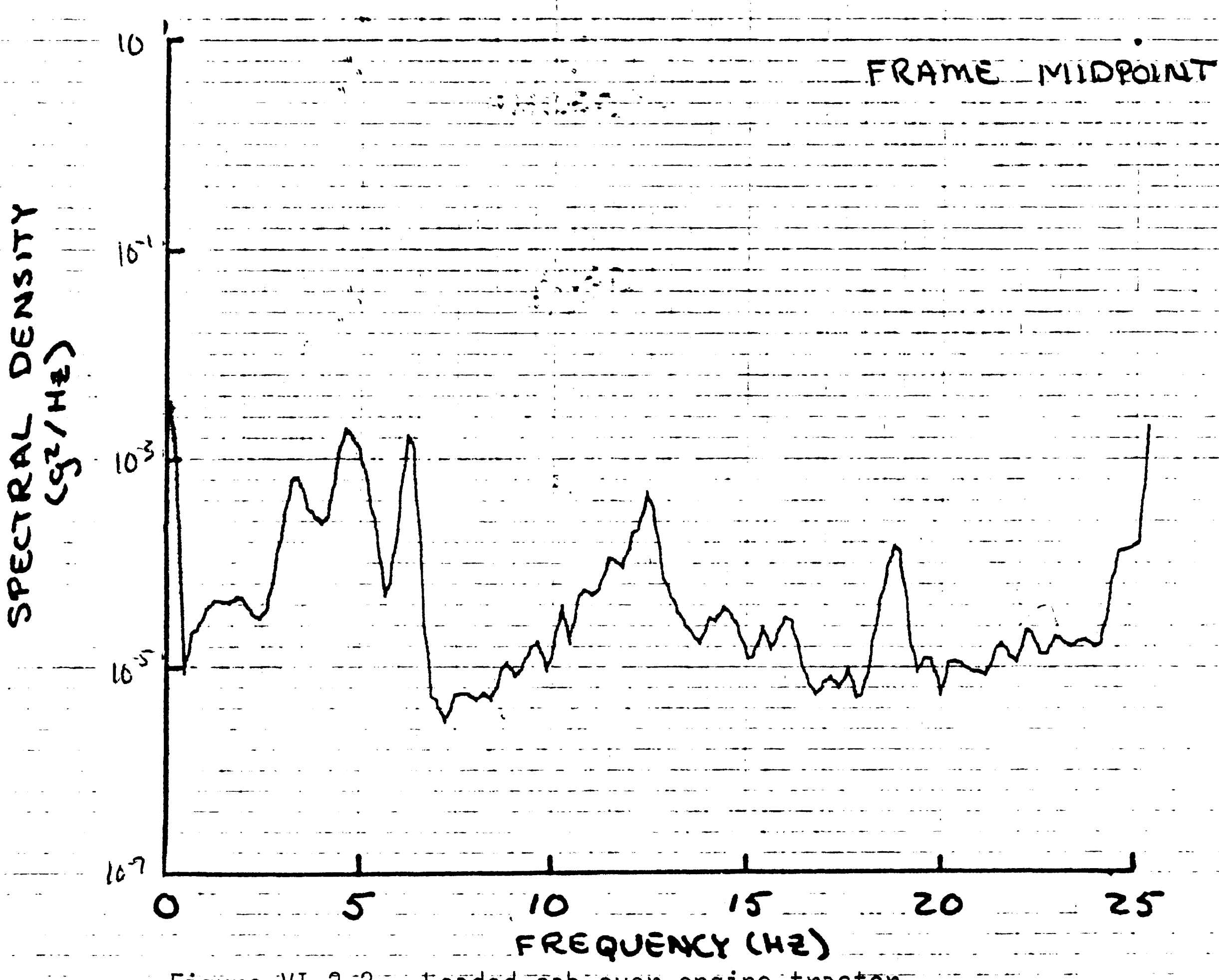
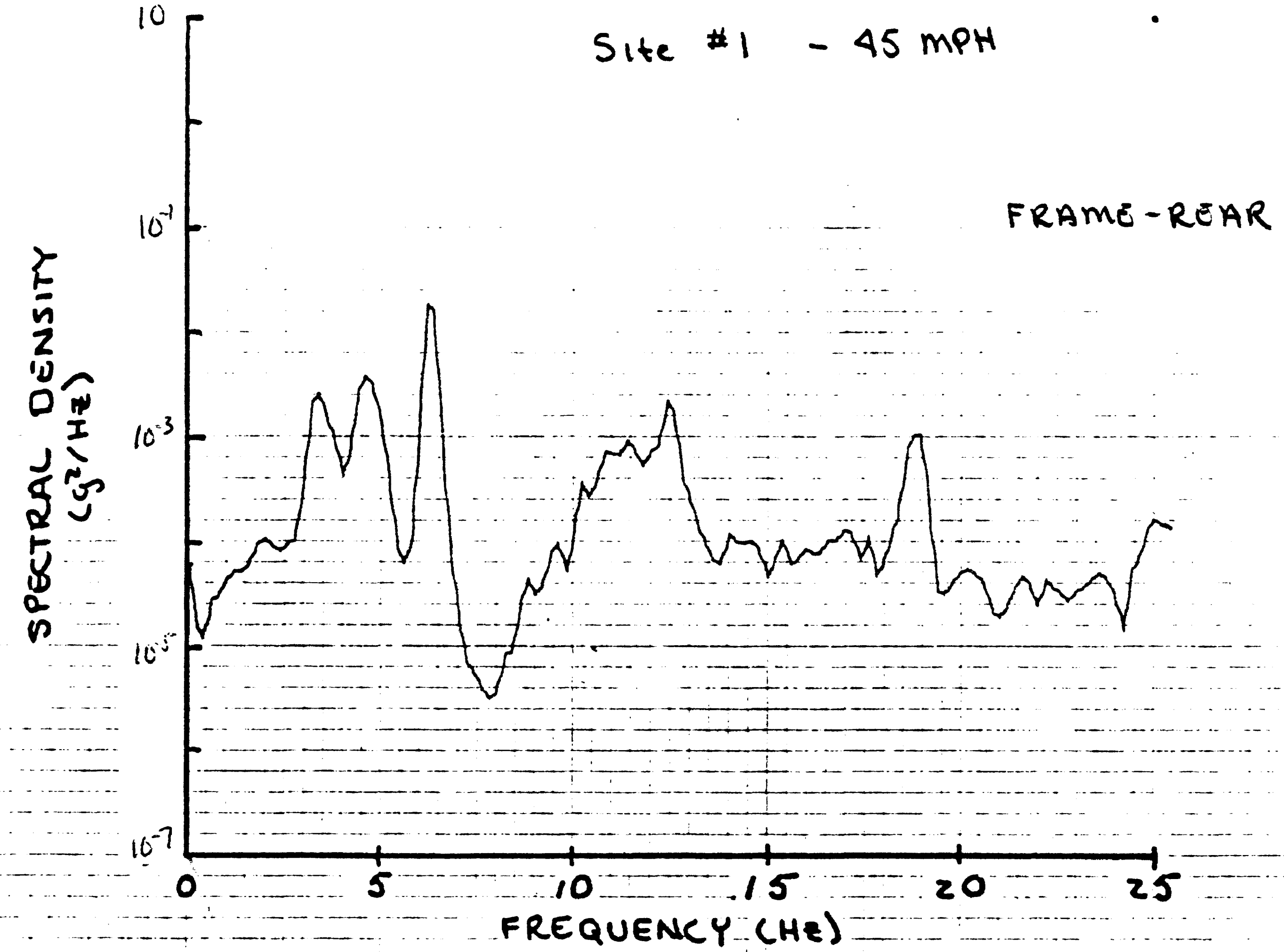
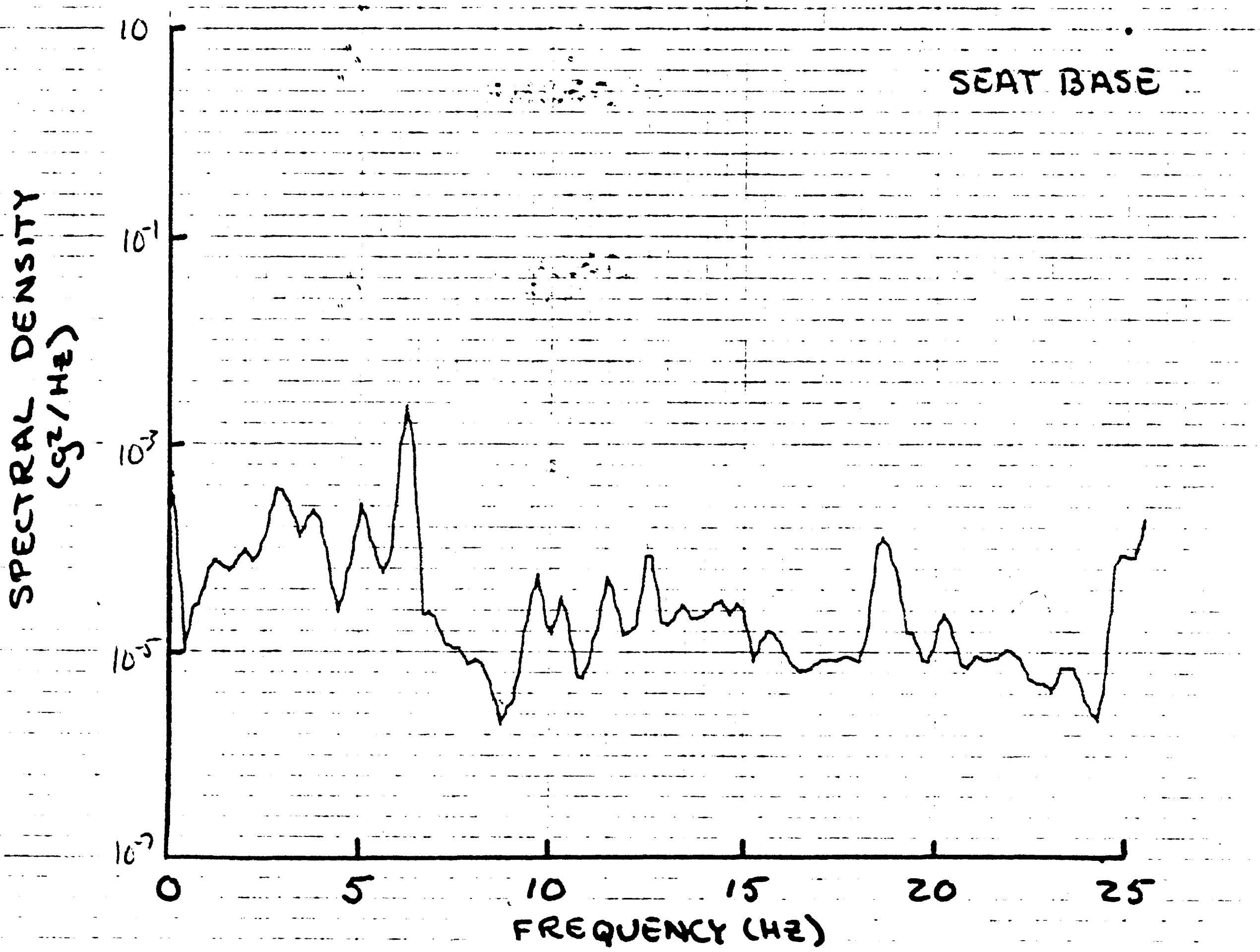


Figure VI.2.2. Loaded cab-over-engine tractor.





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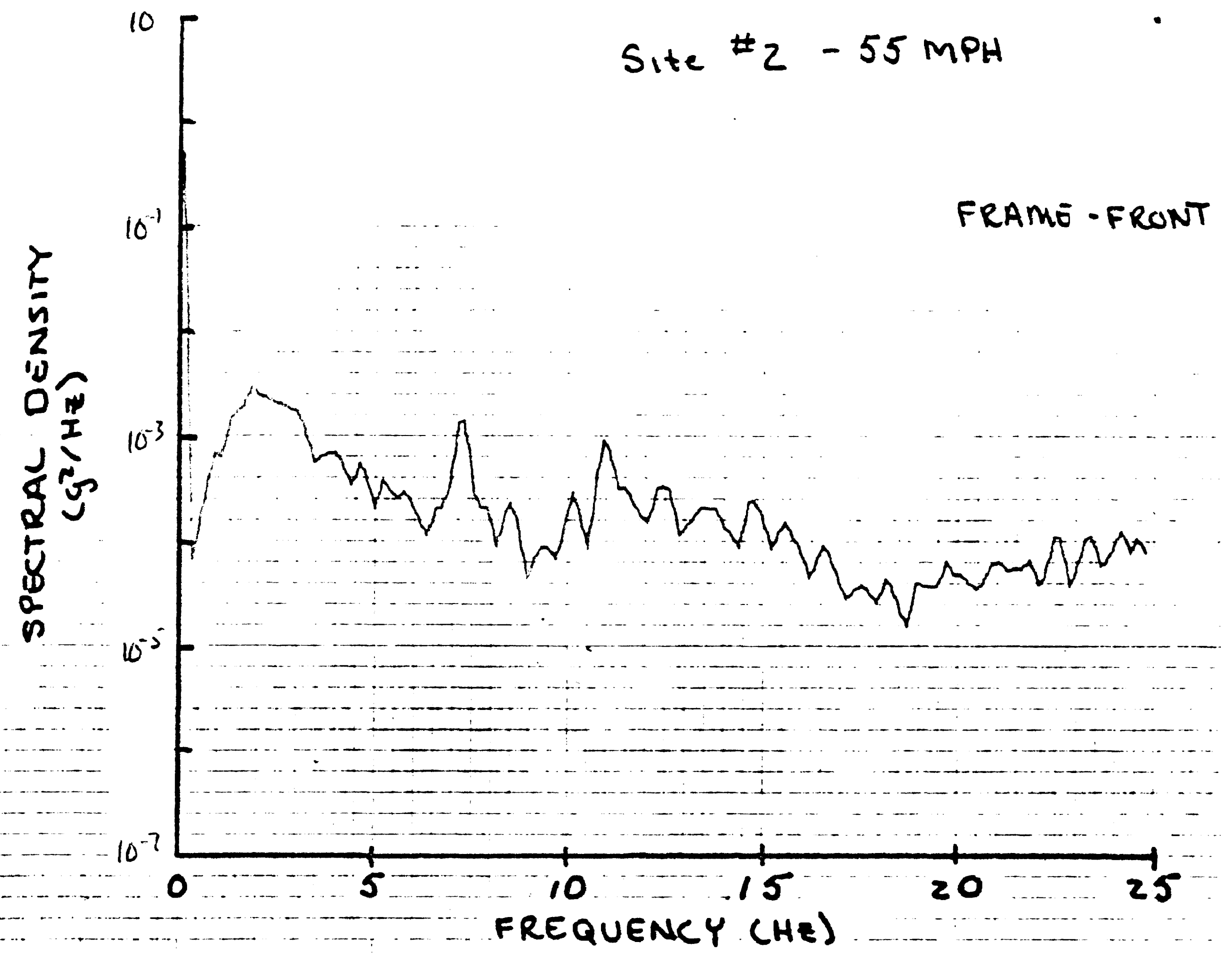

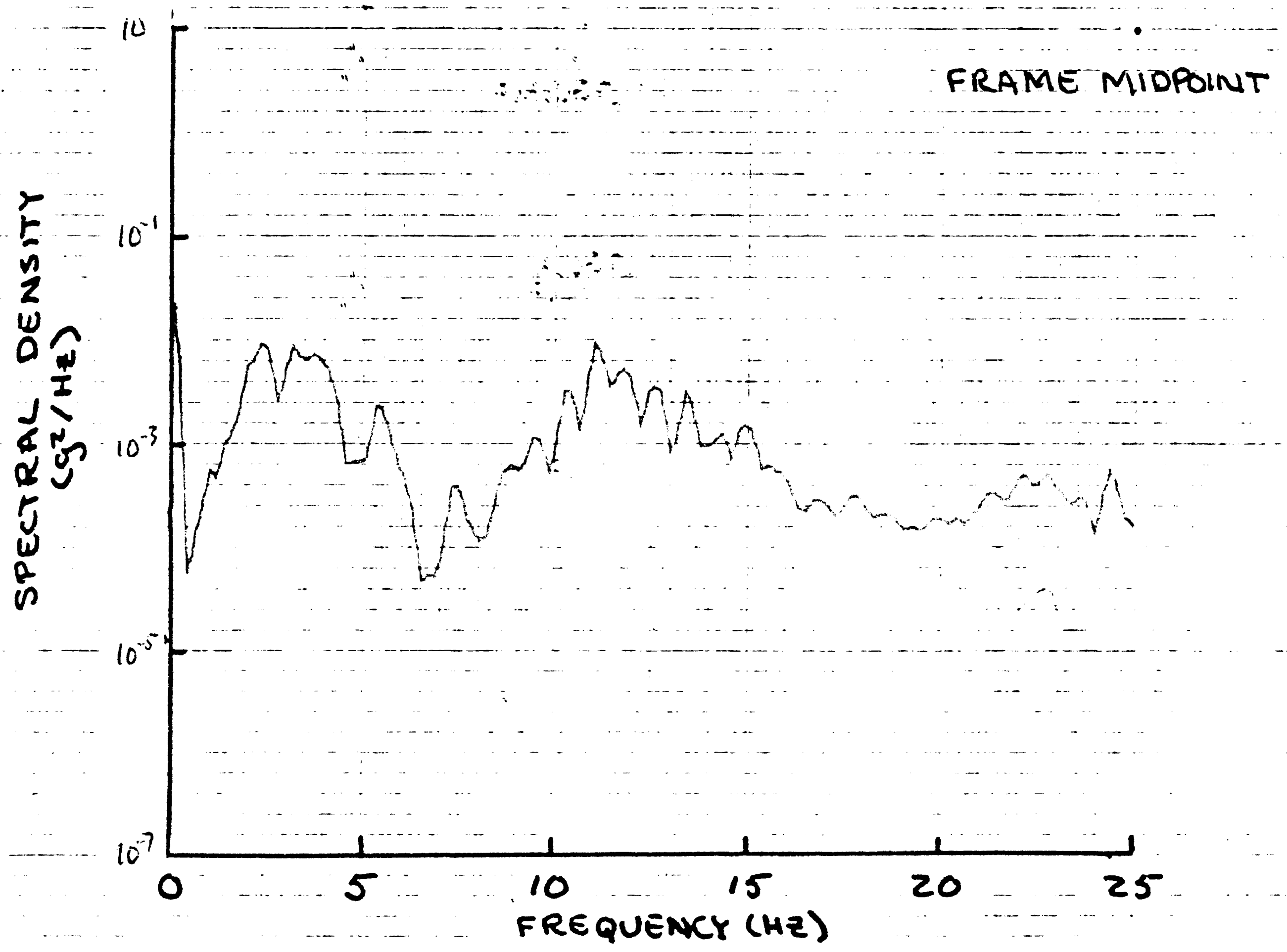

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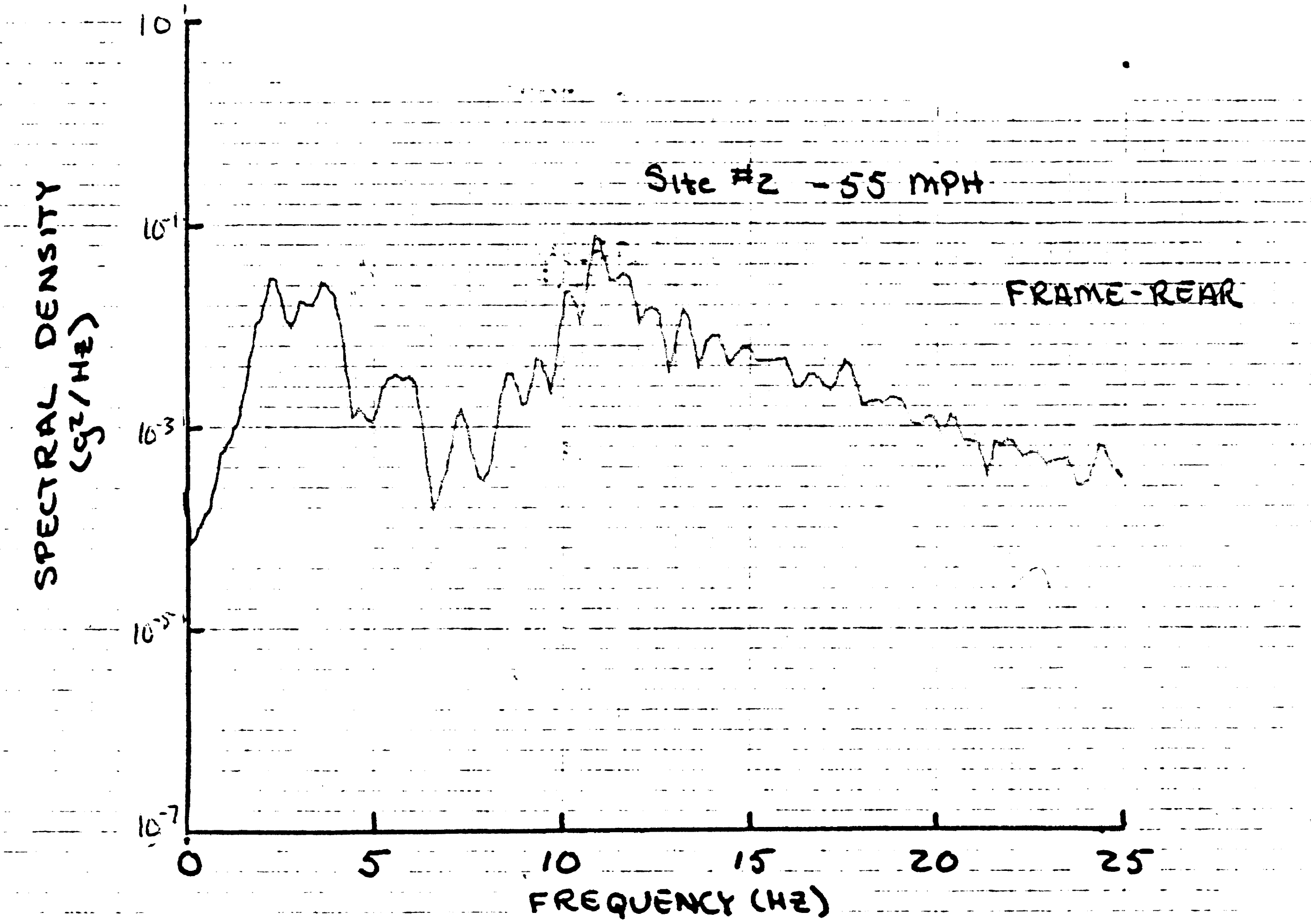

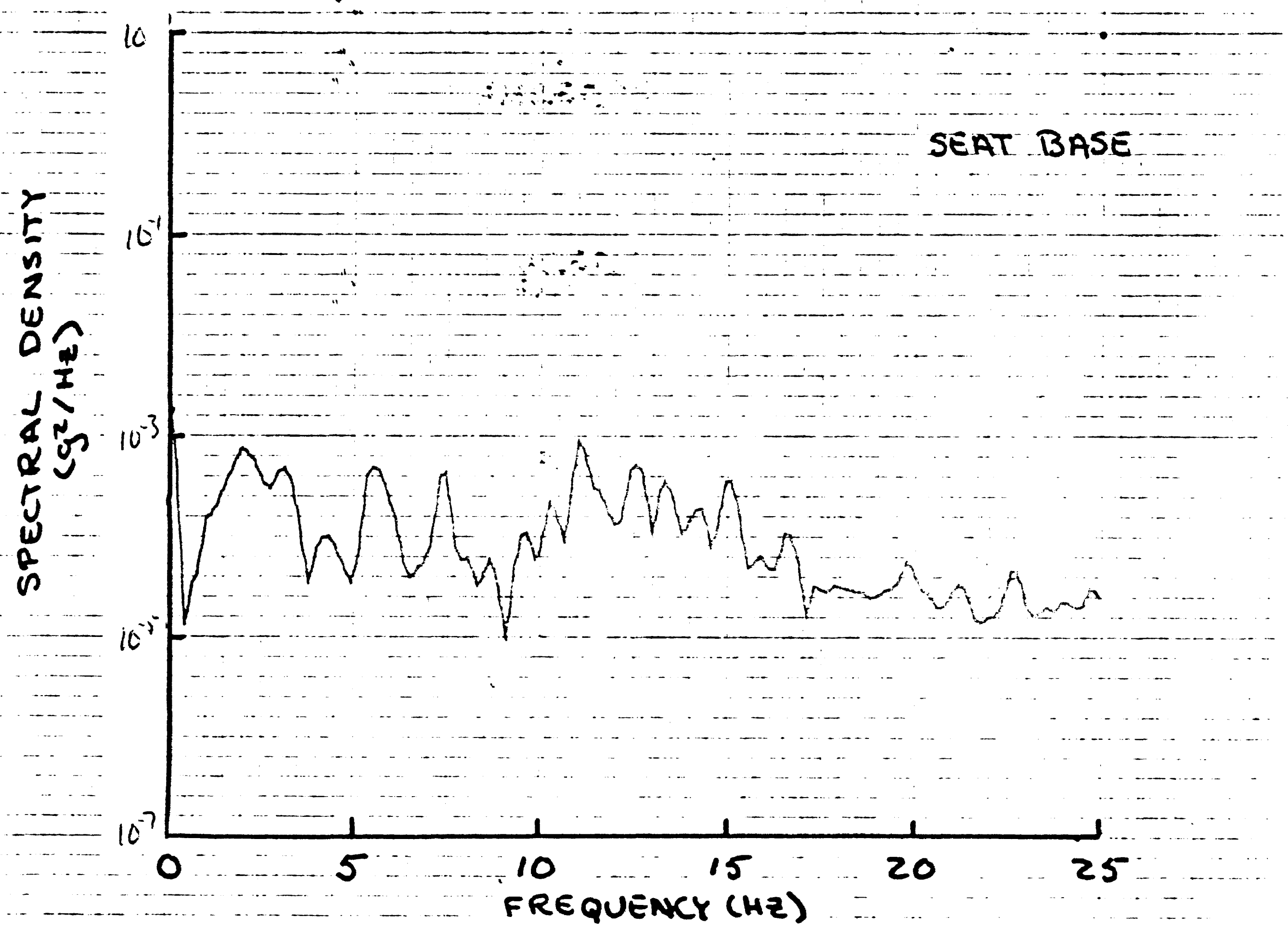

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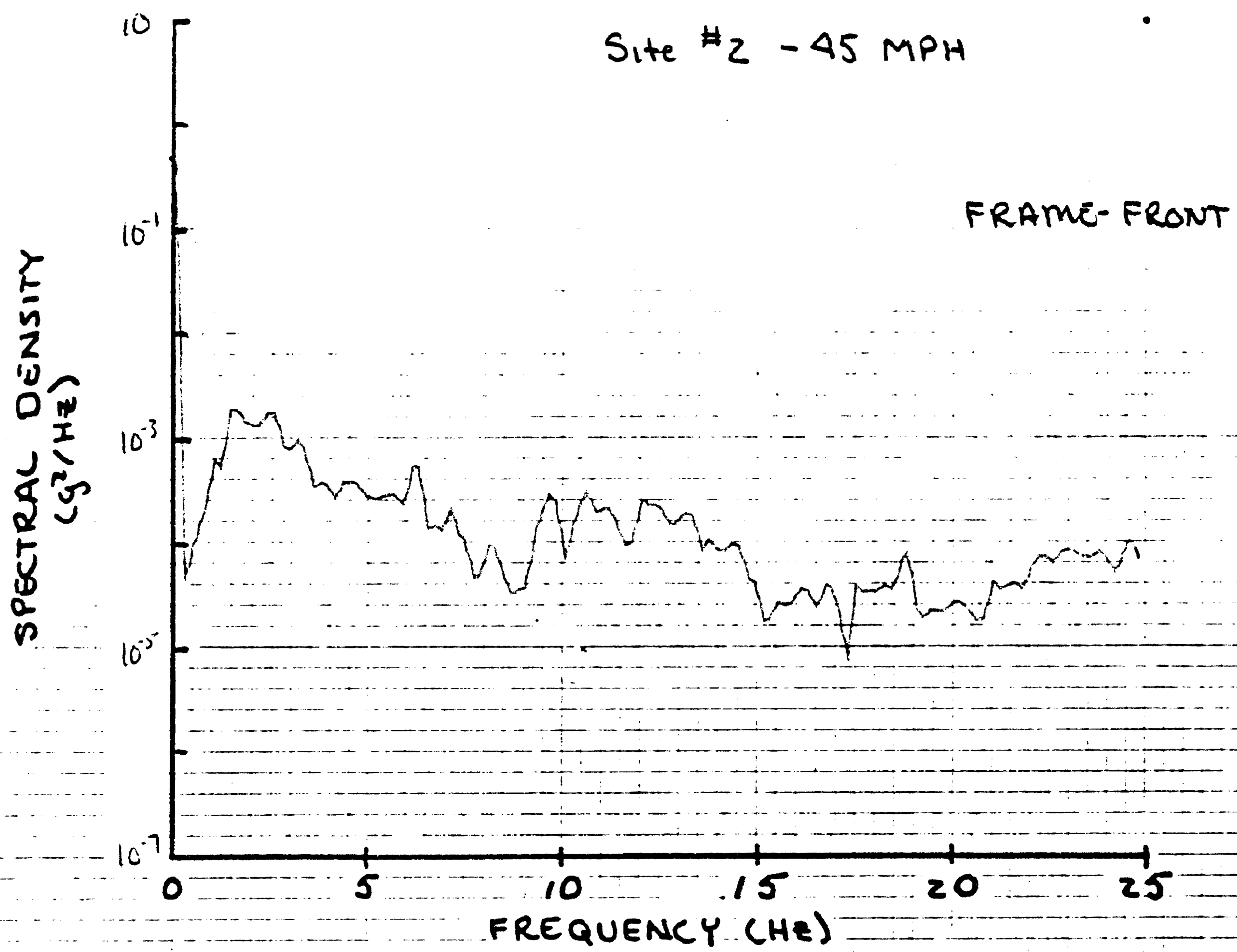

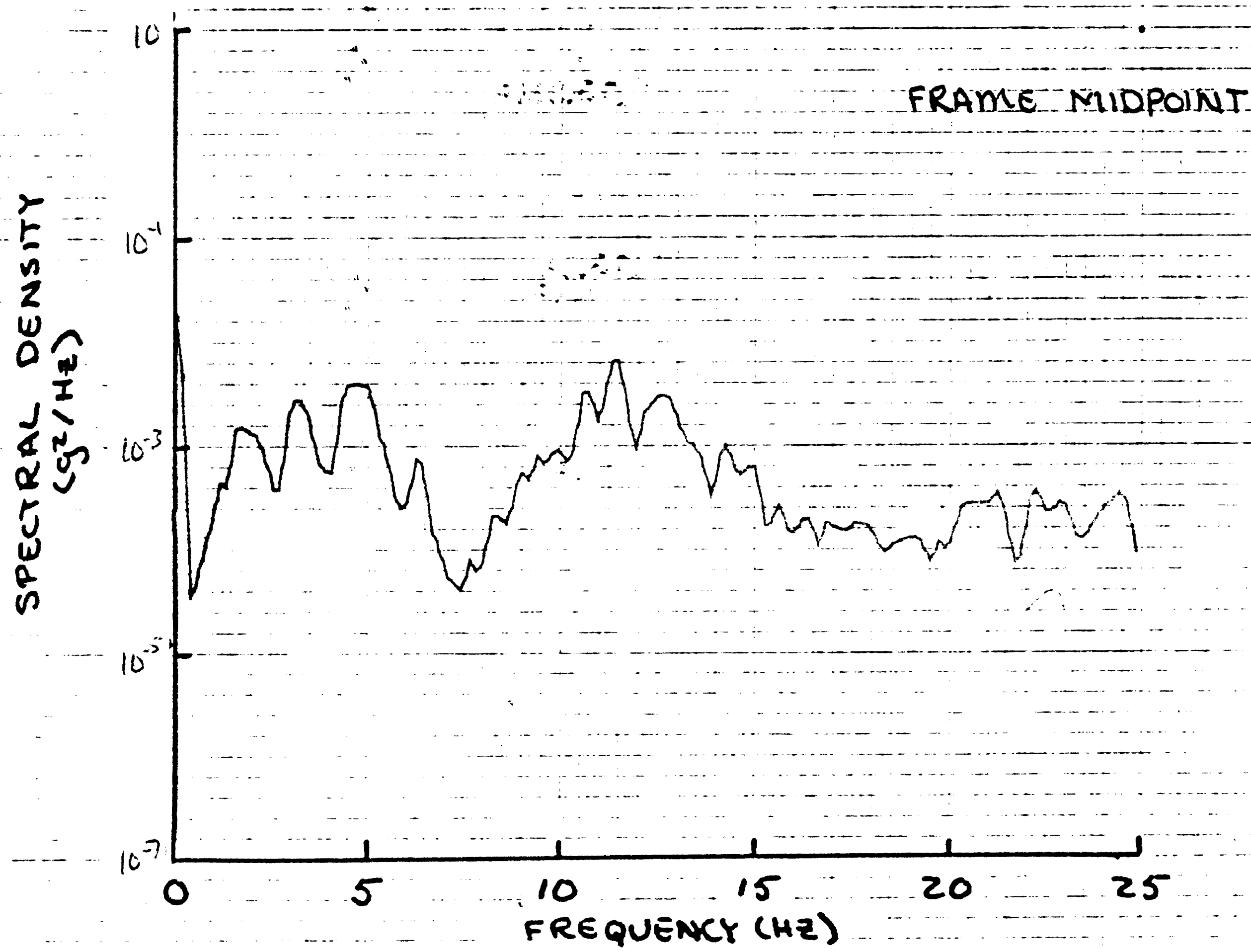

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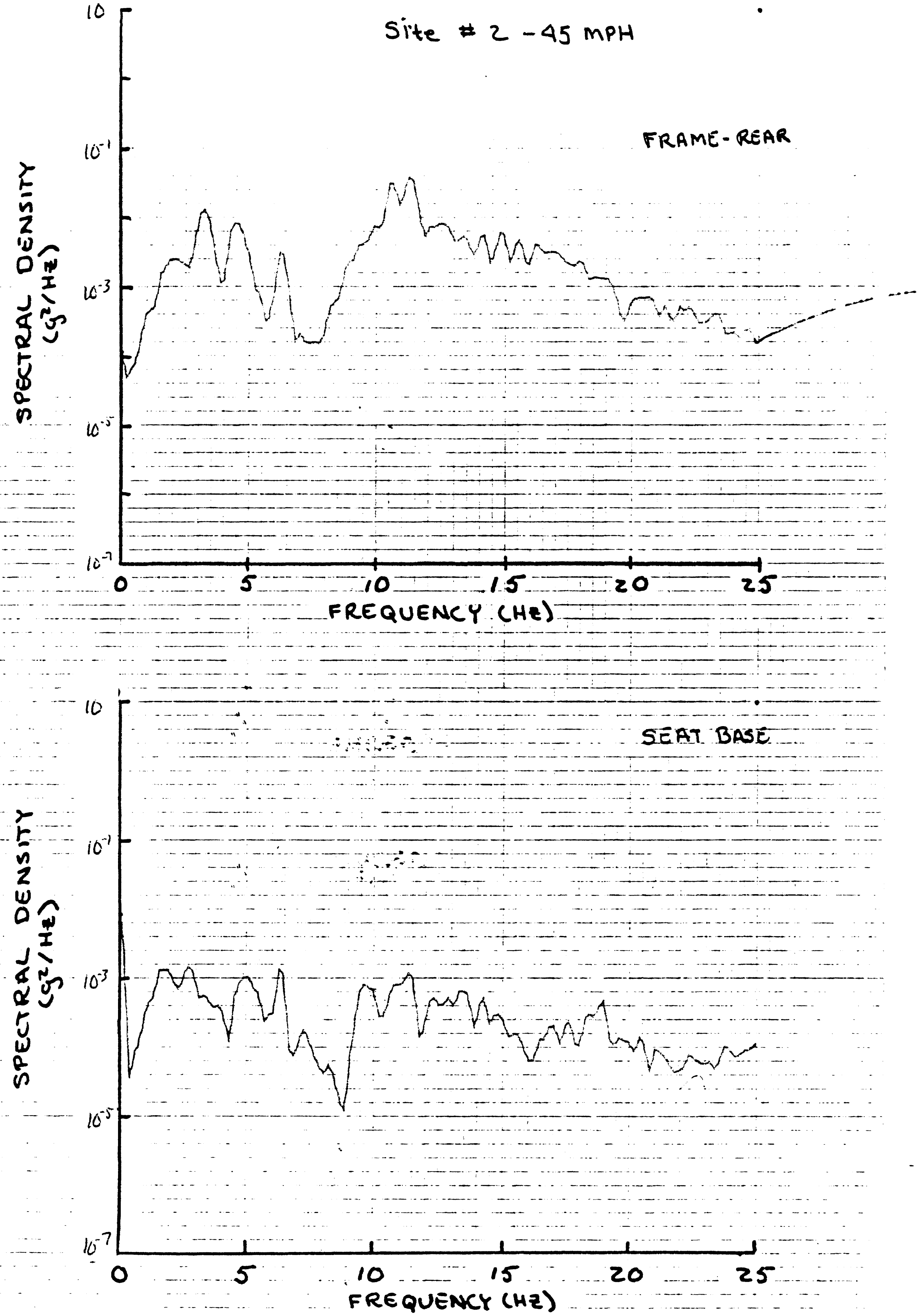

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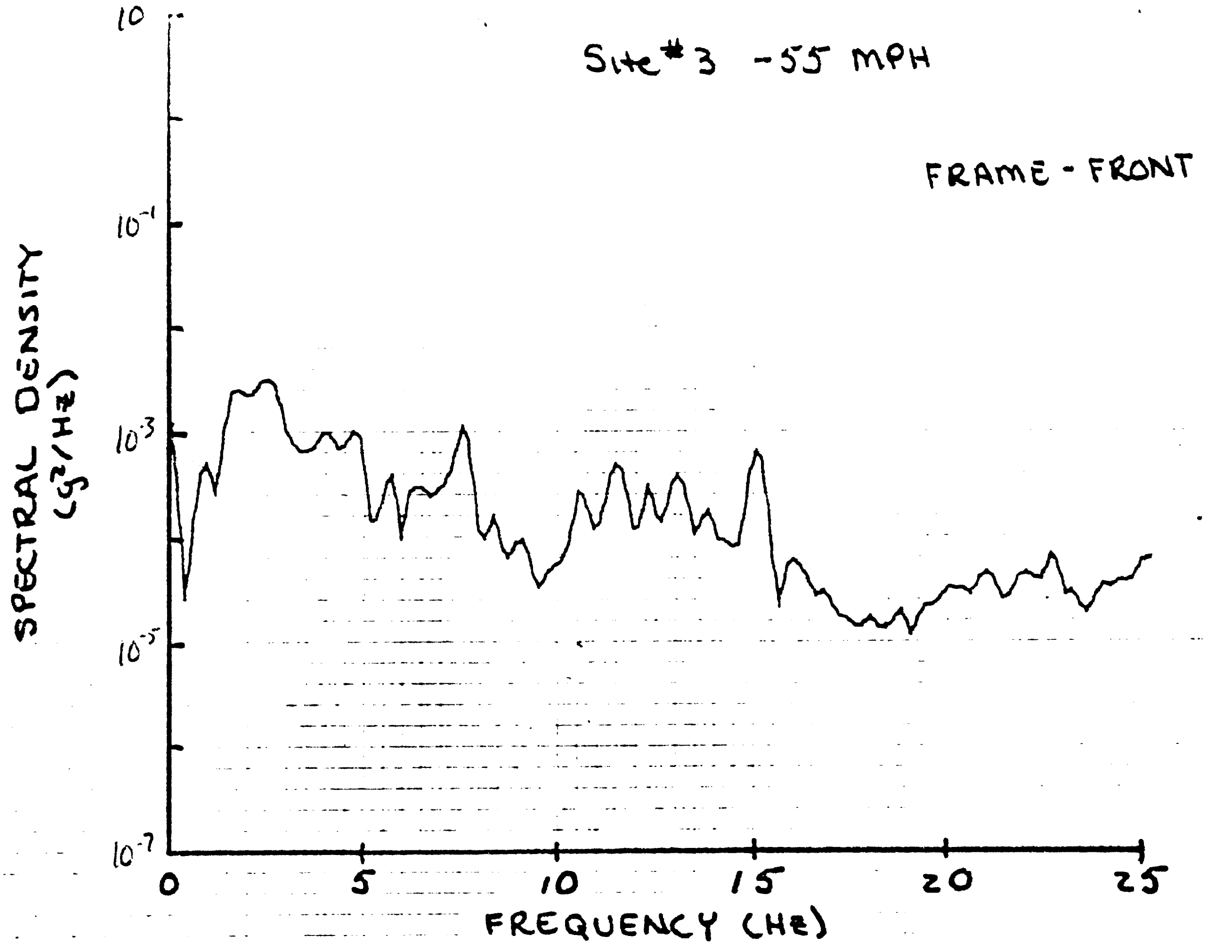

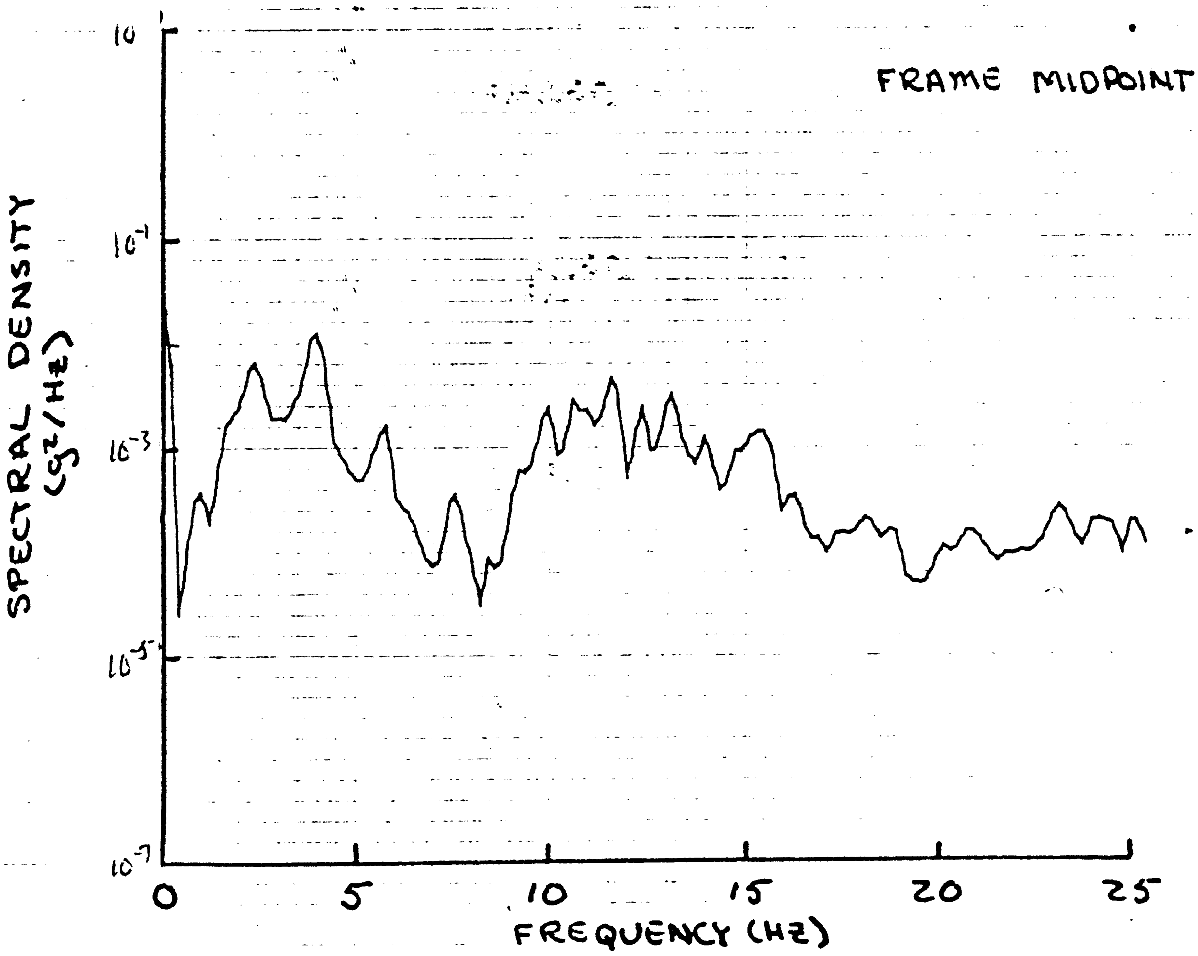

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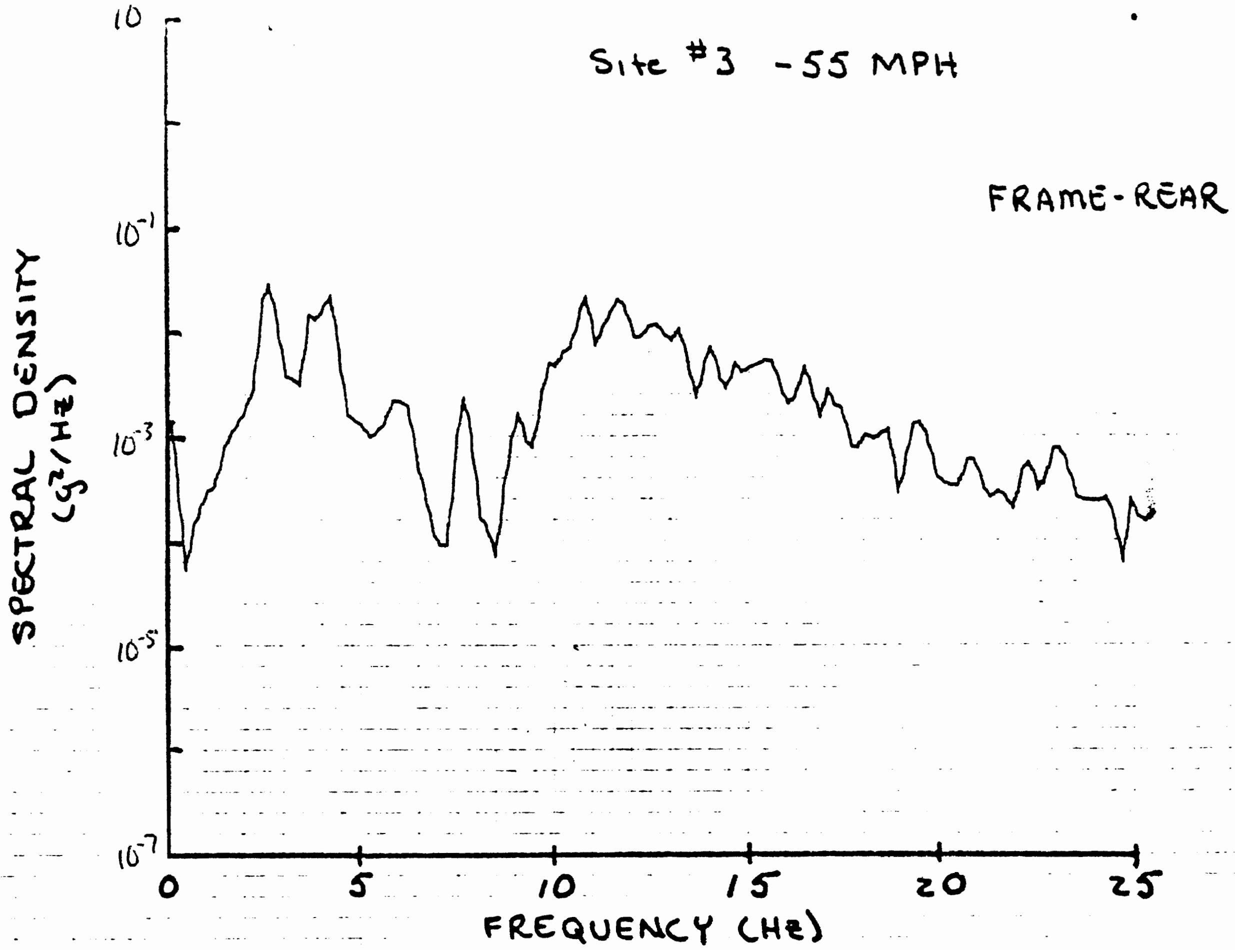

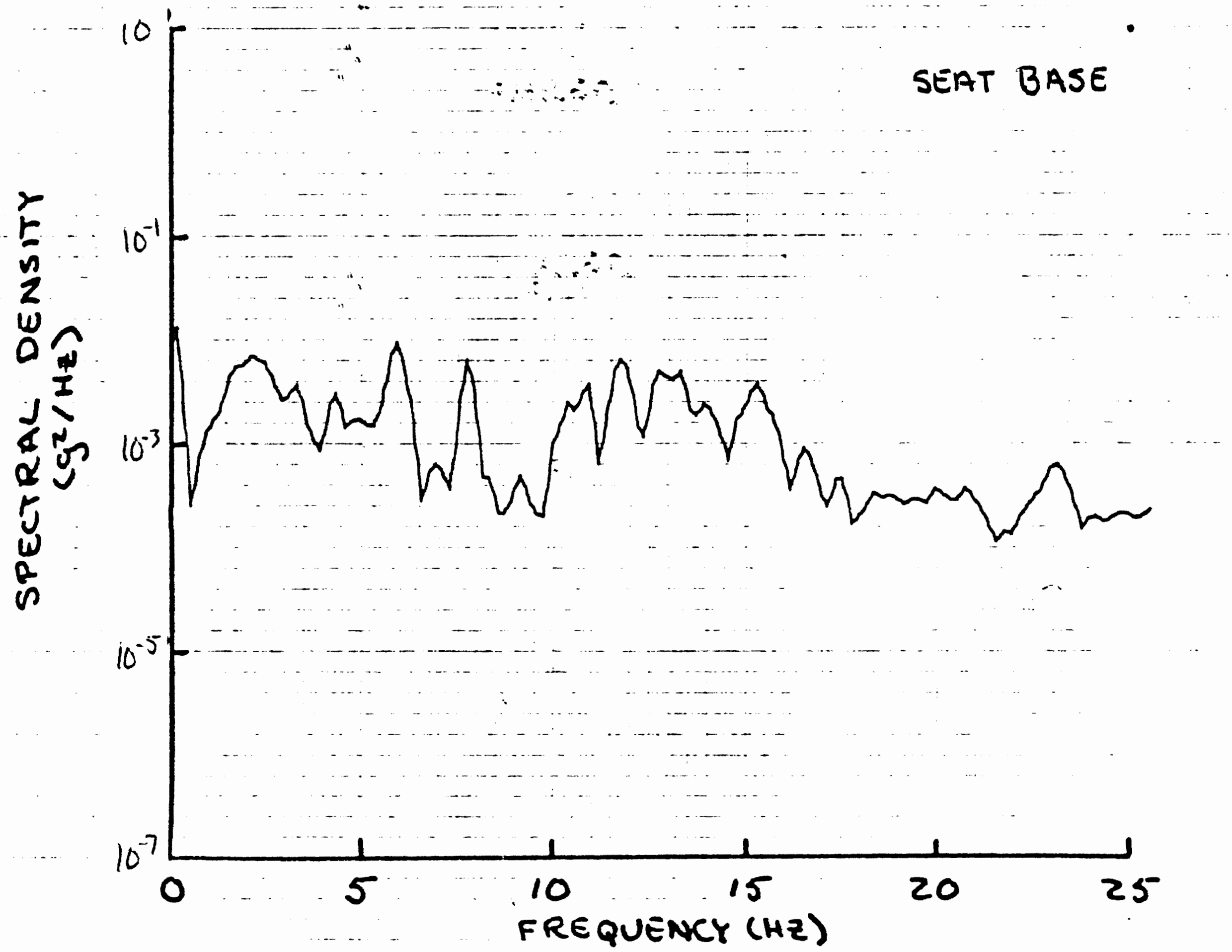

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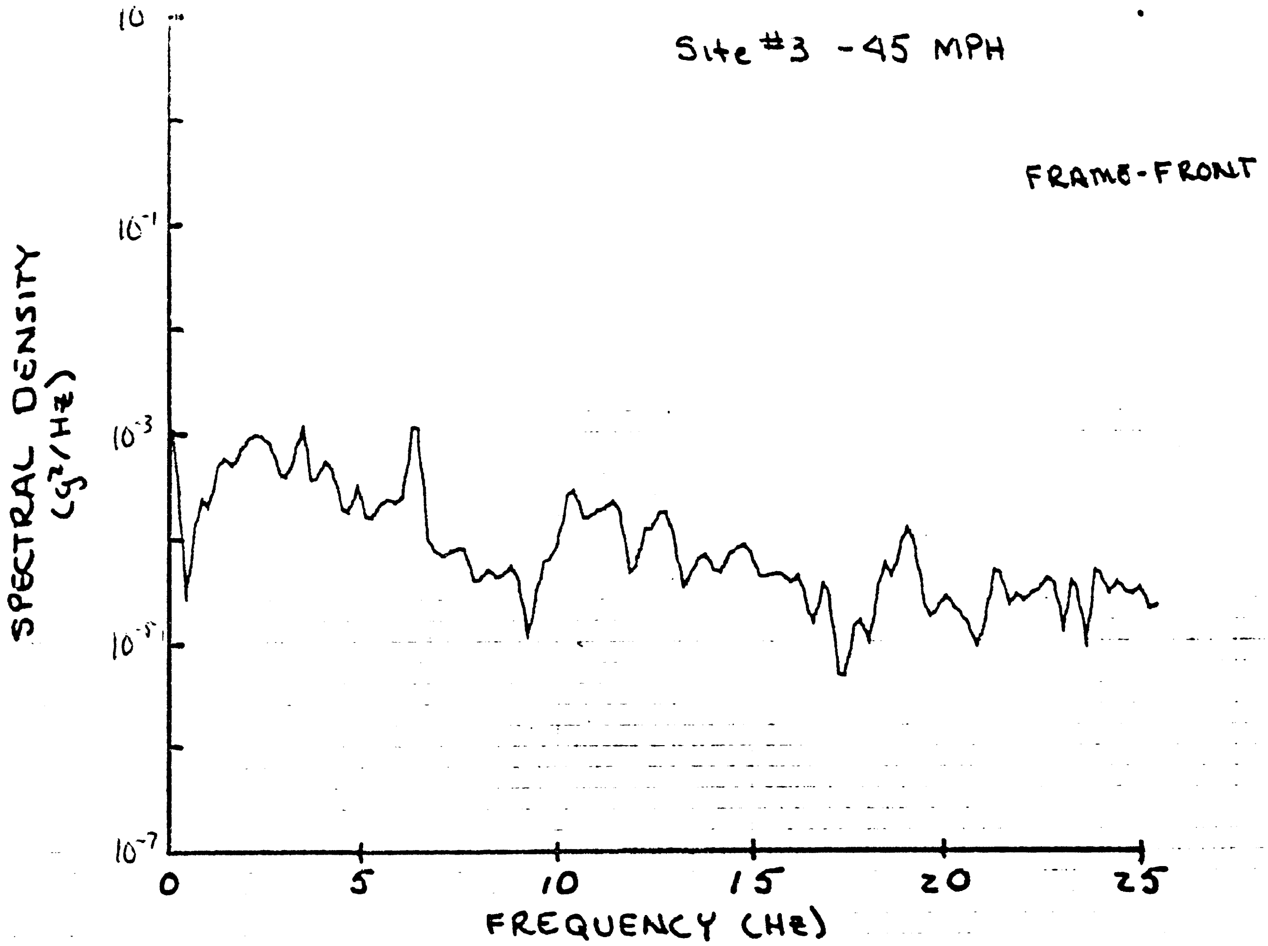

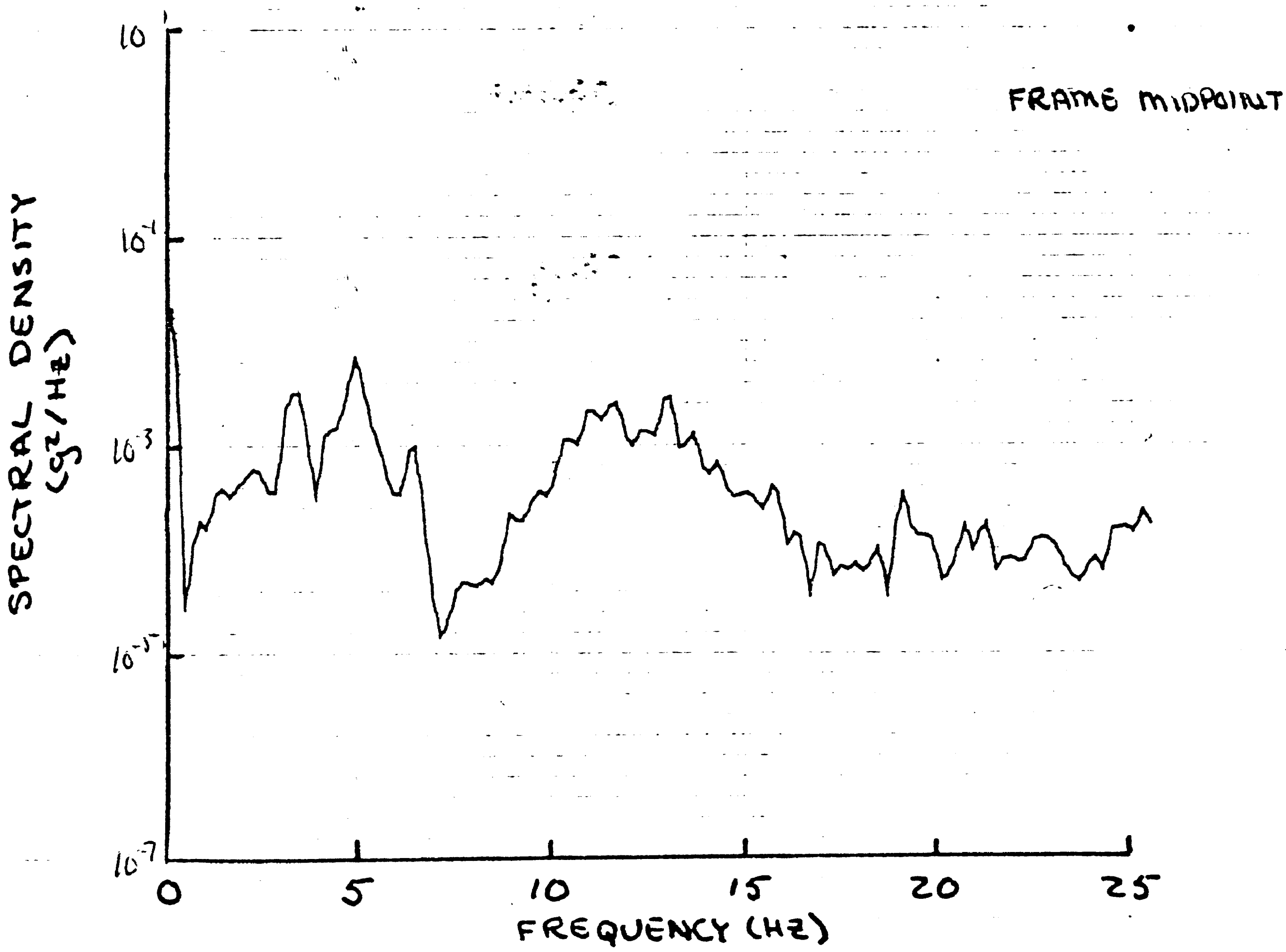

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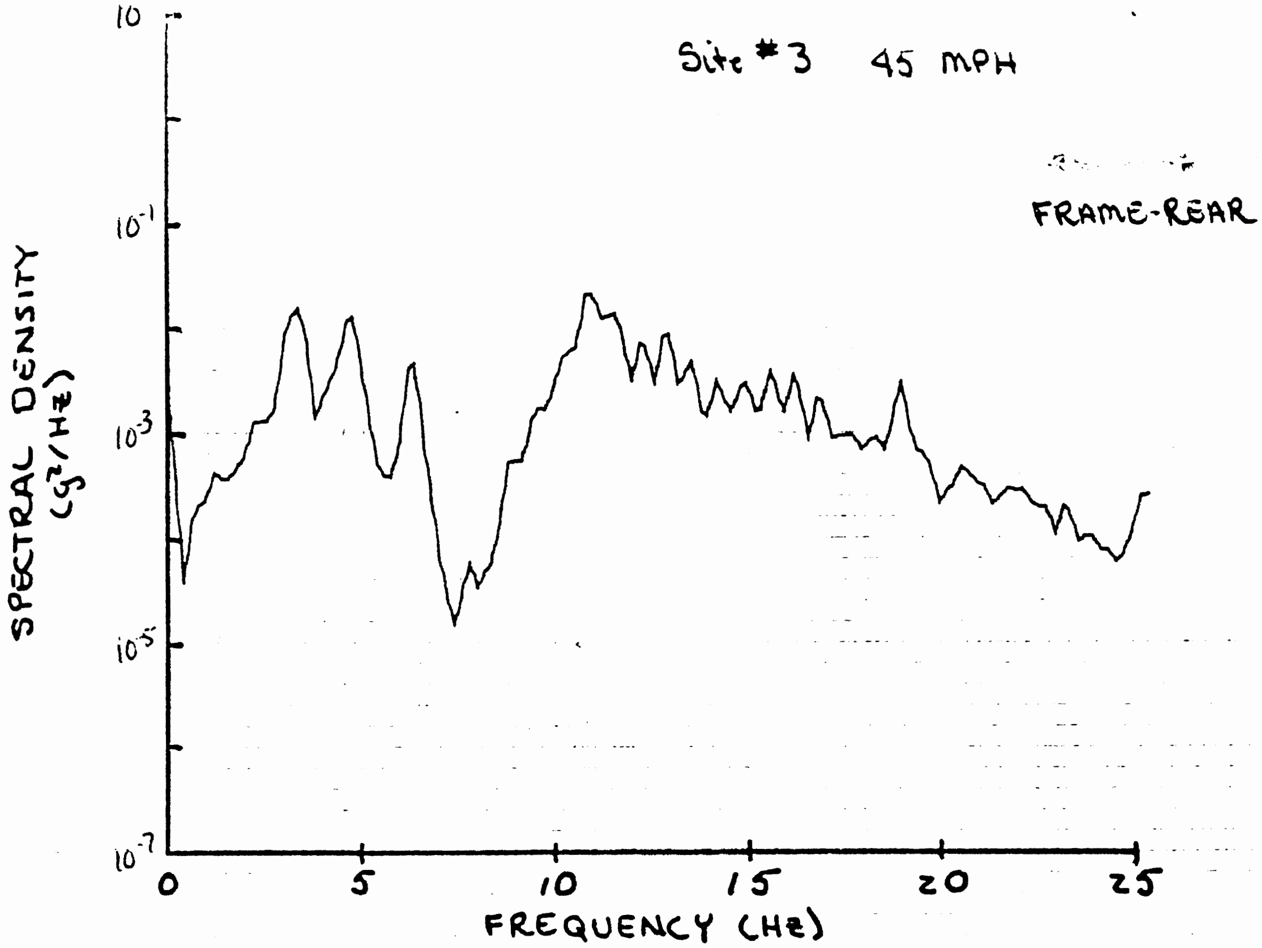

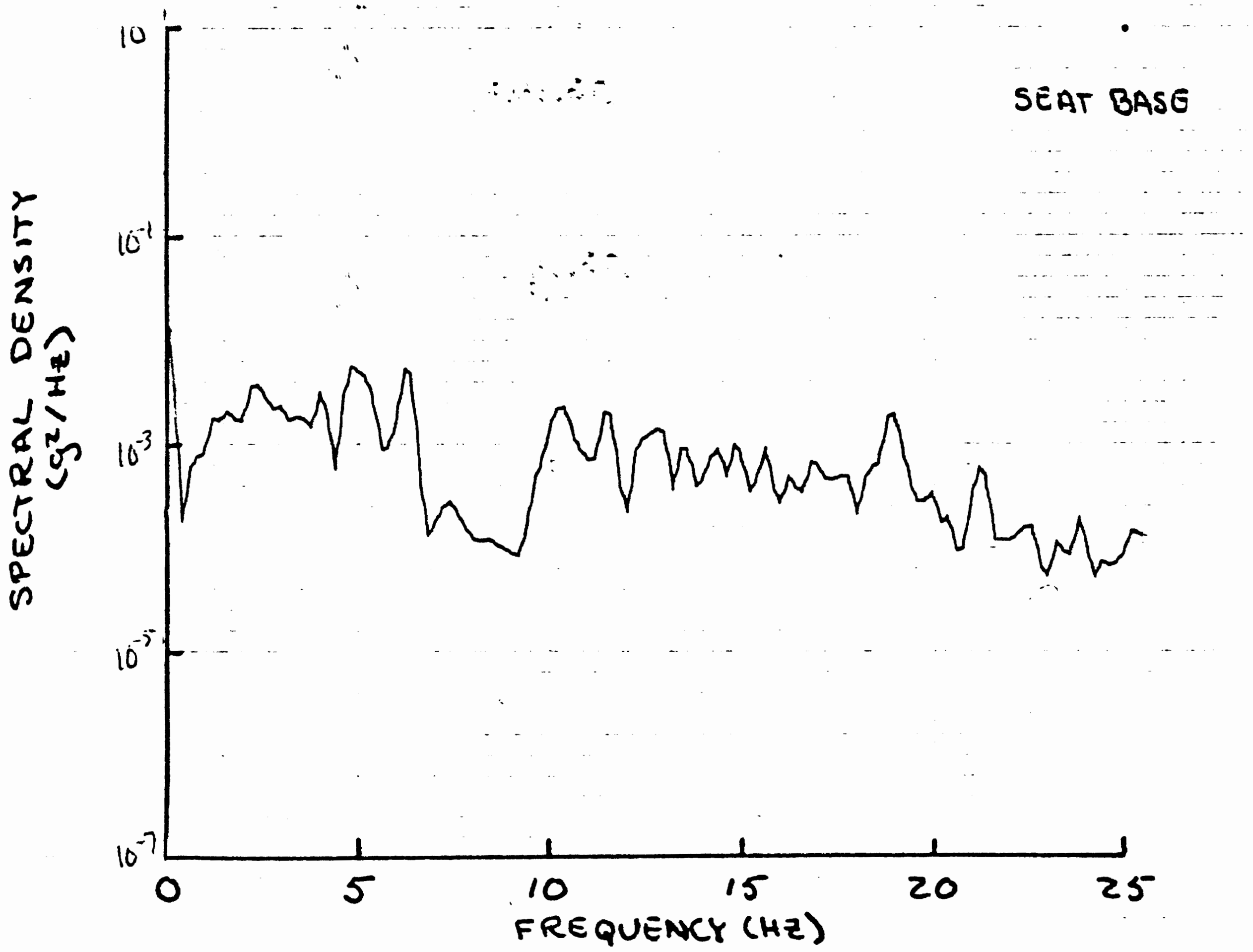

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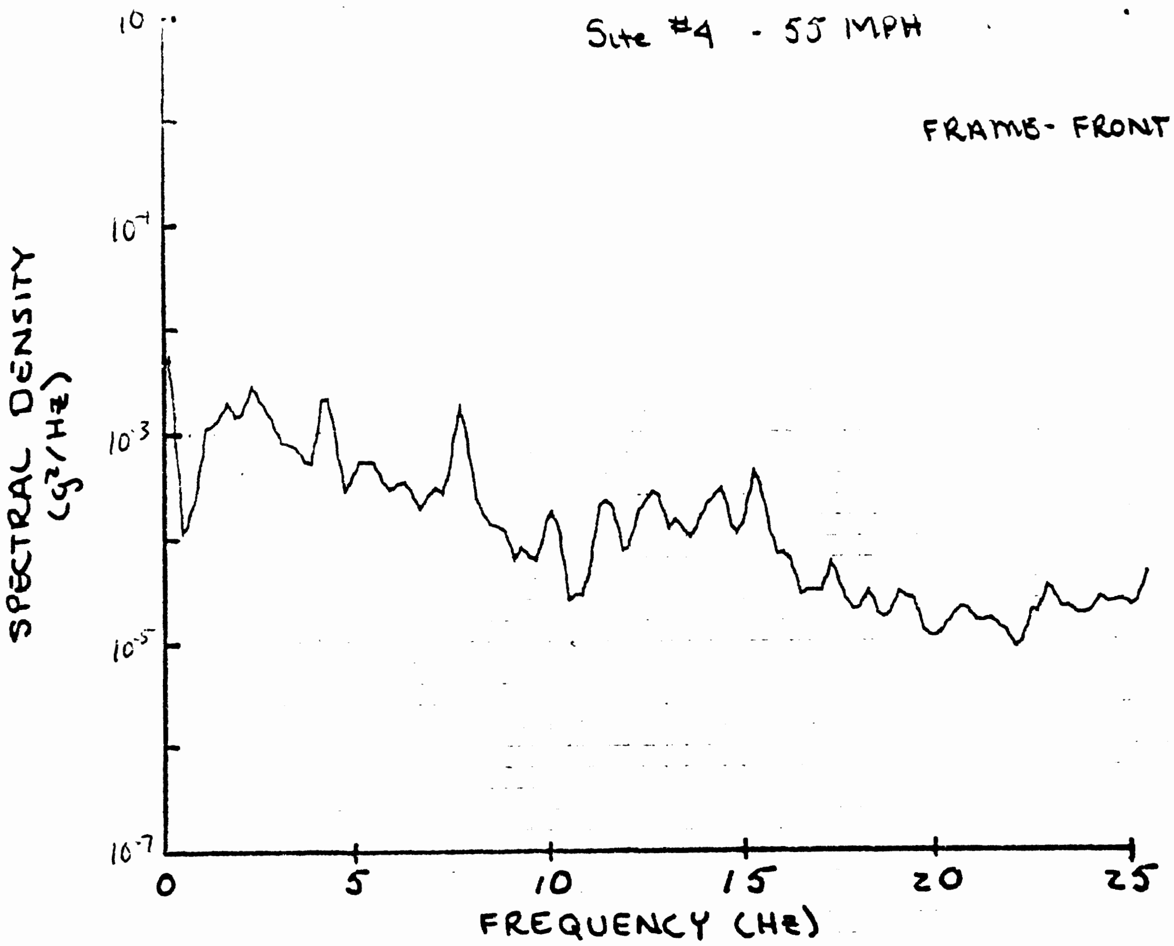

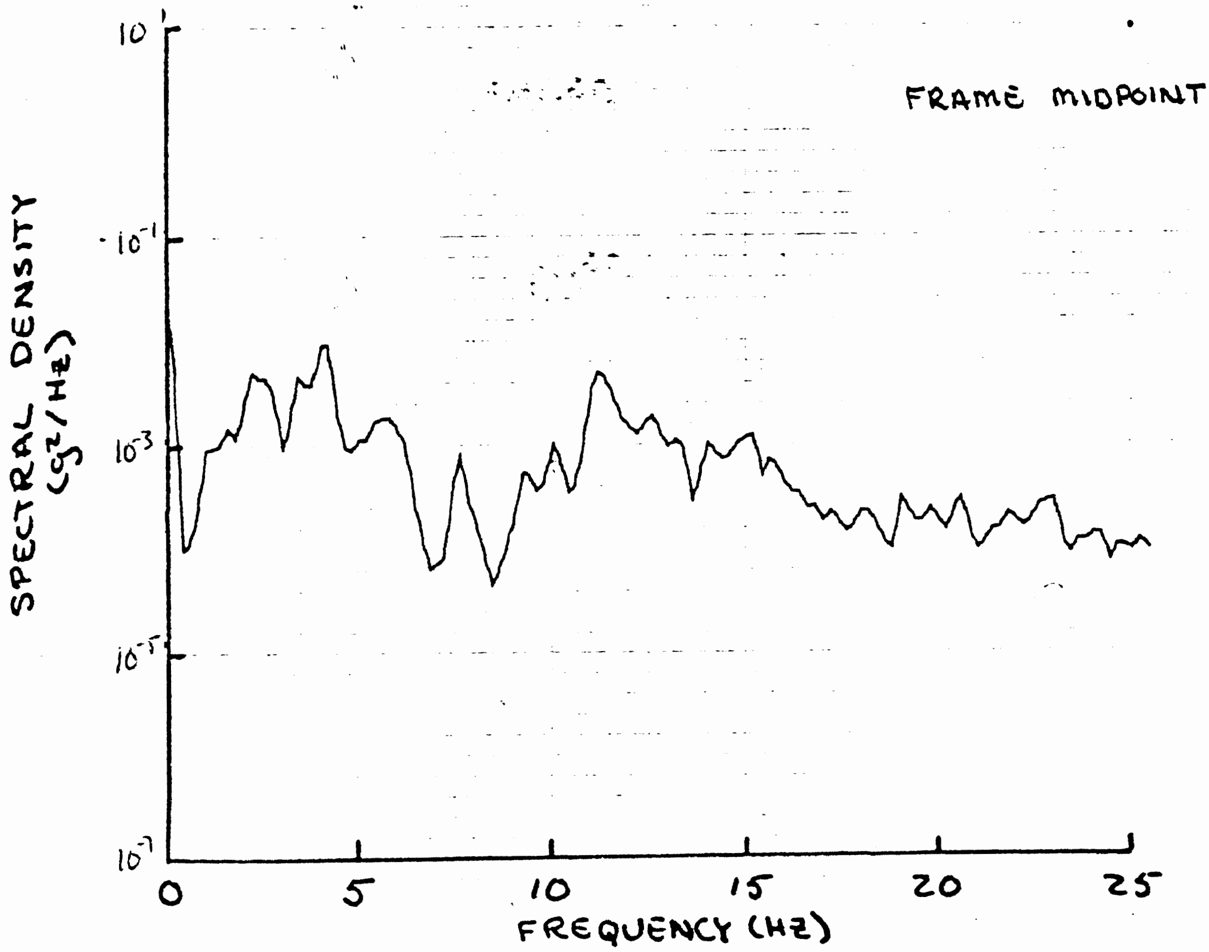

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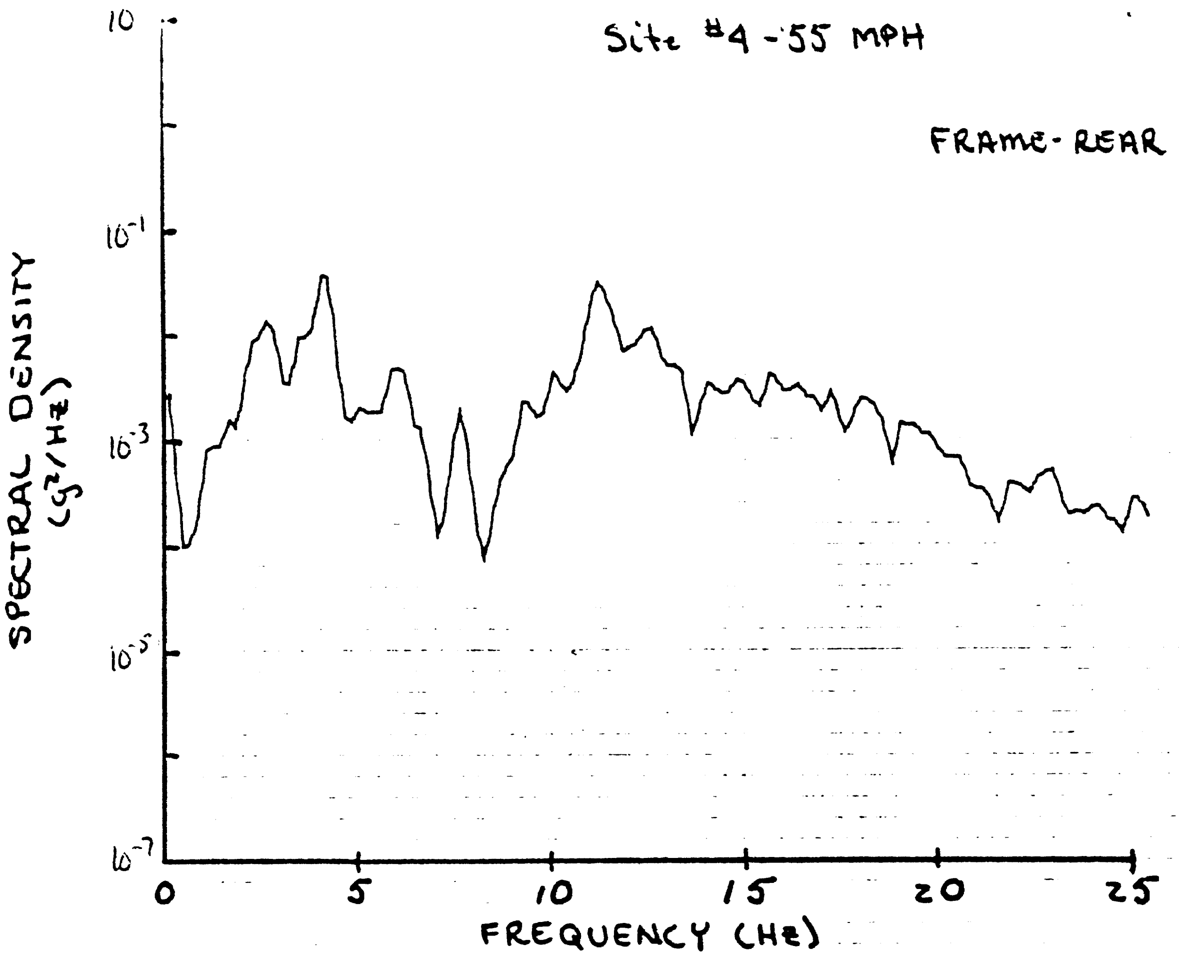

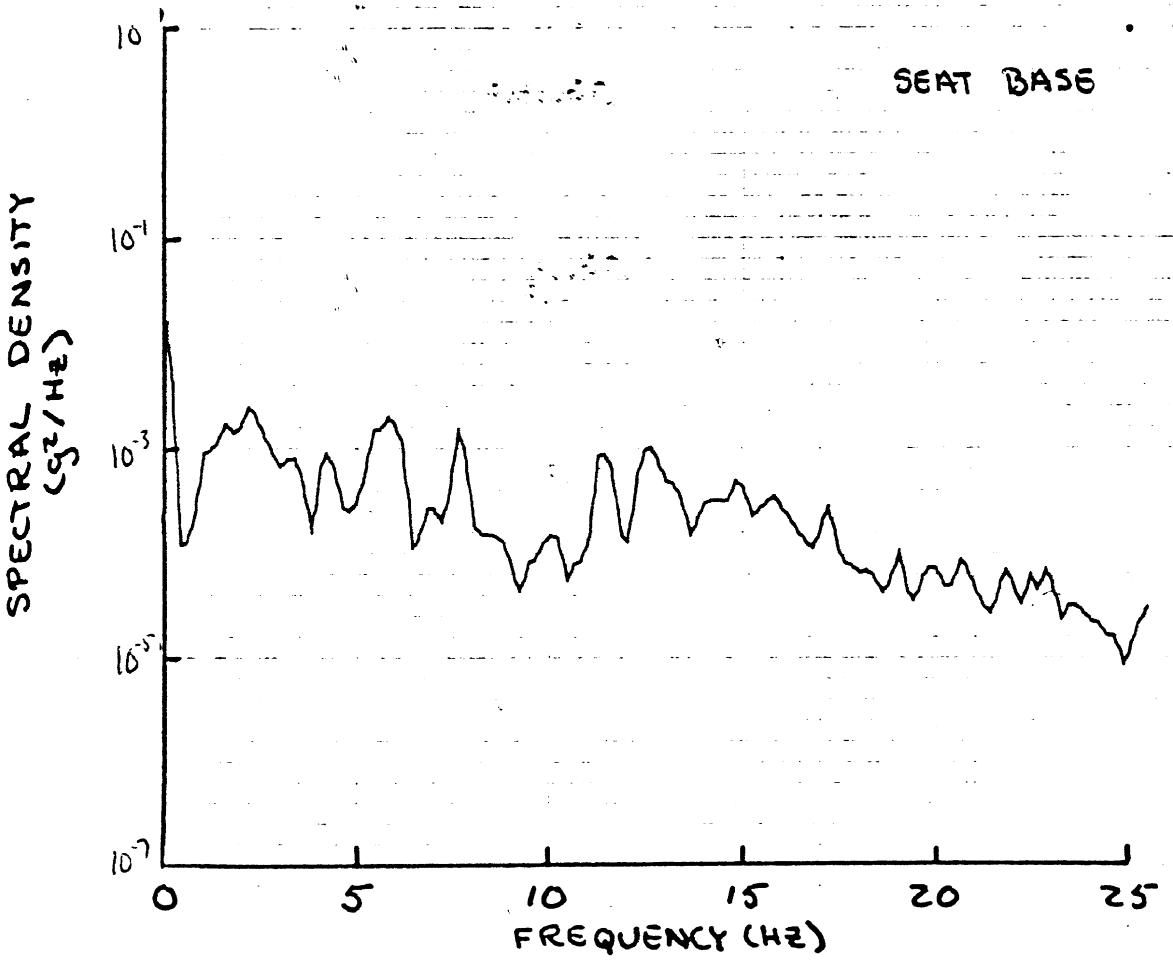

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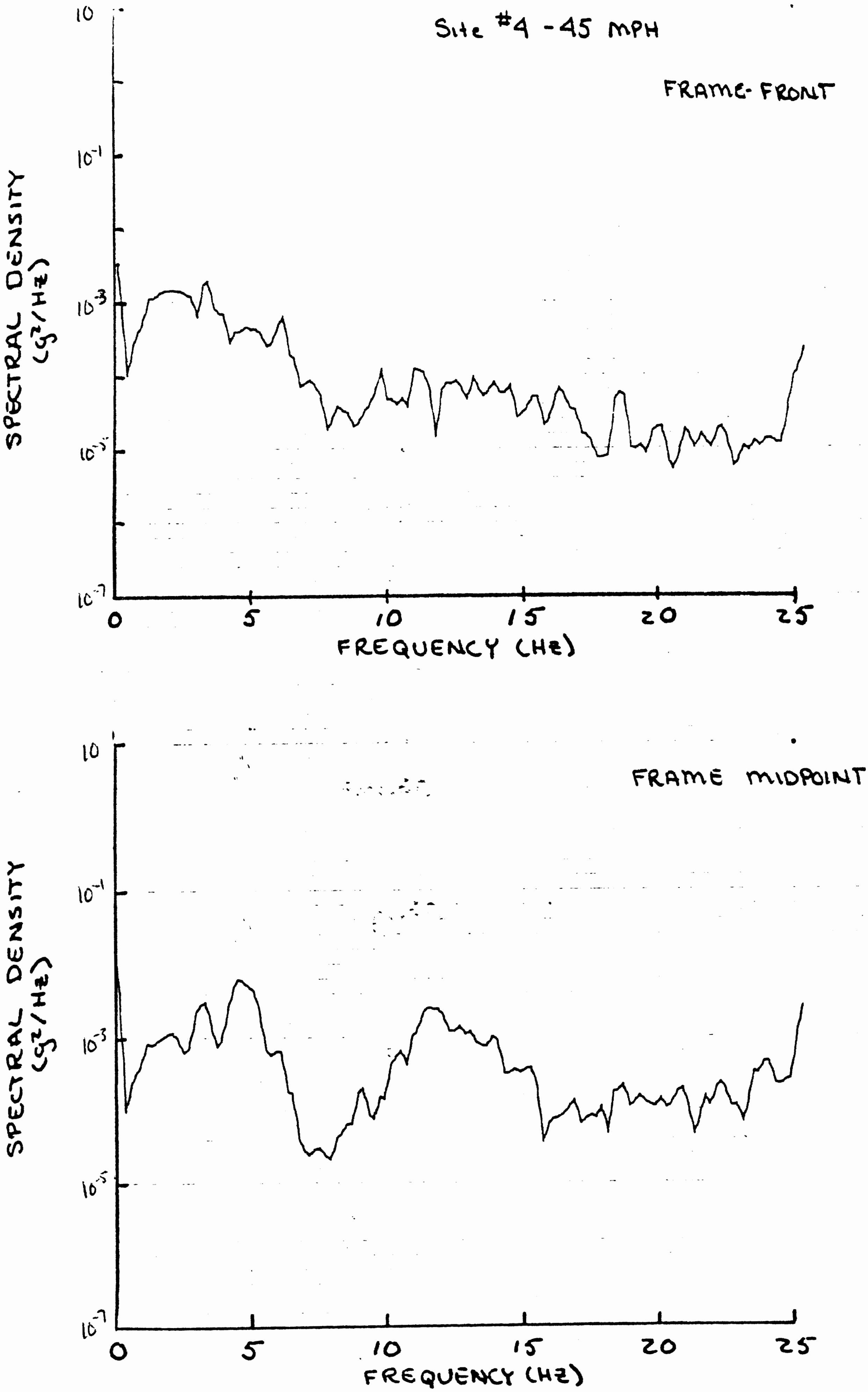

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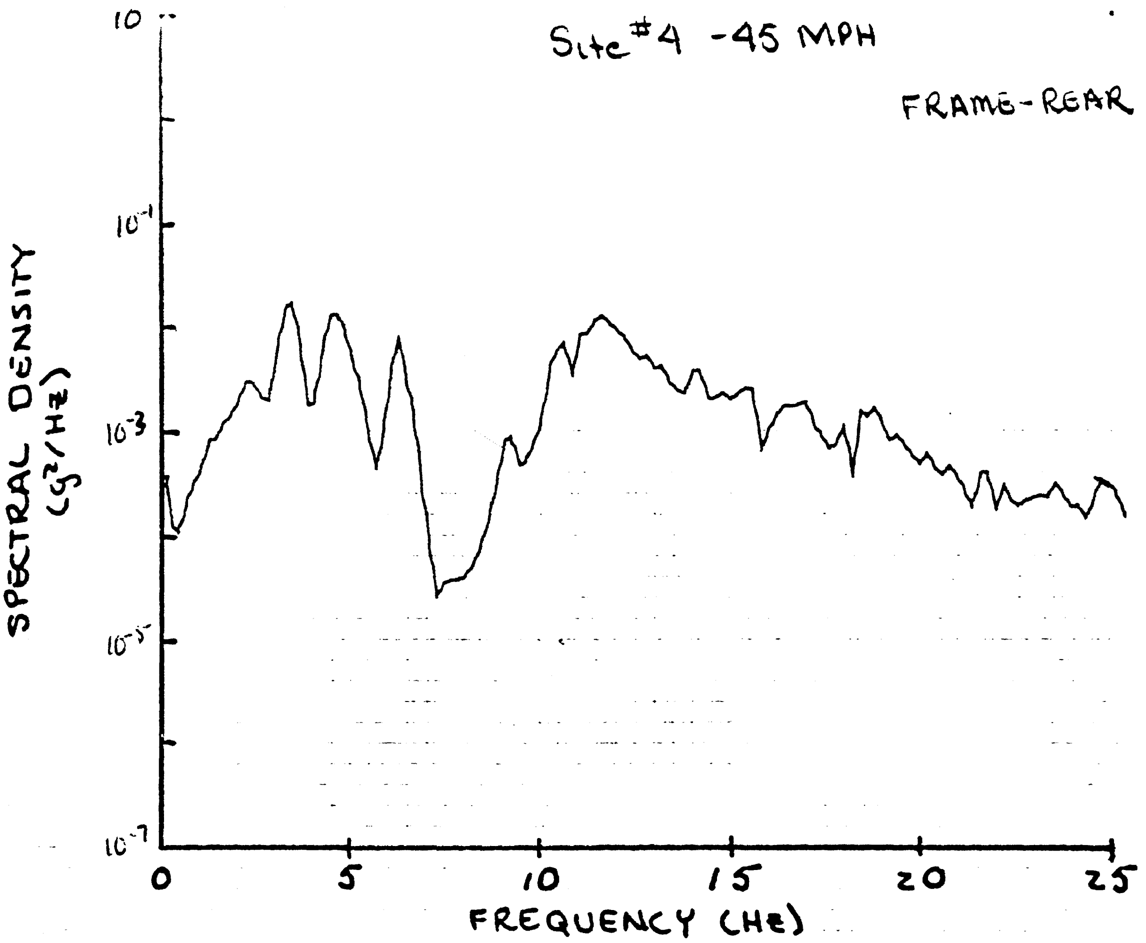

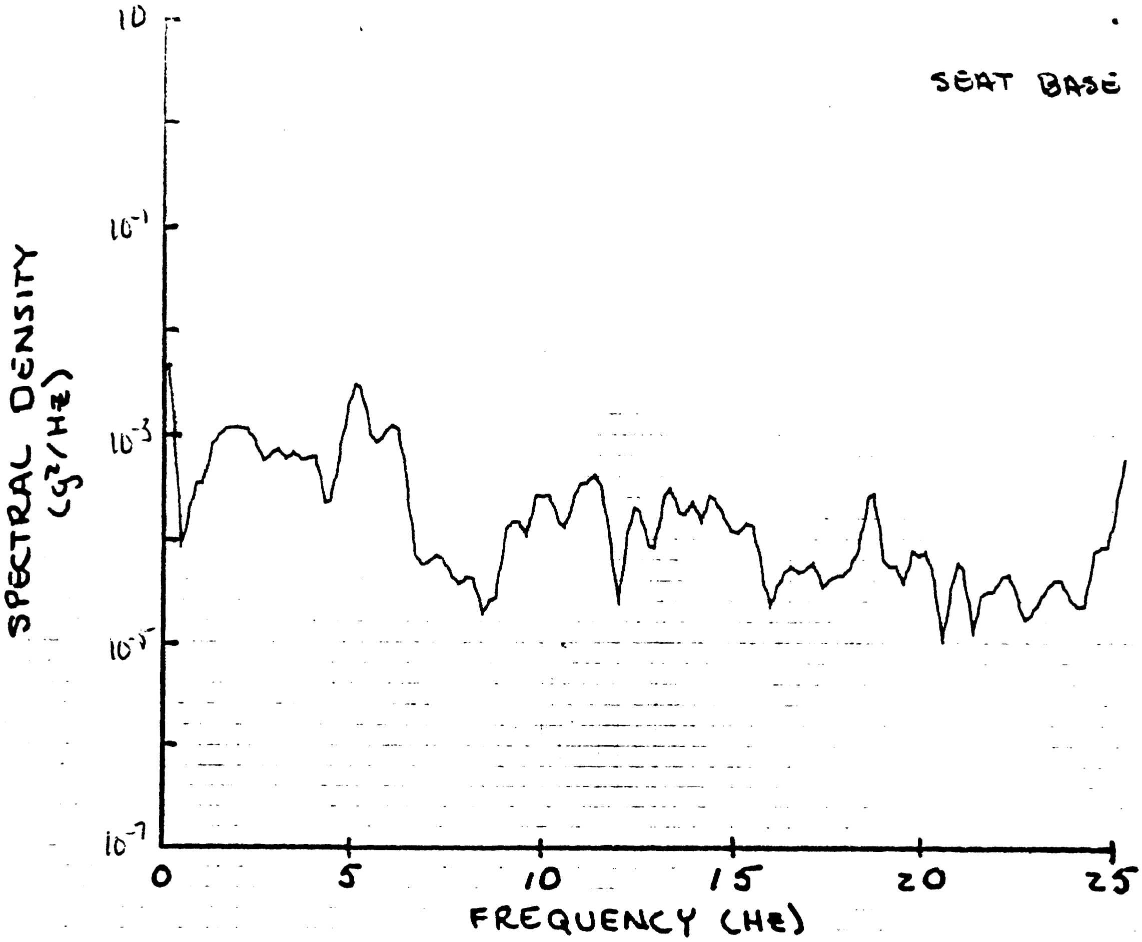

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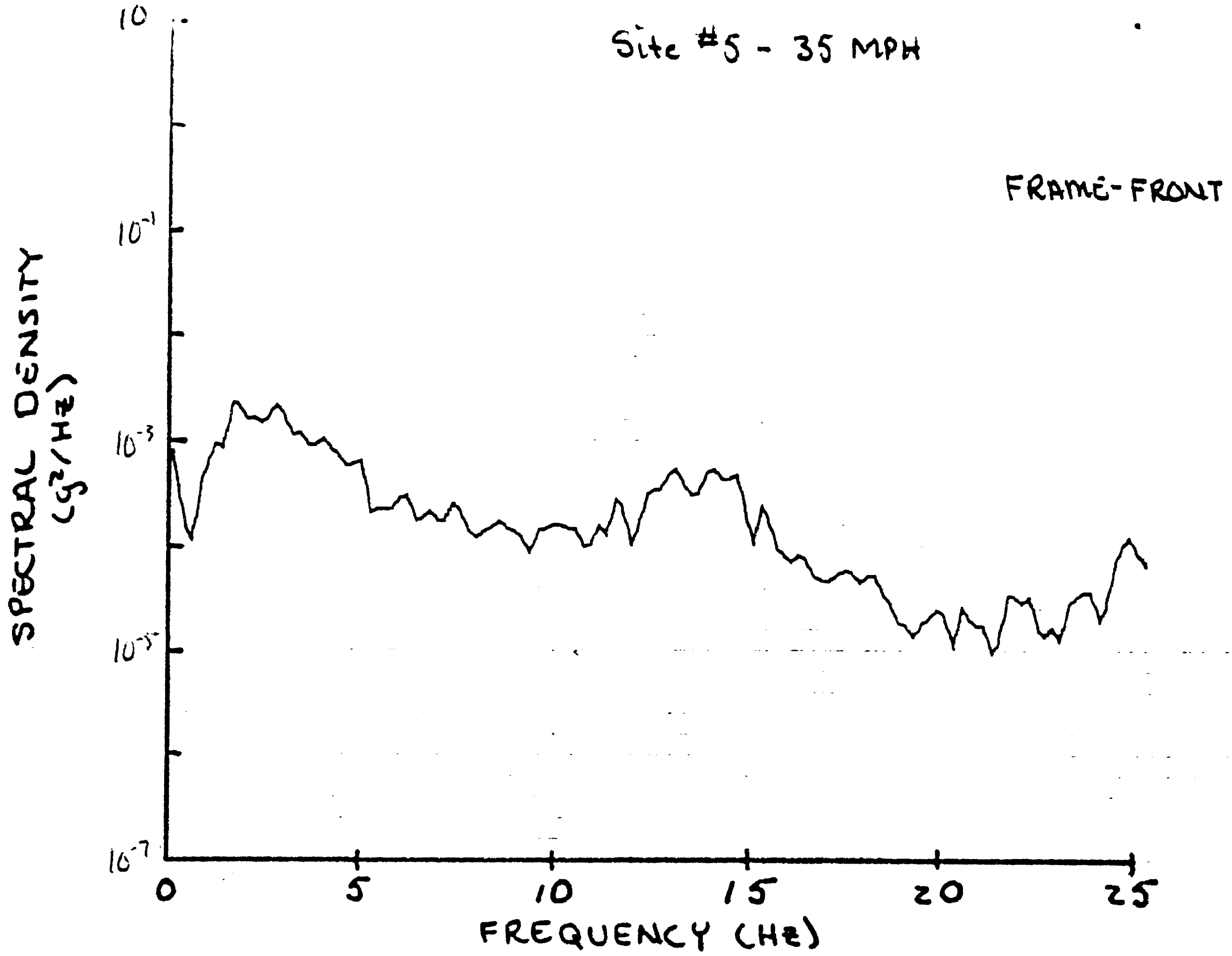

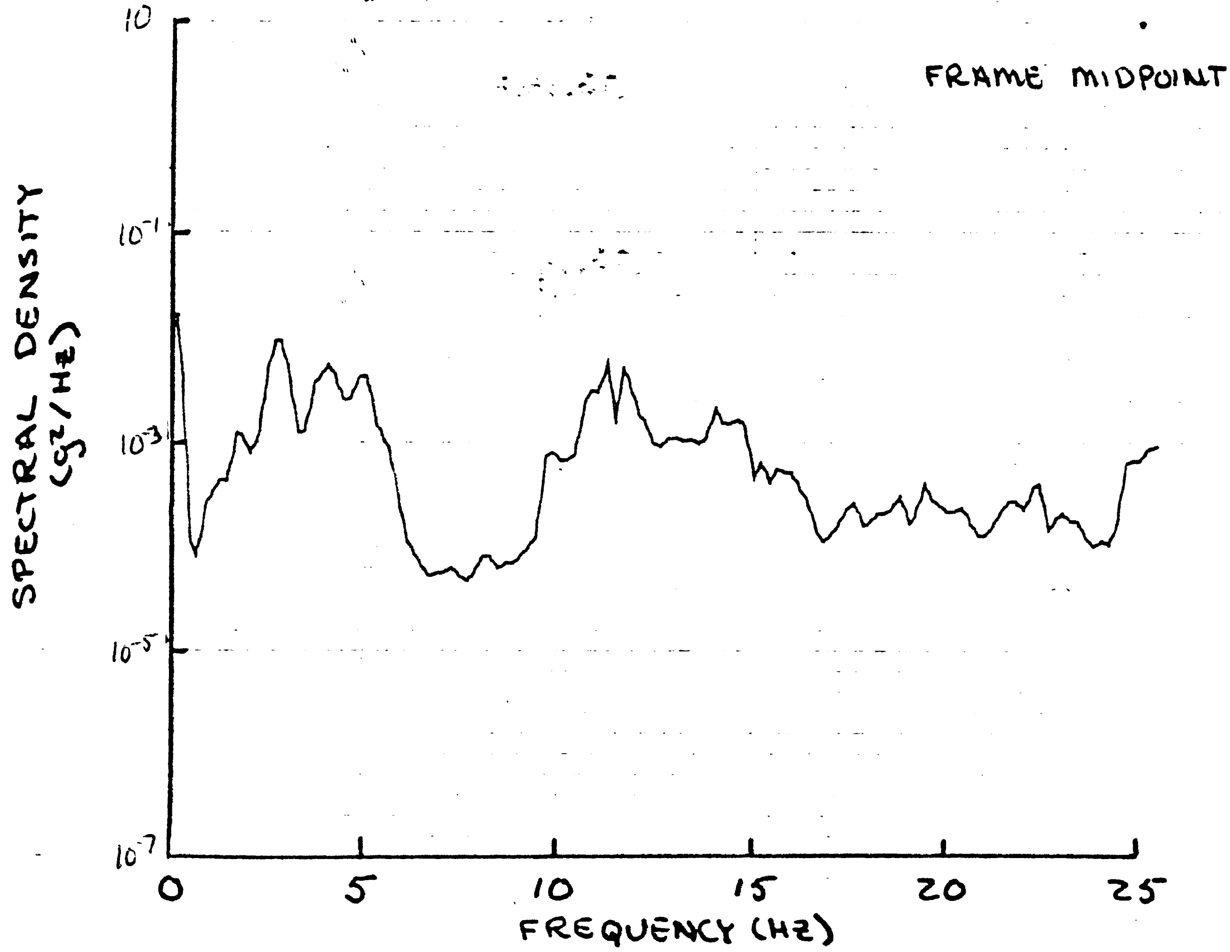

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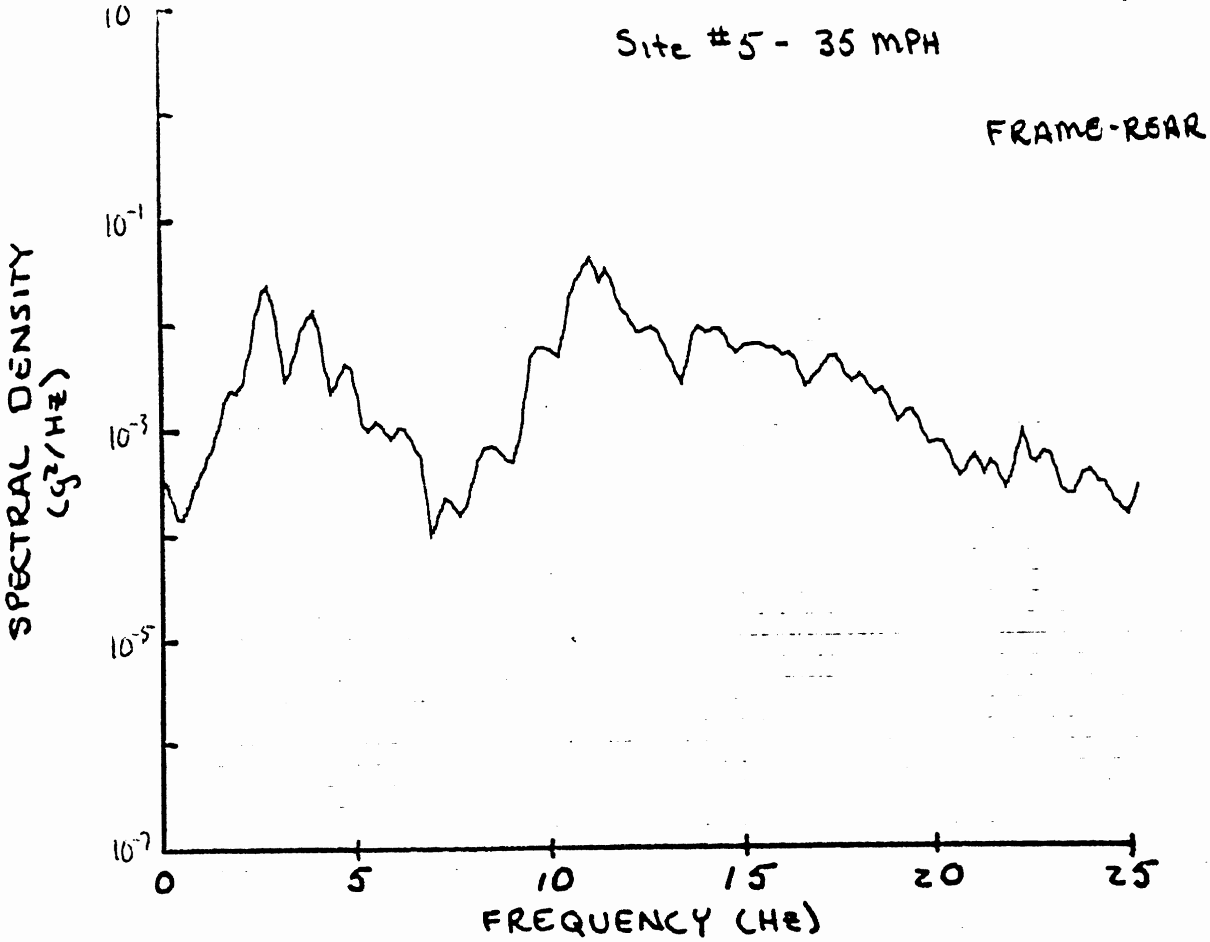

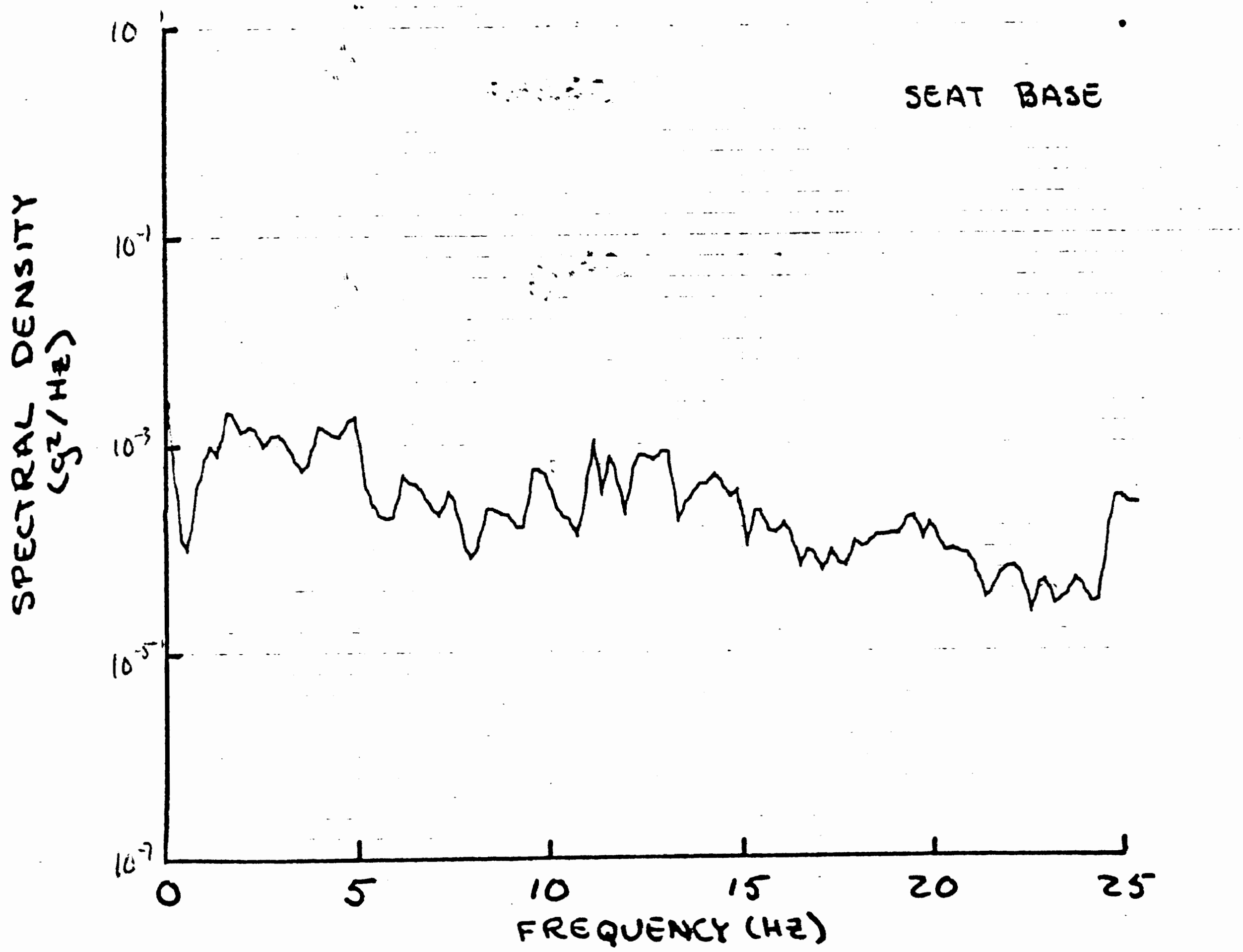

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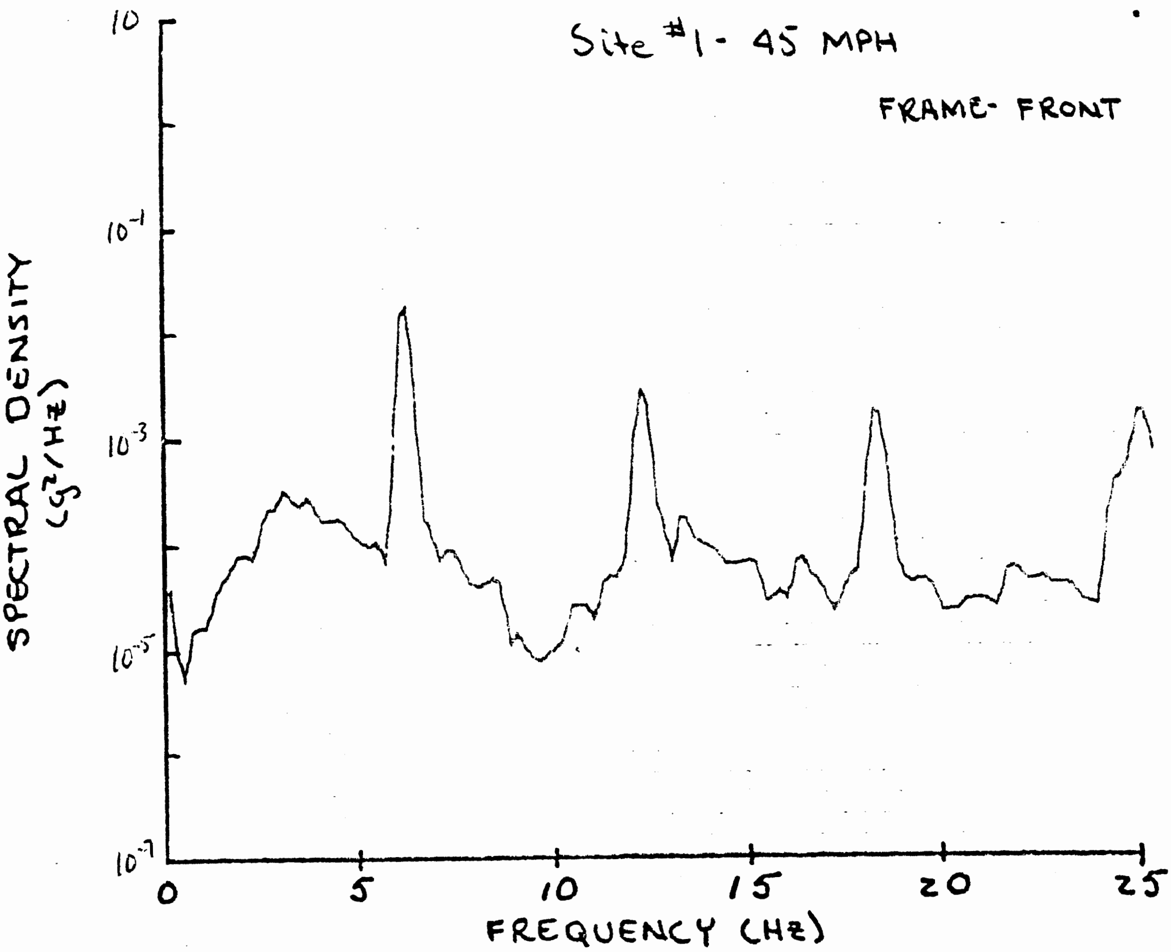


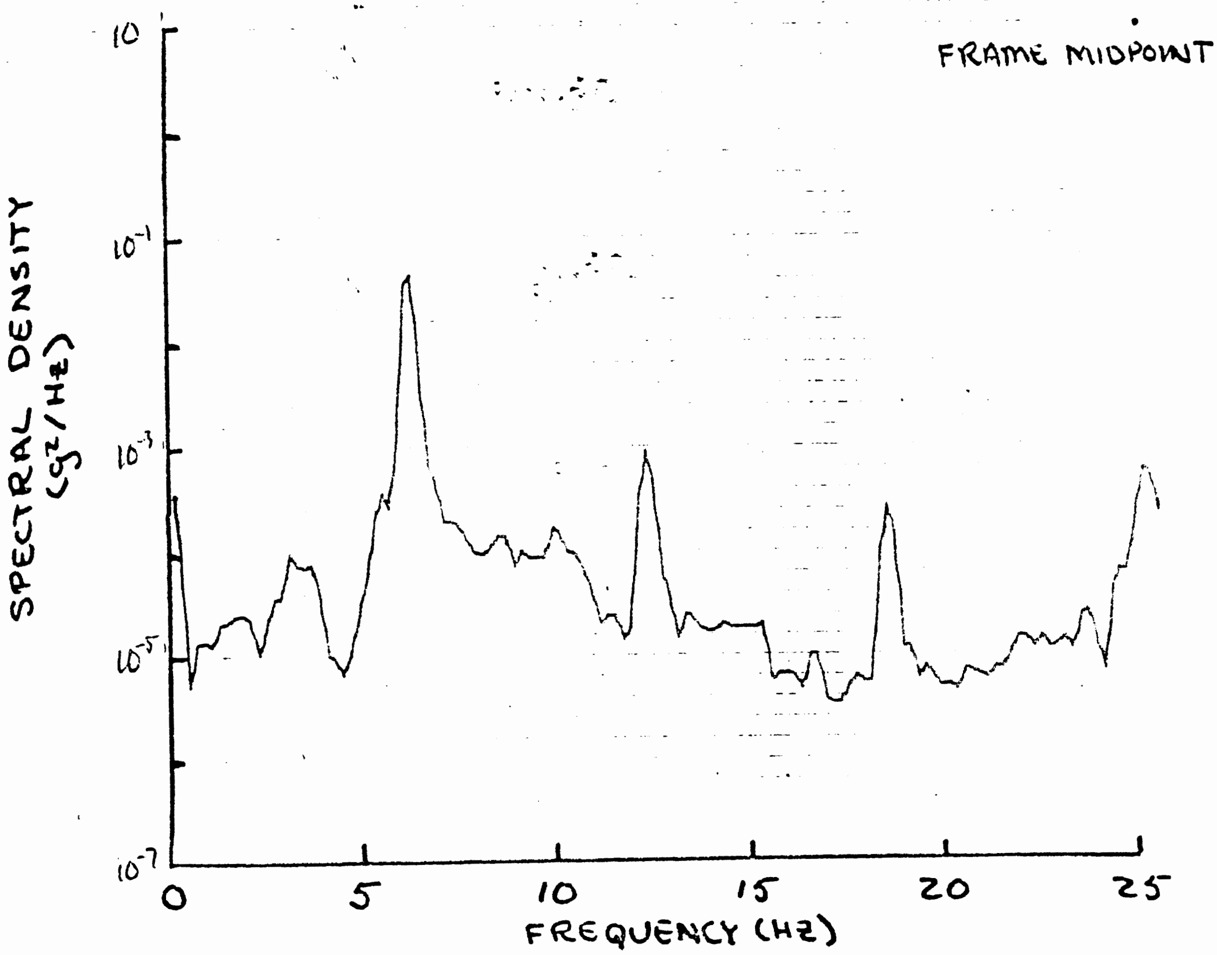
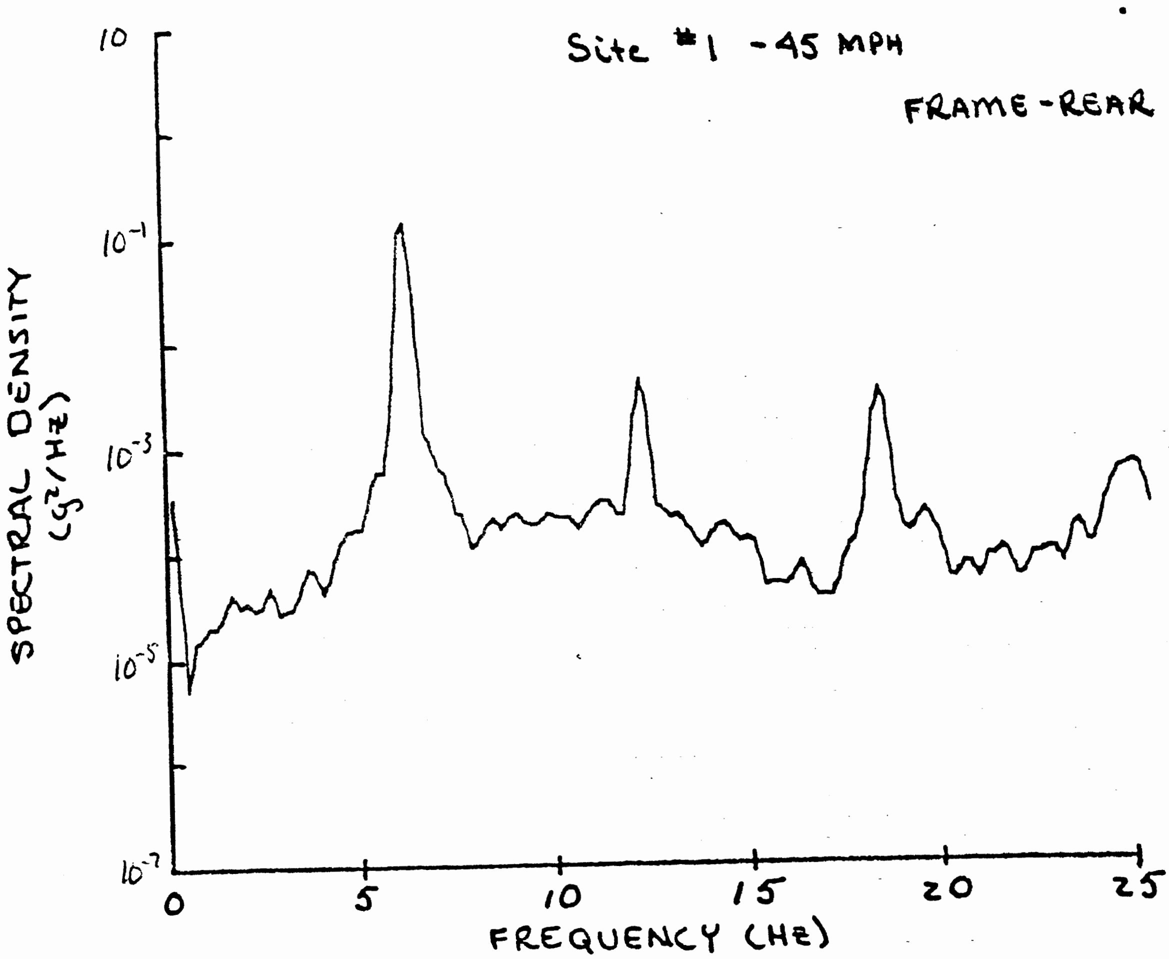
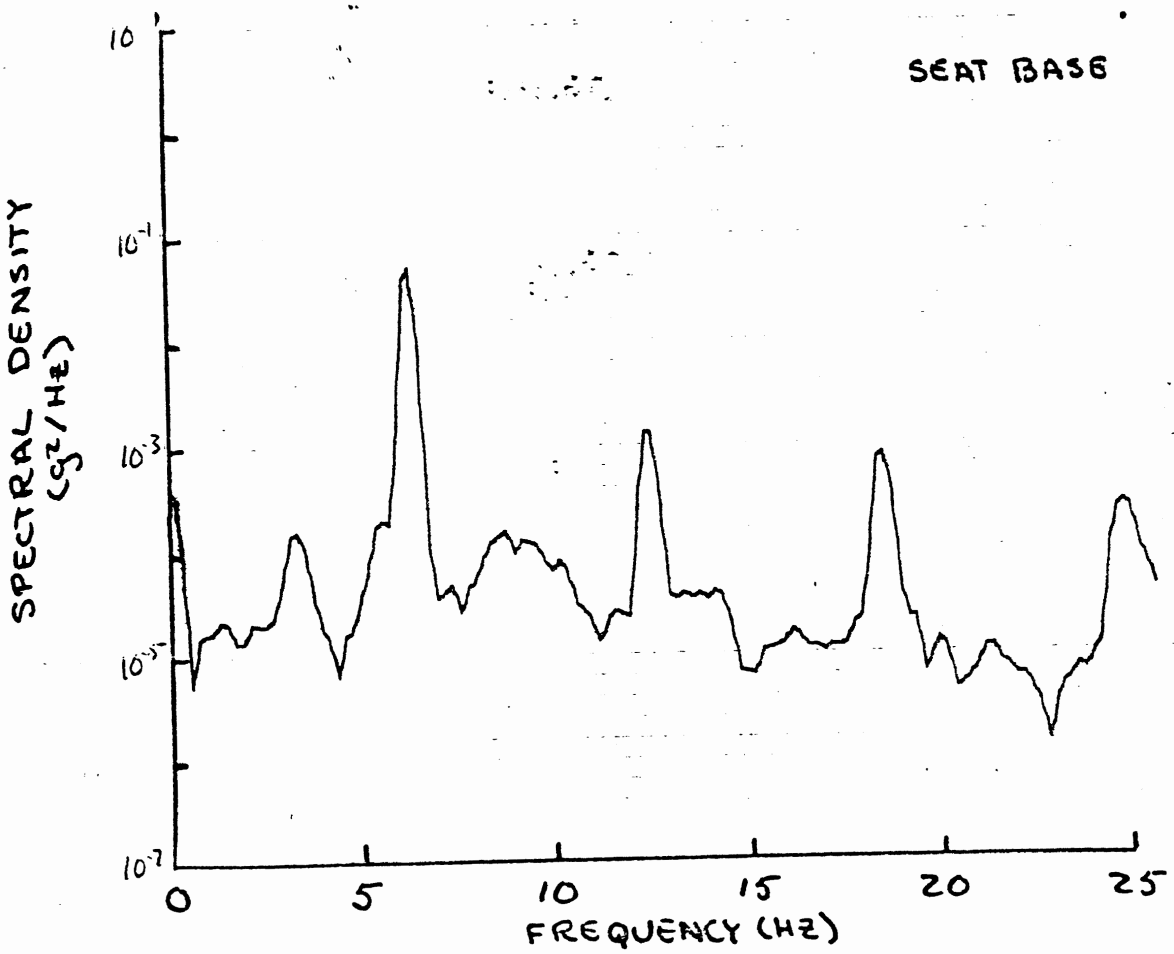


Figure VI.2.3. Bobtail conventional tractor.





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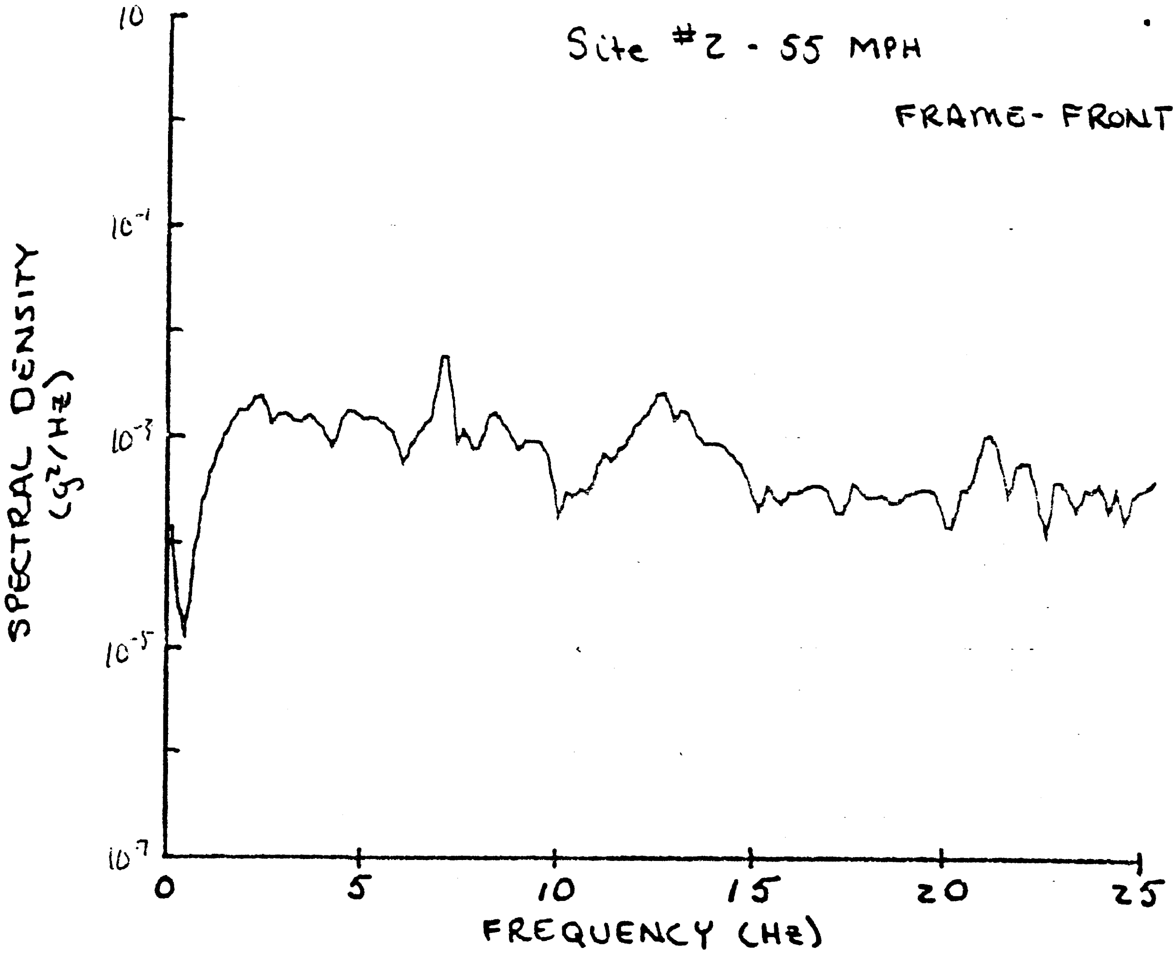
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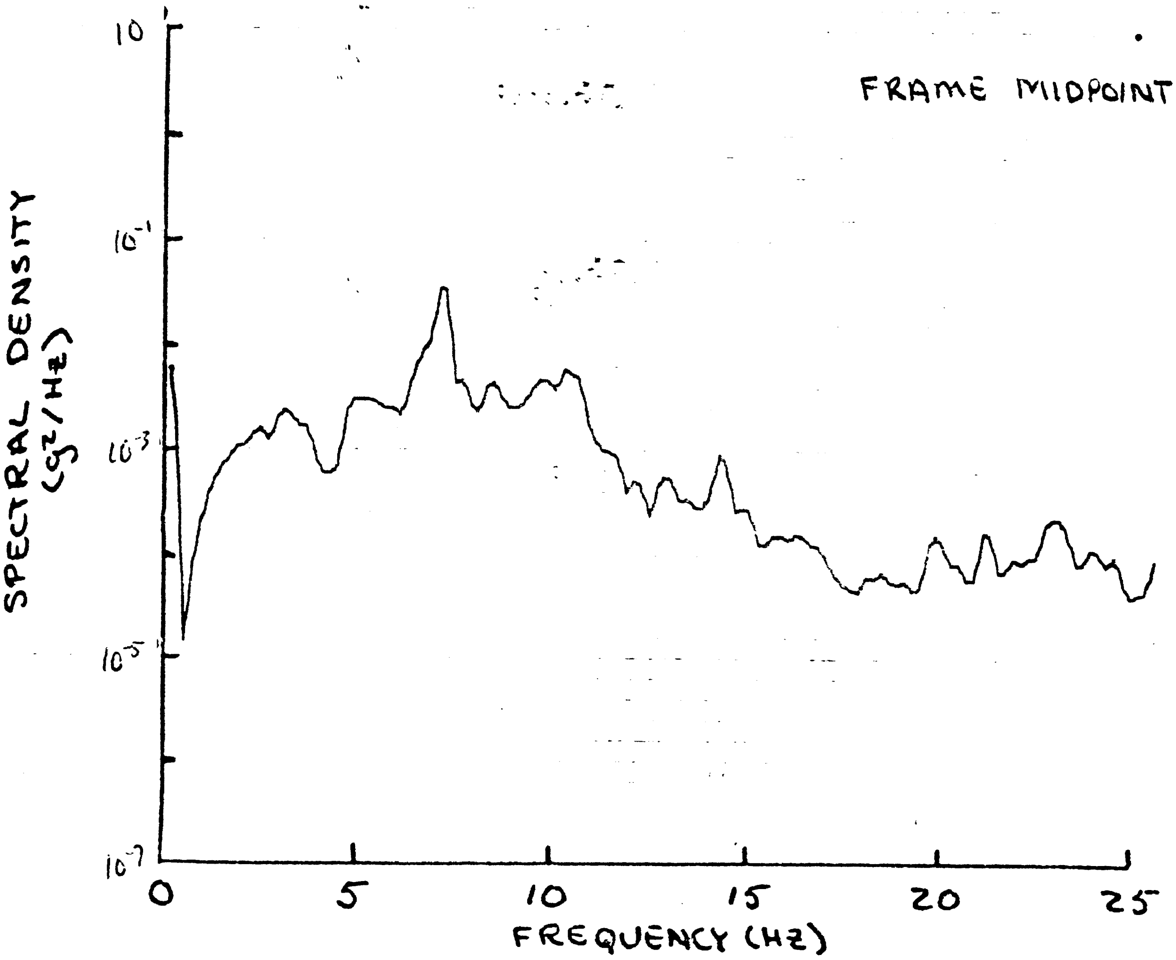
10⁻³
10⁻⁵
10⁻⁷
0
5
10
15
20
25
FREQUENCY (Hz)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SPECTRAL DENSITY (g²/Hz)
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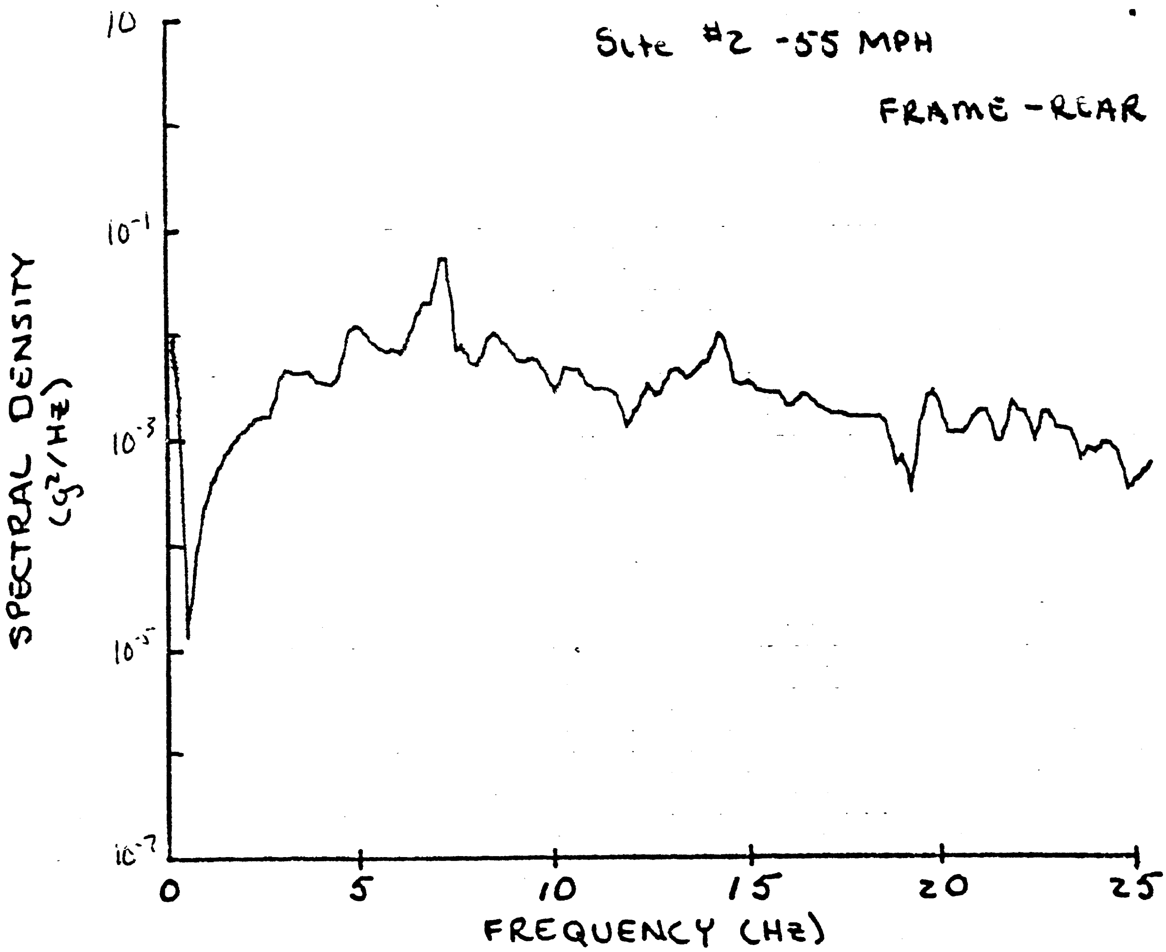
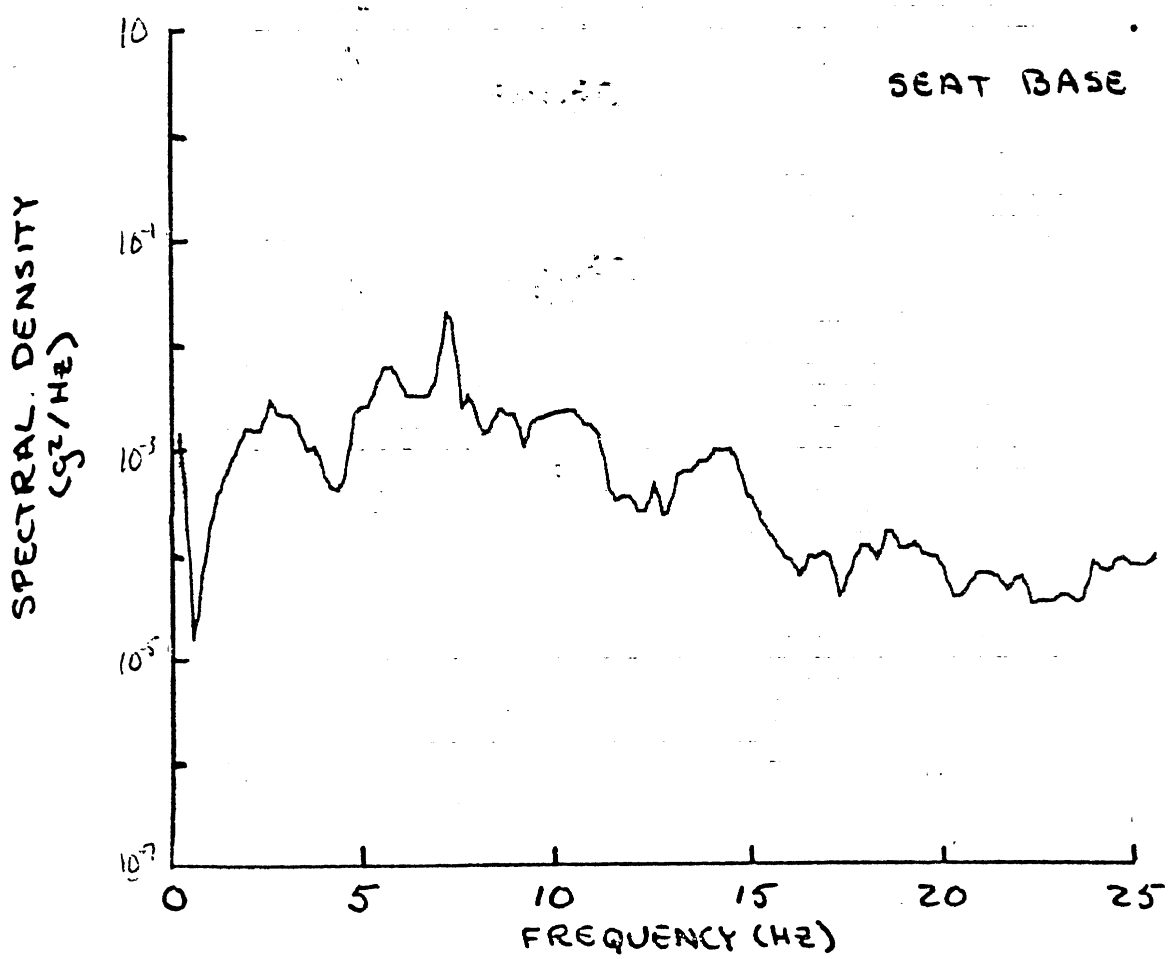
10⁻¹
10⁻³
10⁻⁵
10⁻⁷
0
5
10
15
20
25
FREQUENCY (HZ)

Figure [illegible] (Cont.)





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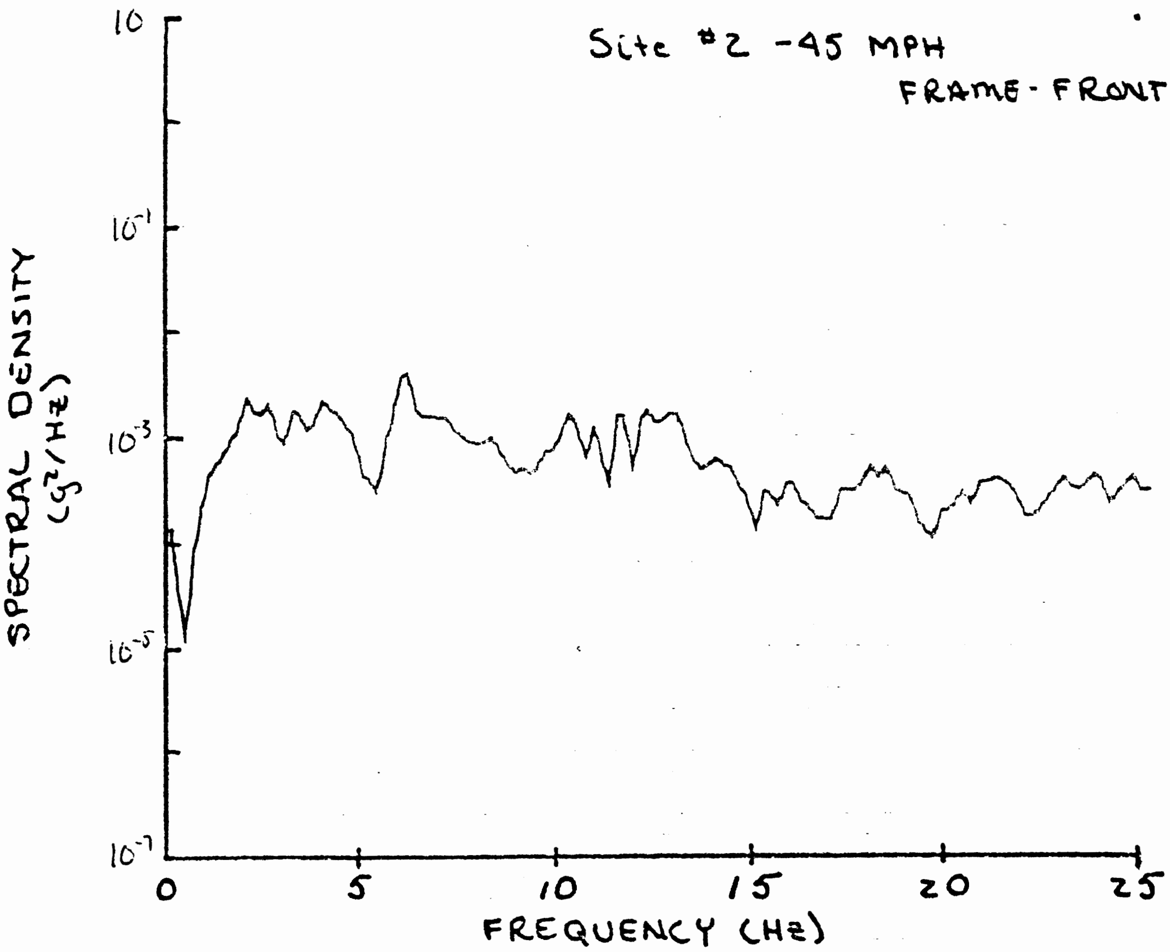

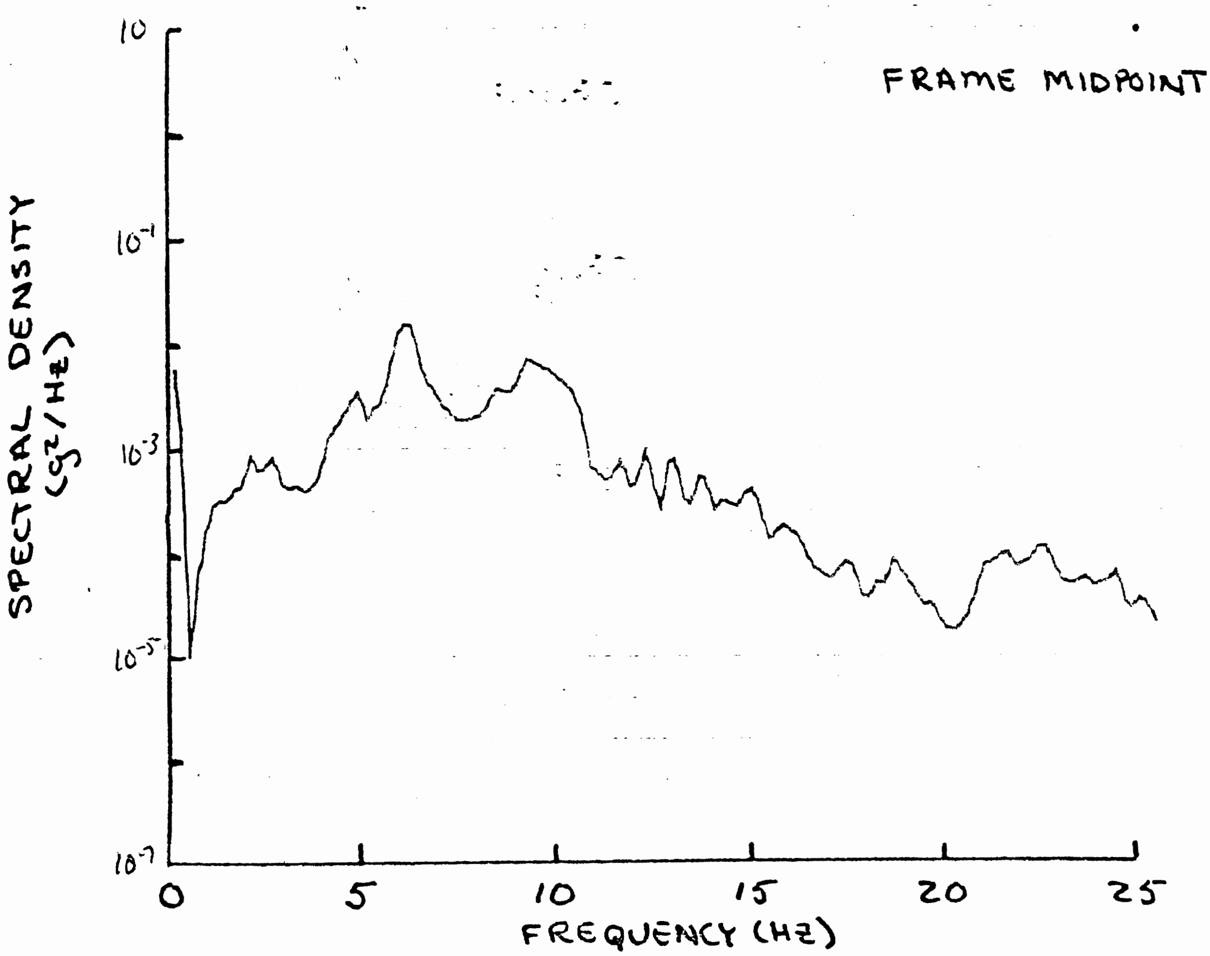

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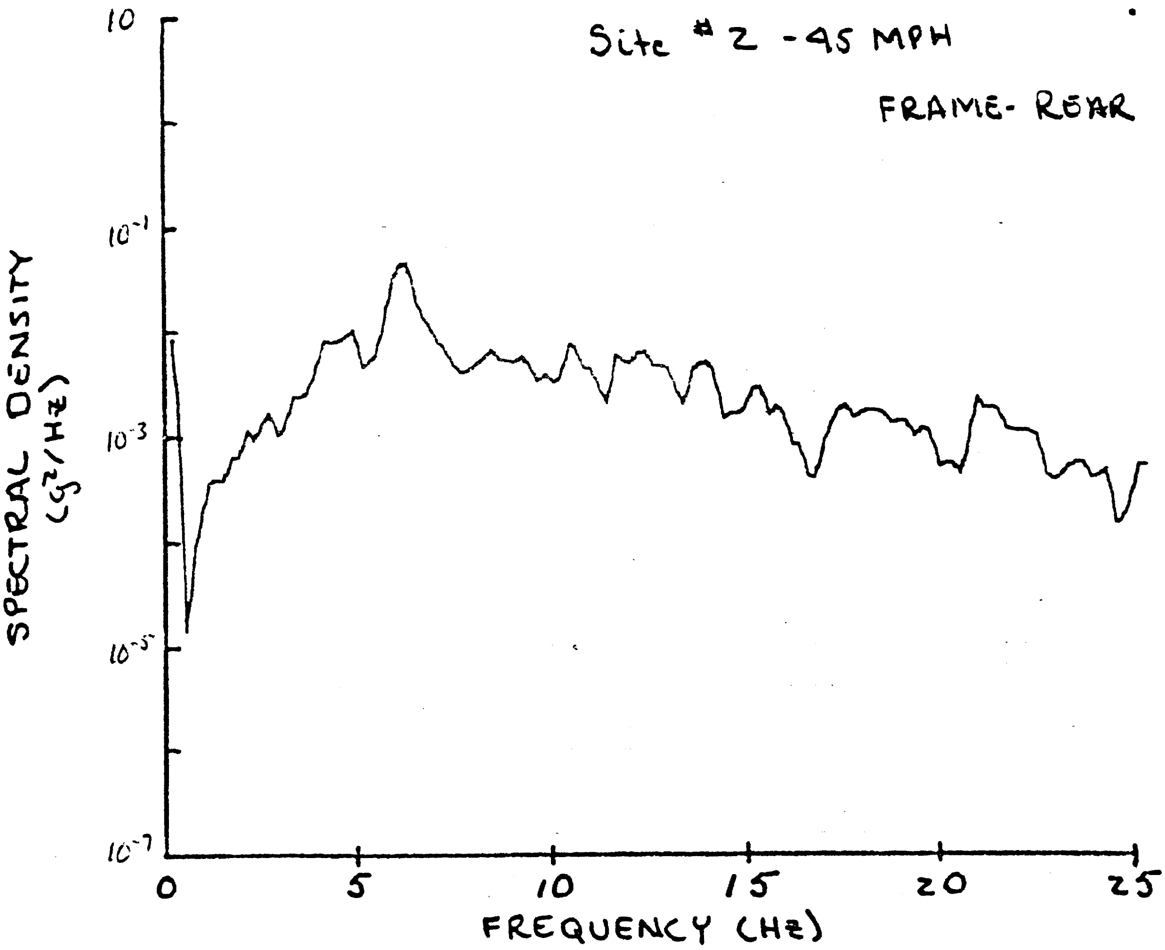

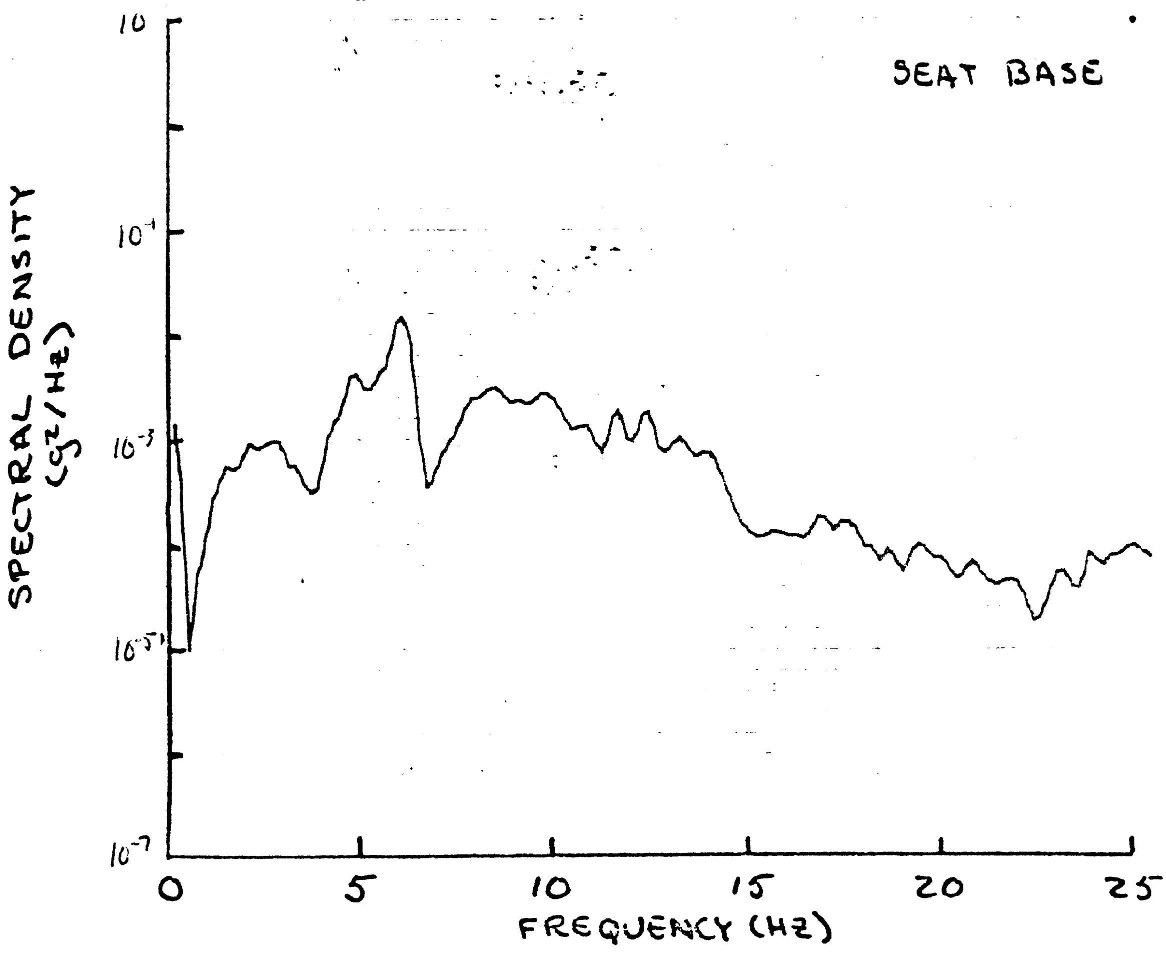

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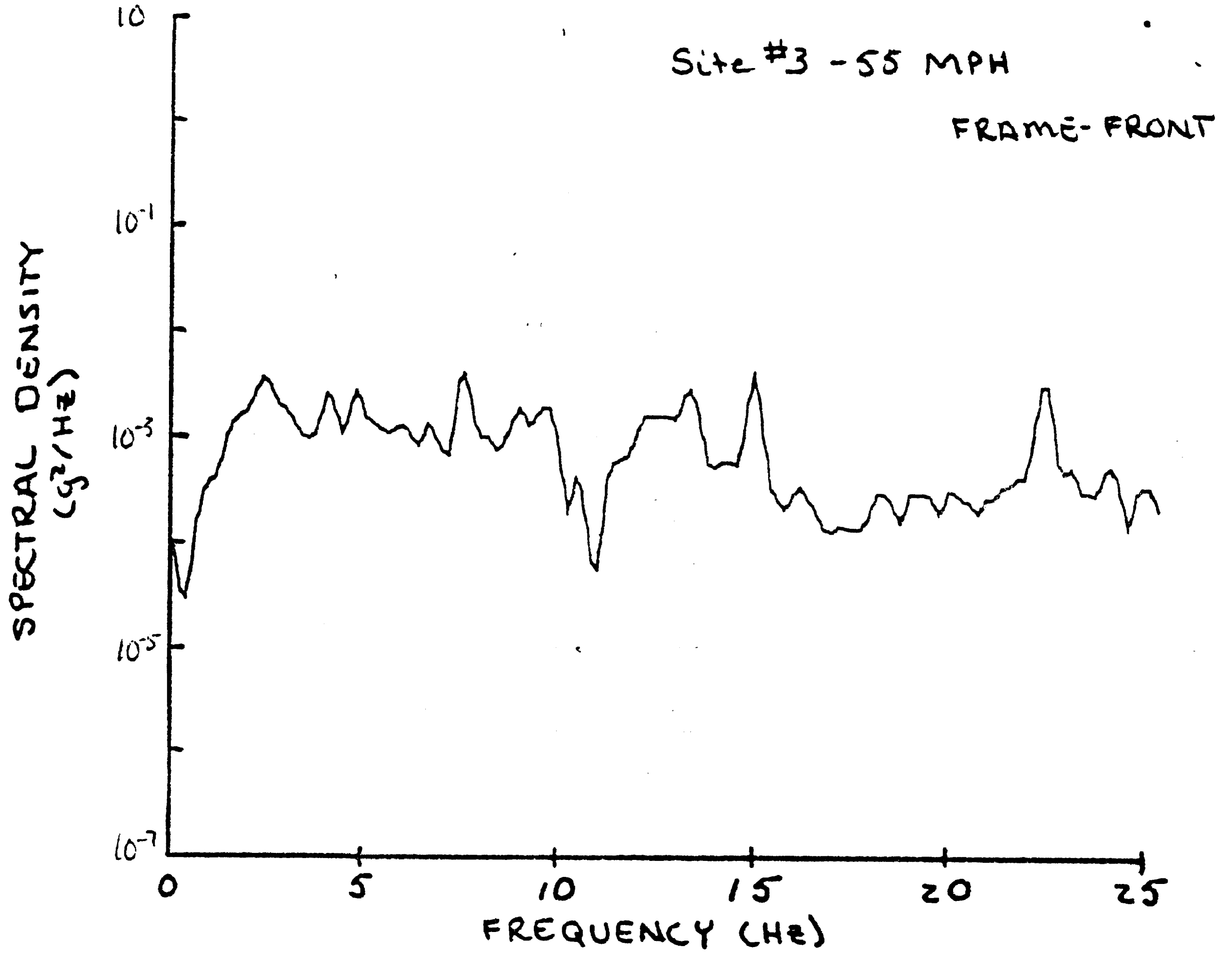


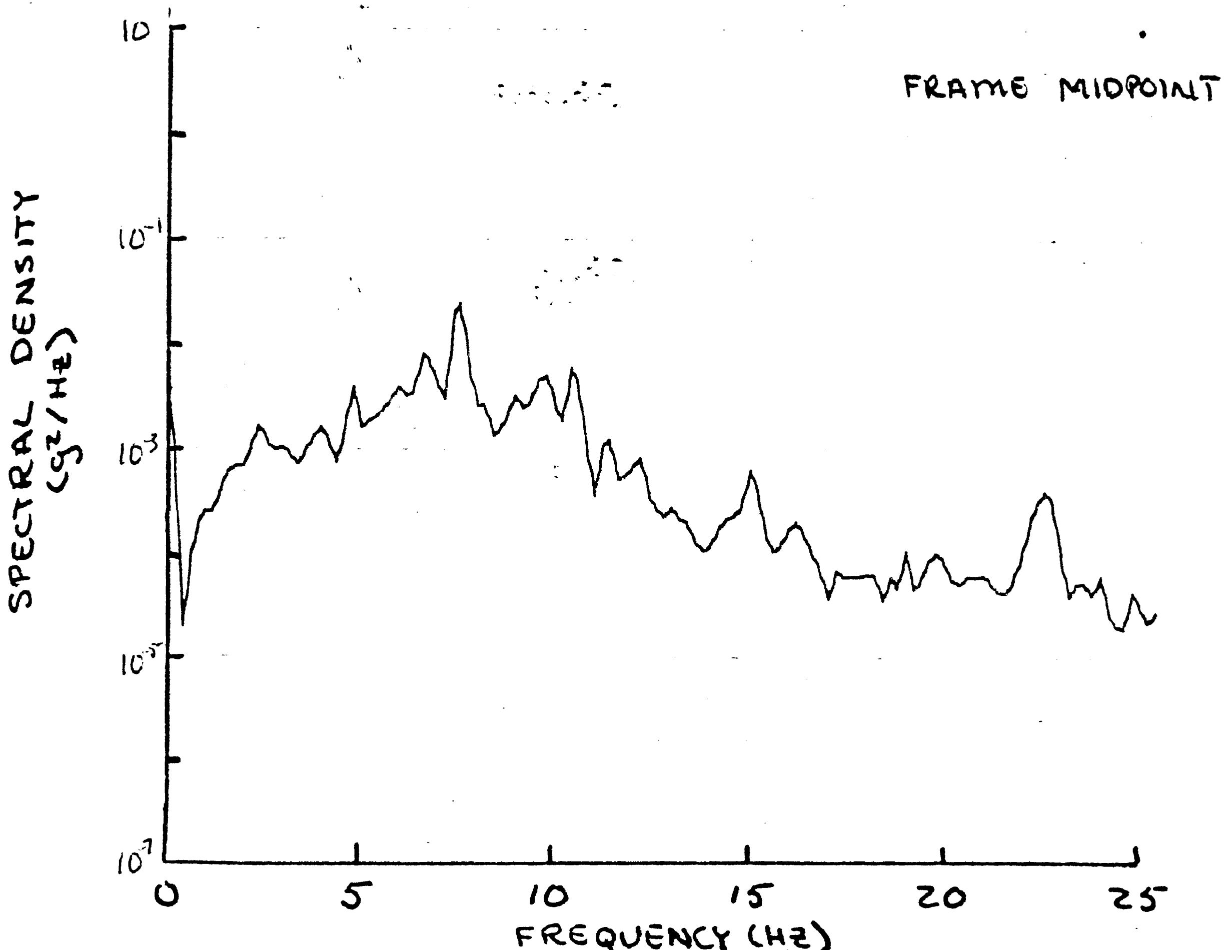
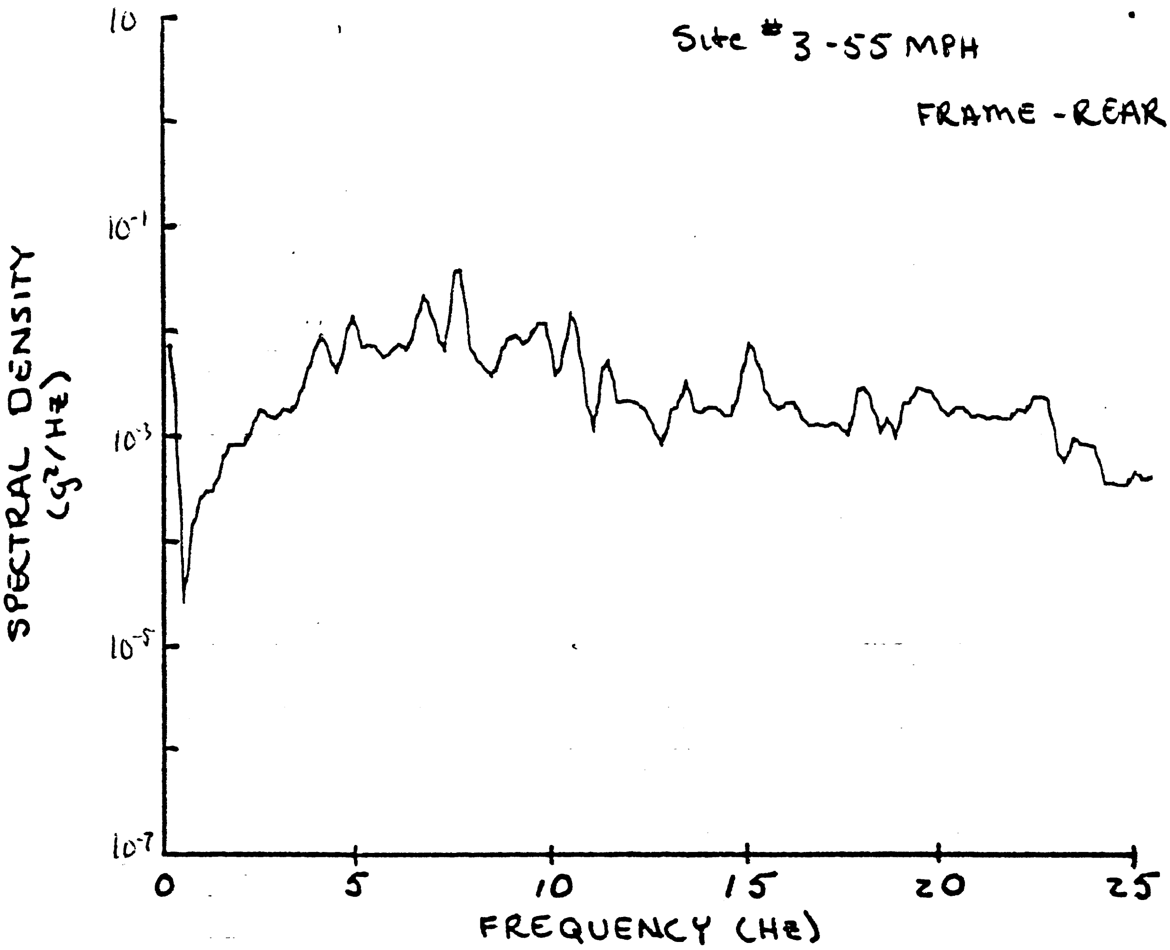
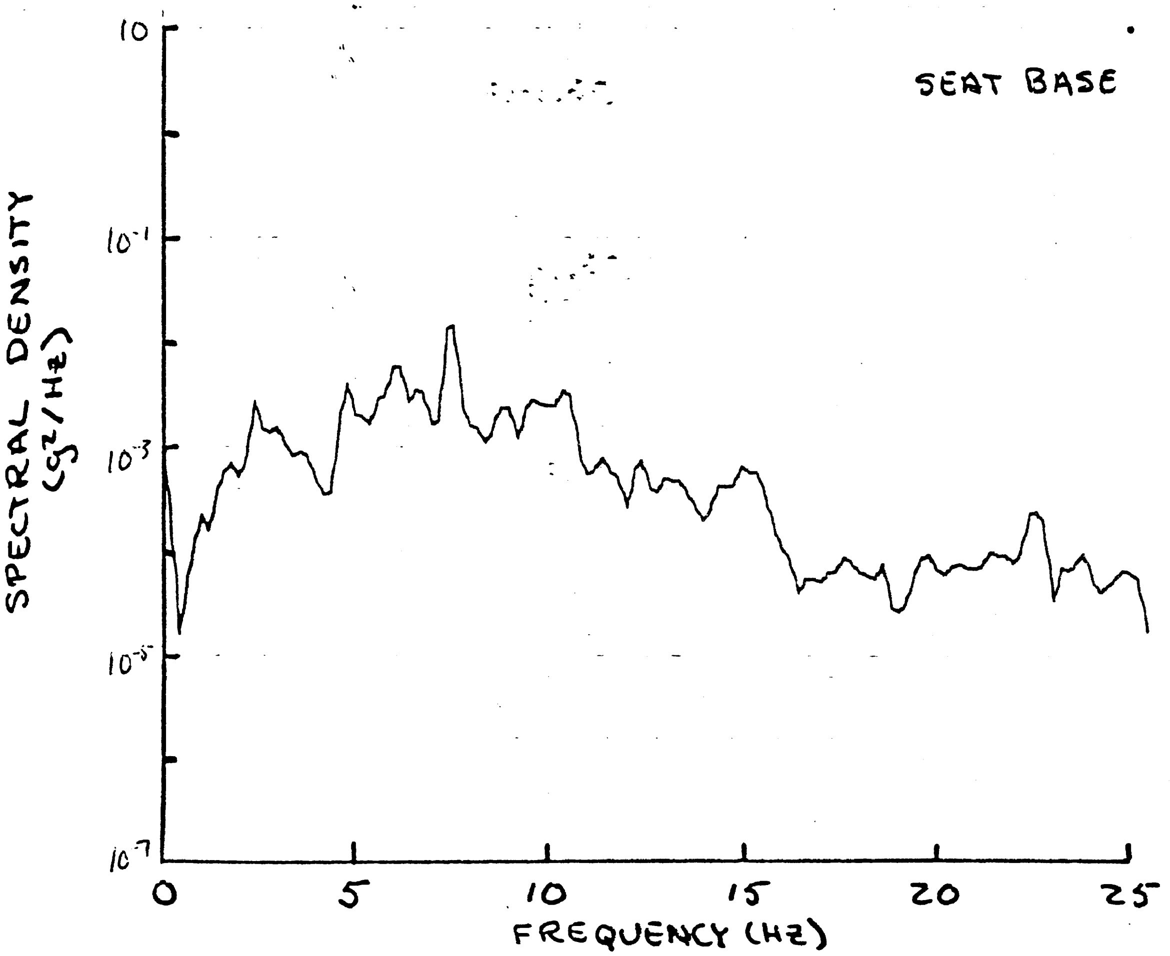


Figure VI.2.3 (Cont.)





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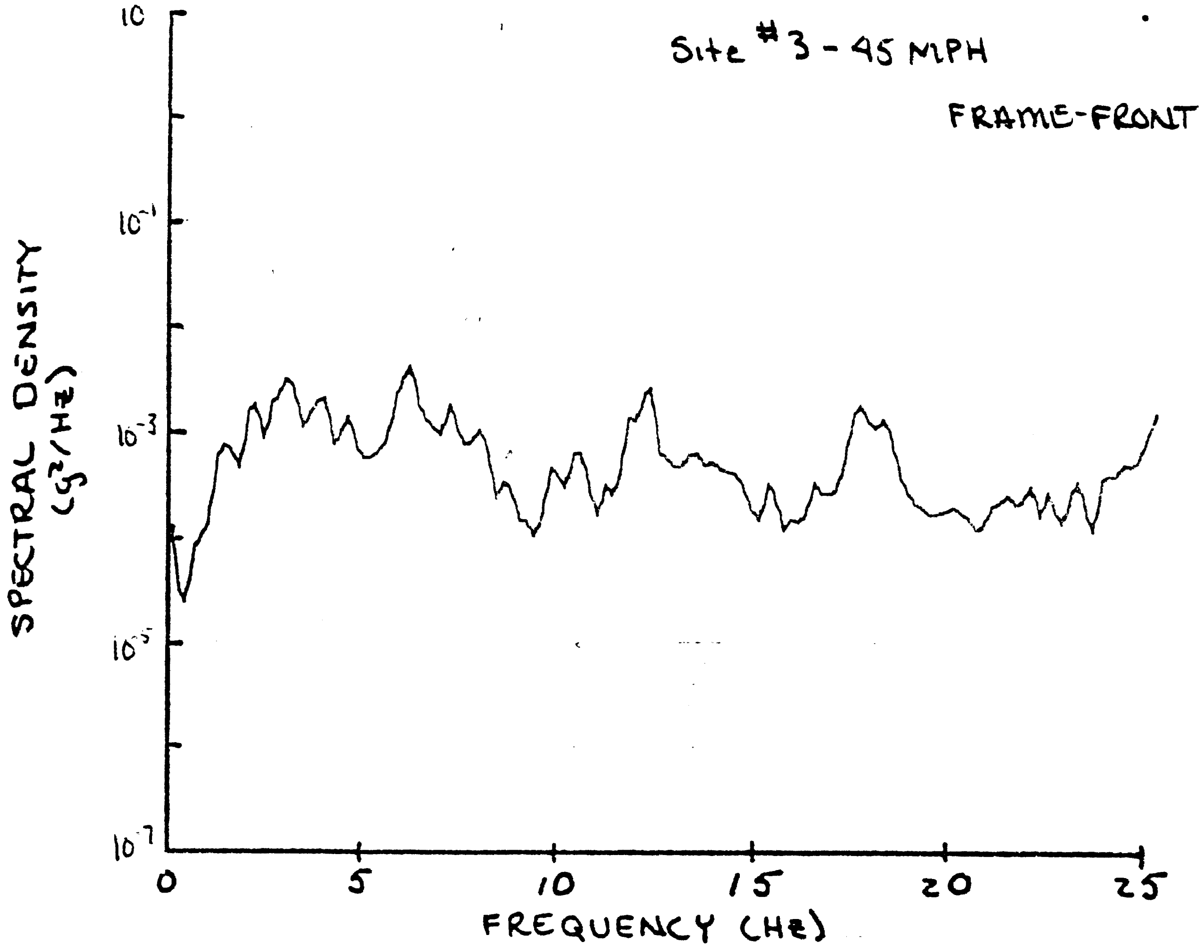

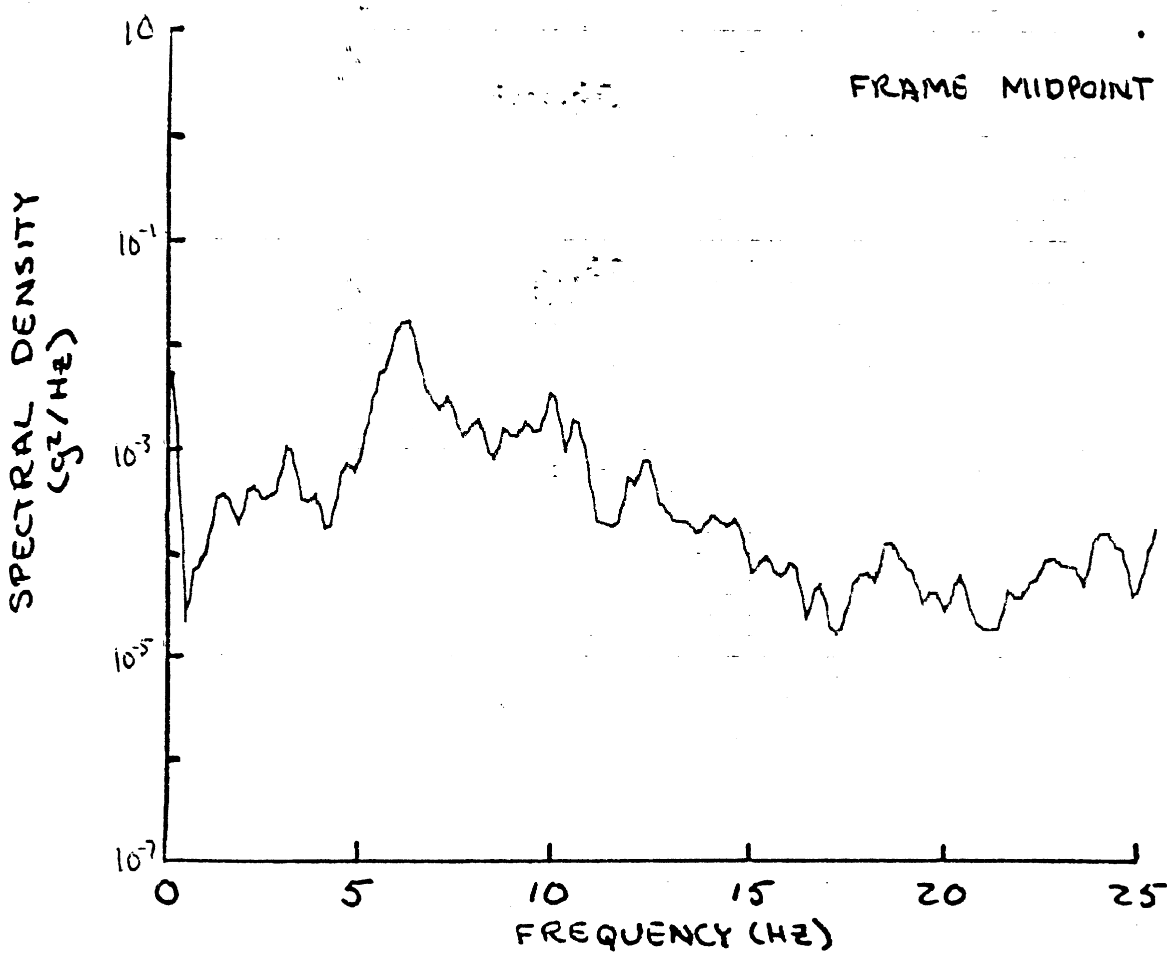

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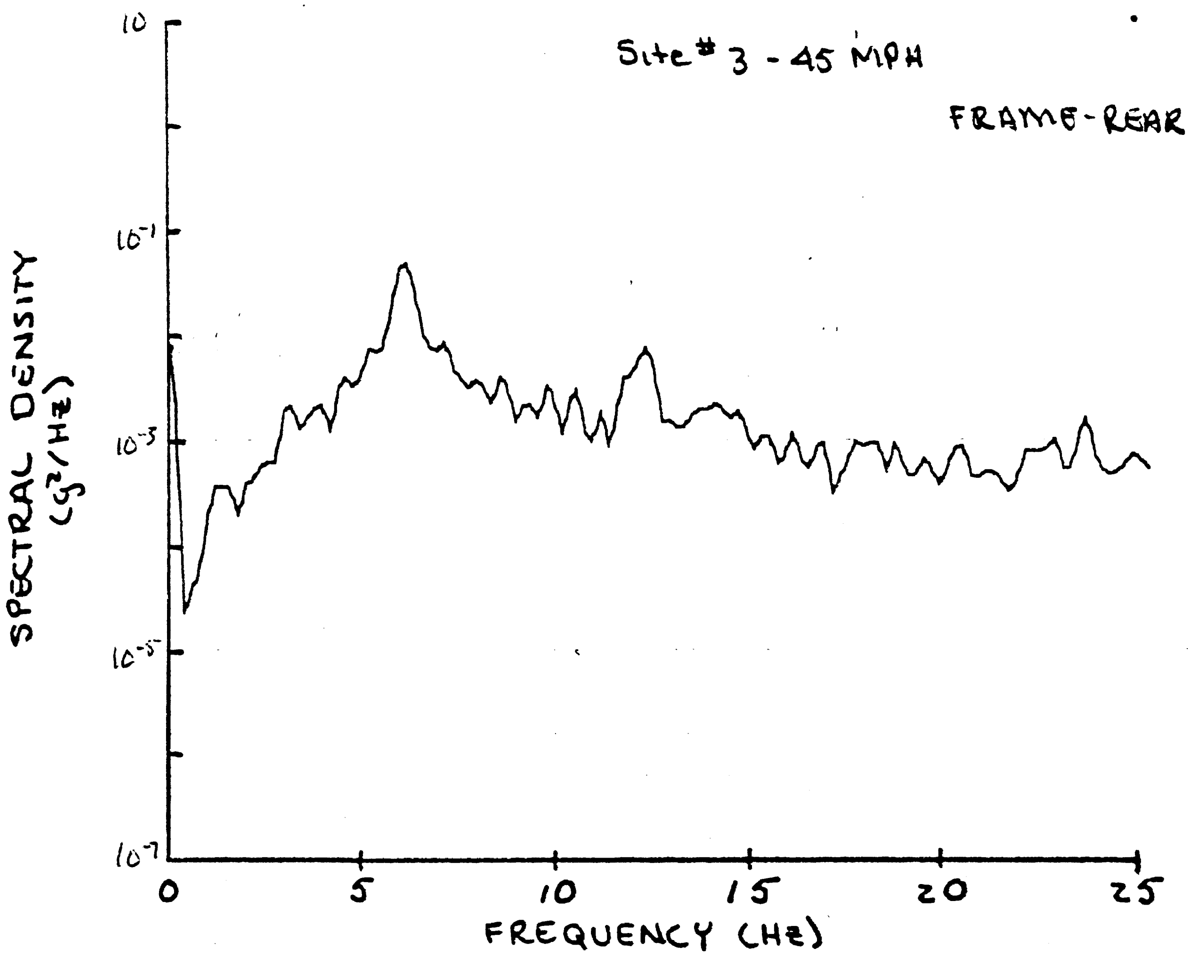


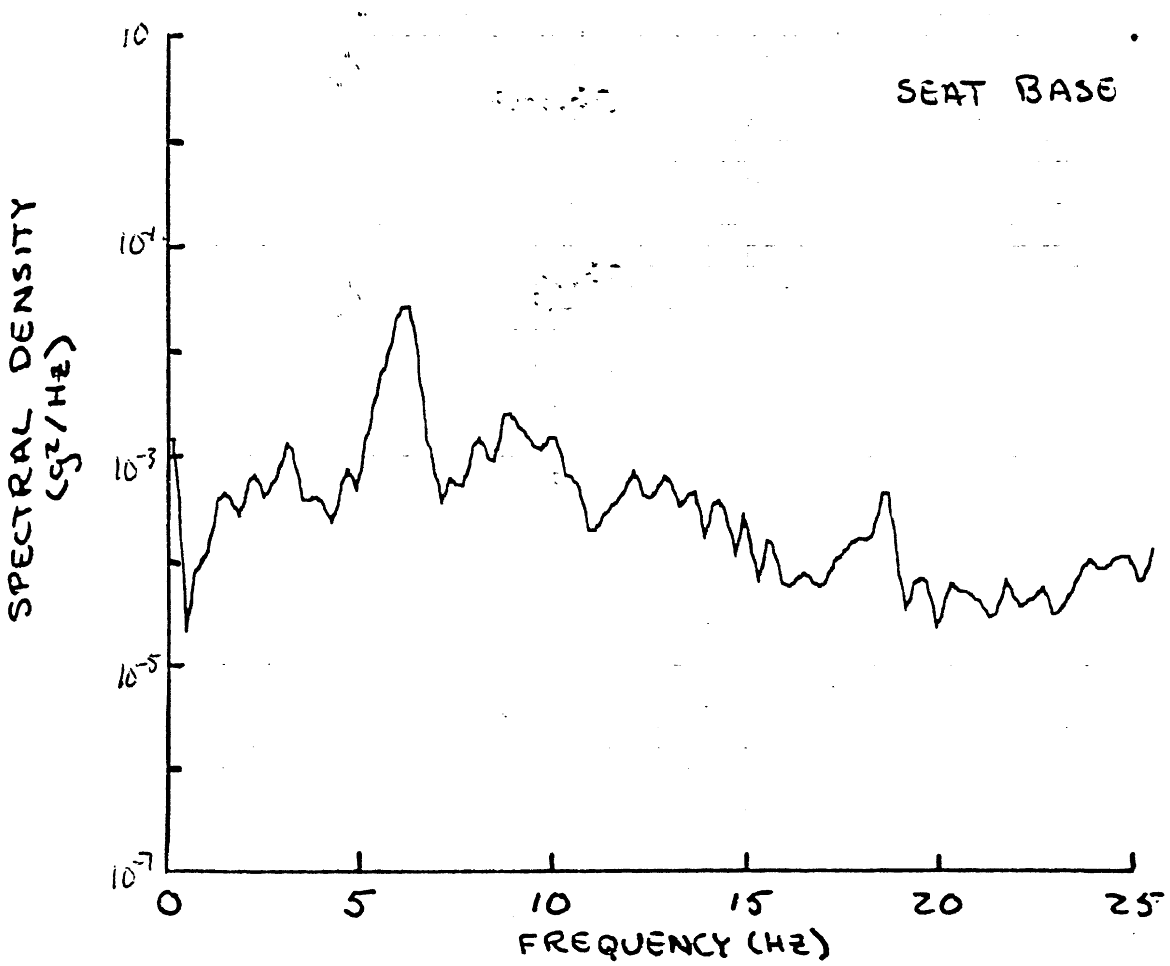
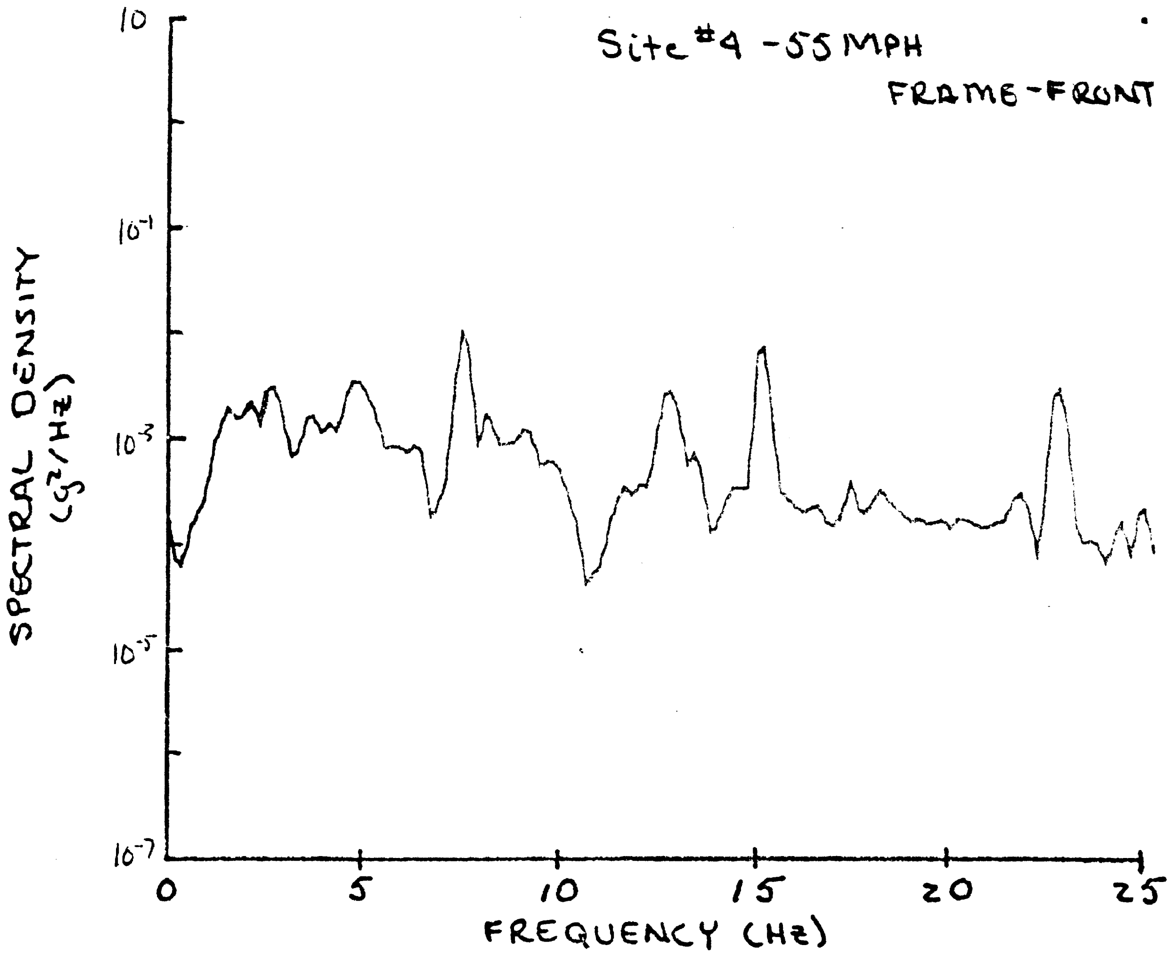
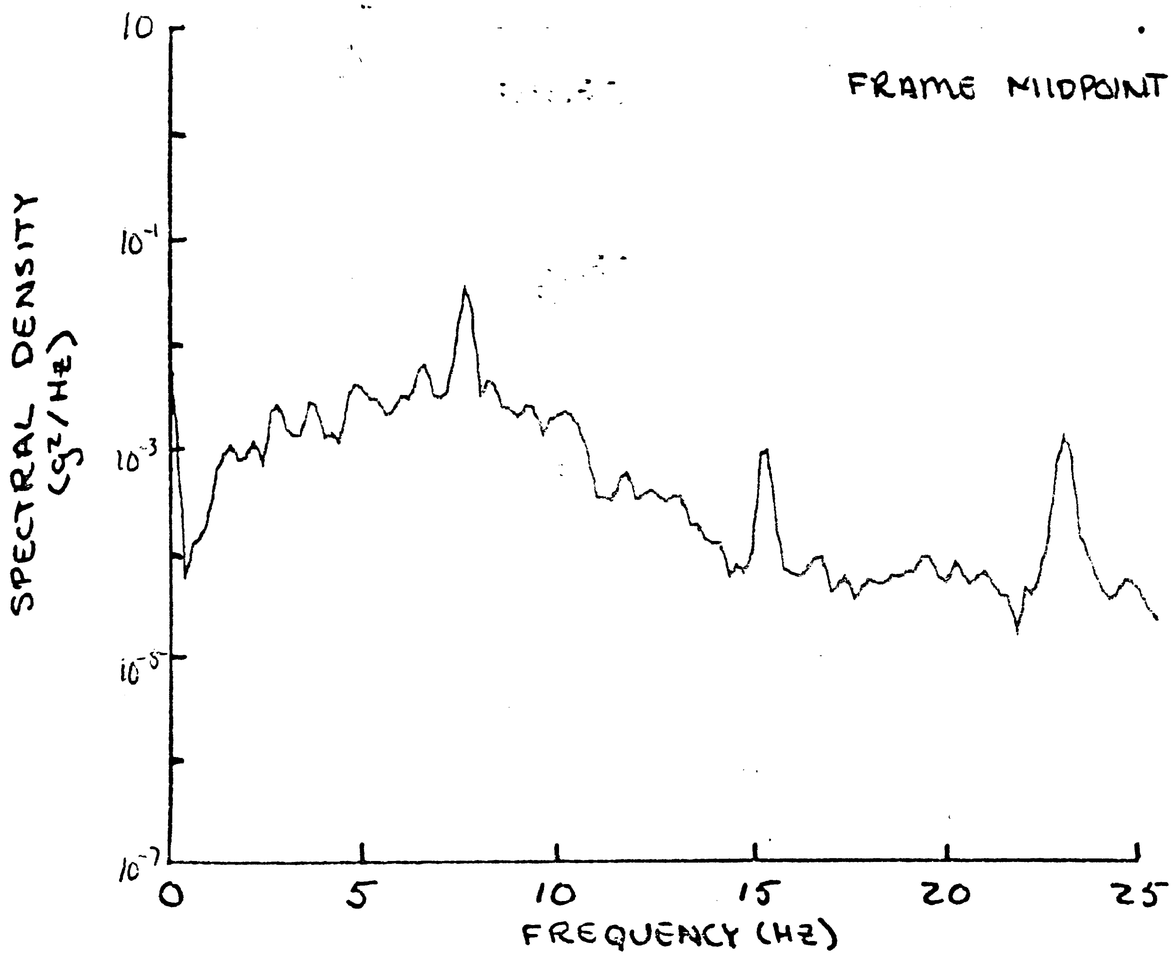


Figure VI.2.3 (Cont.)





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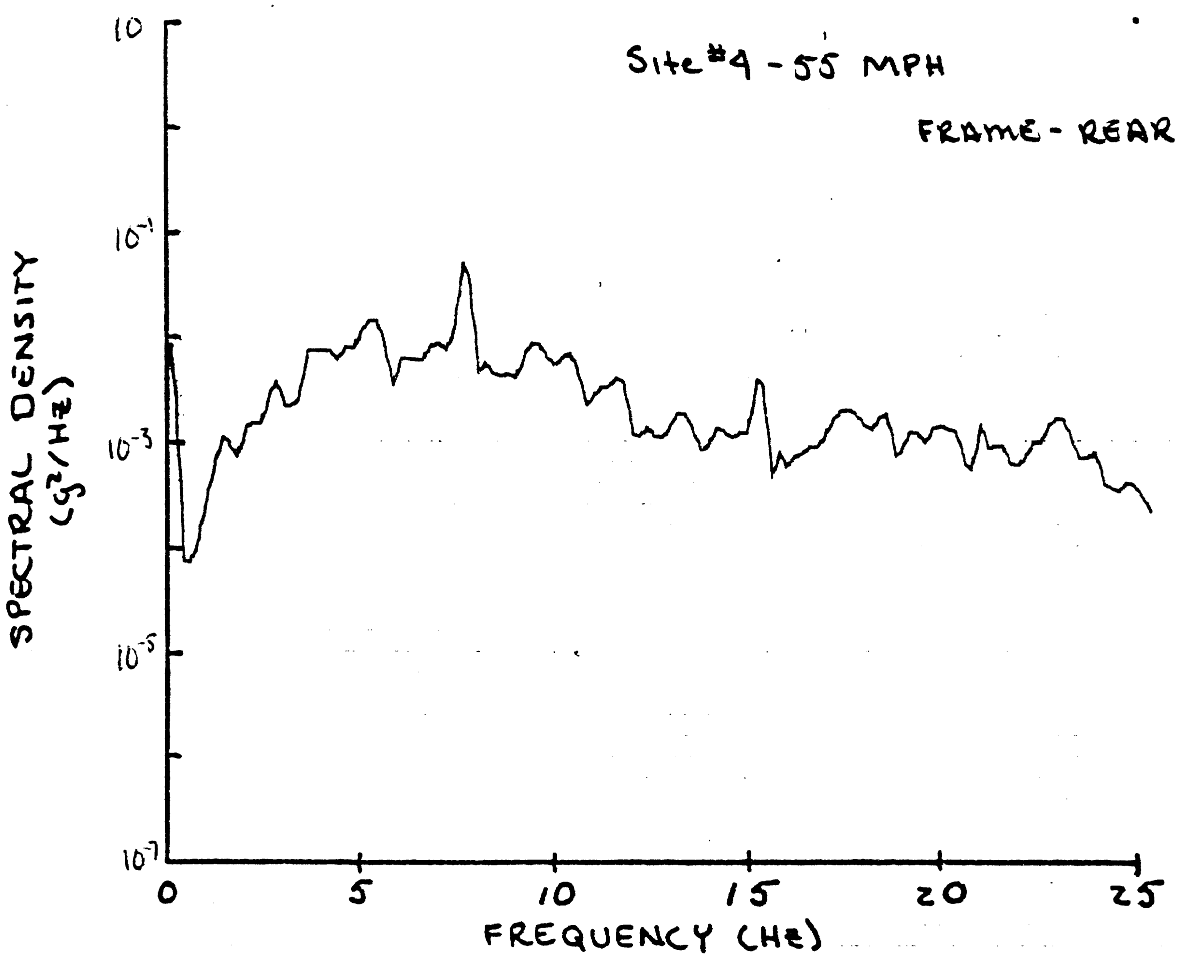

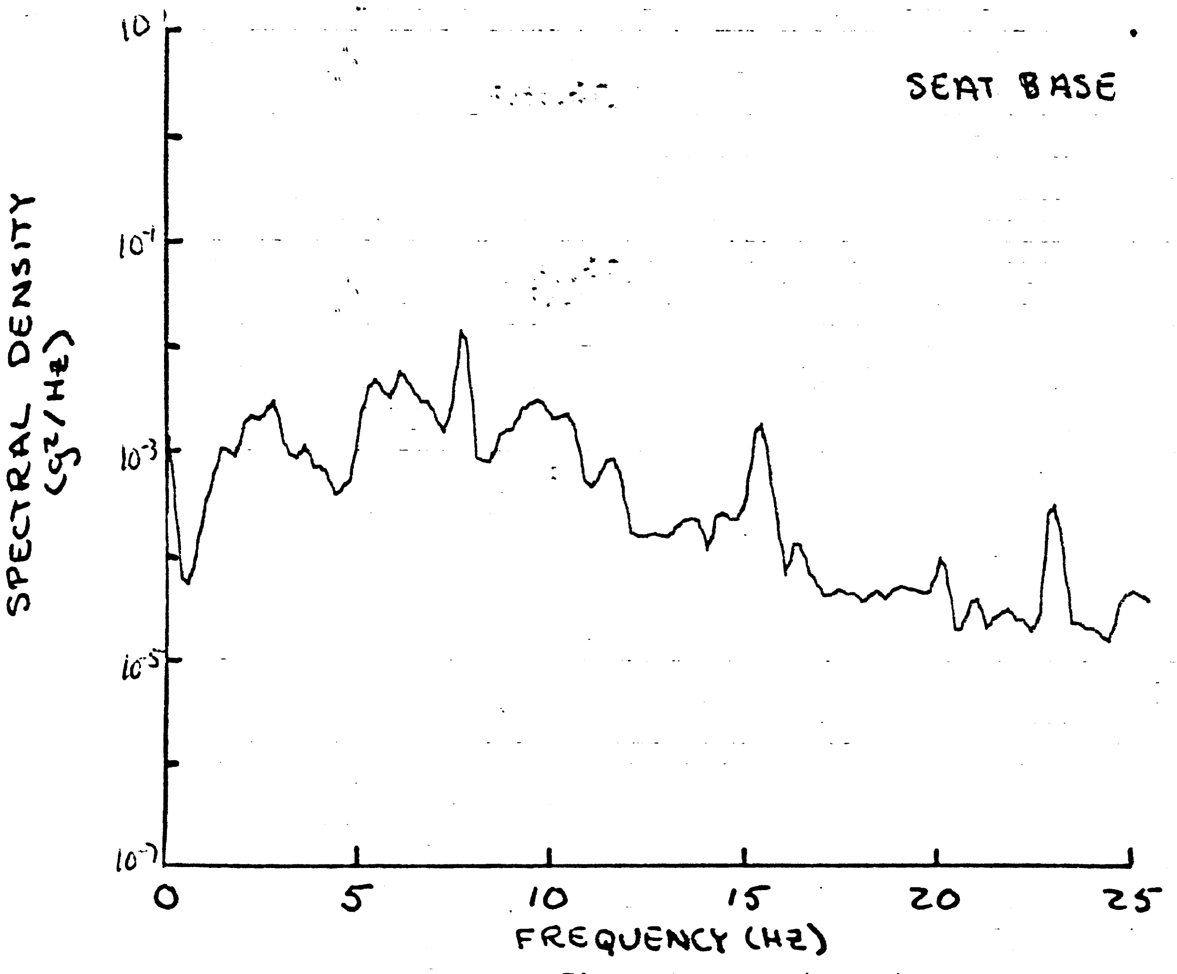

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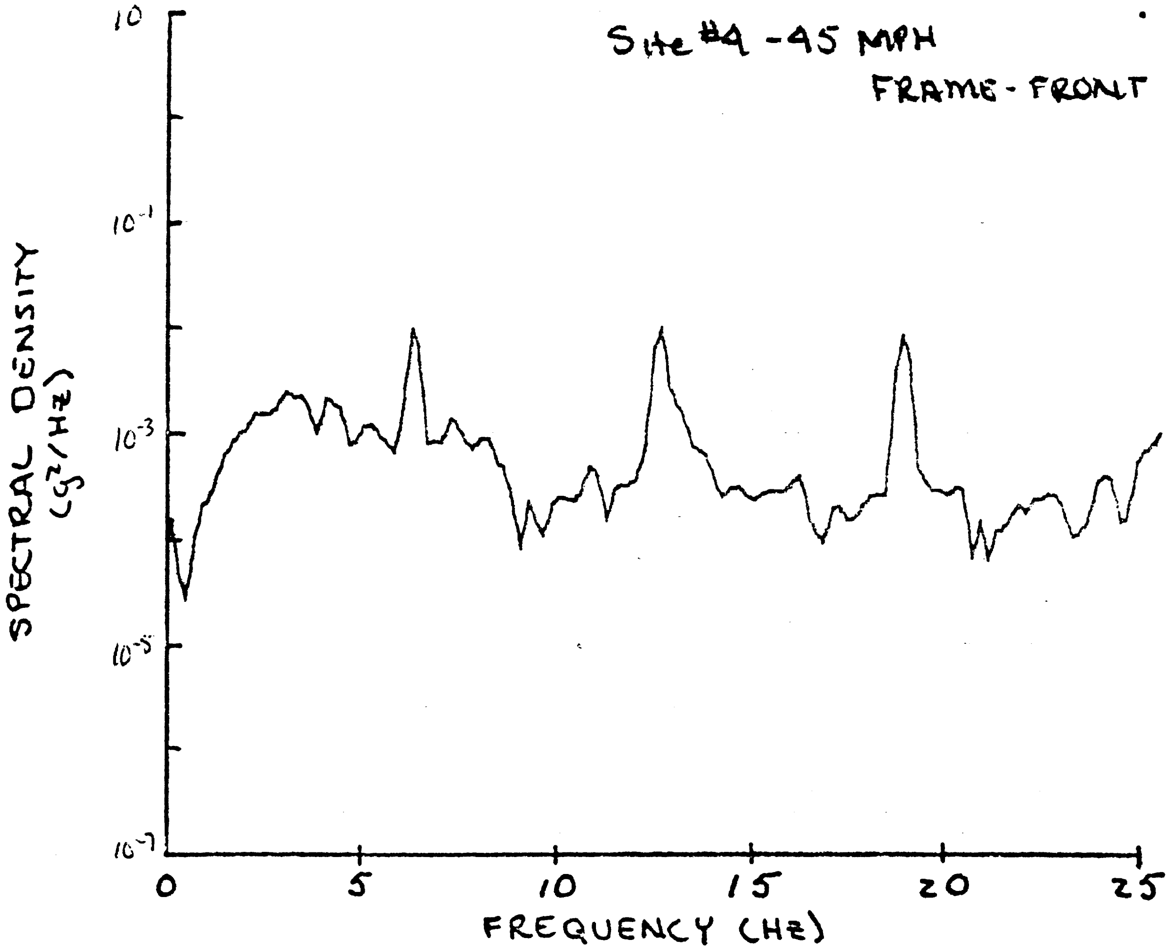

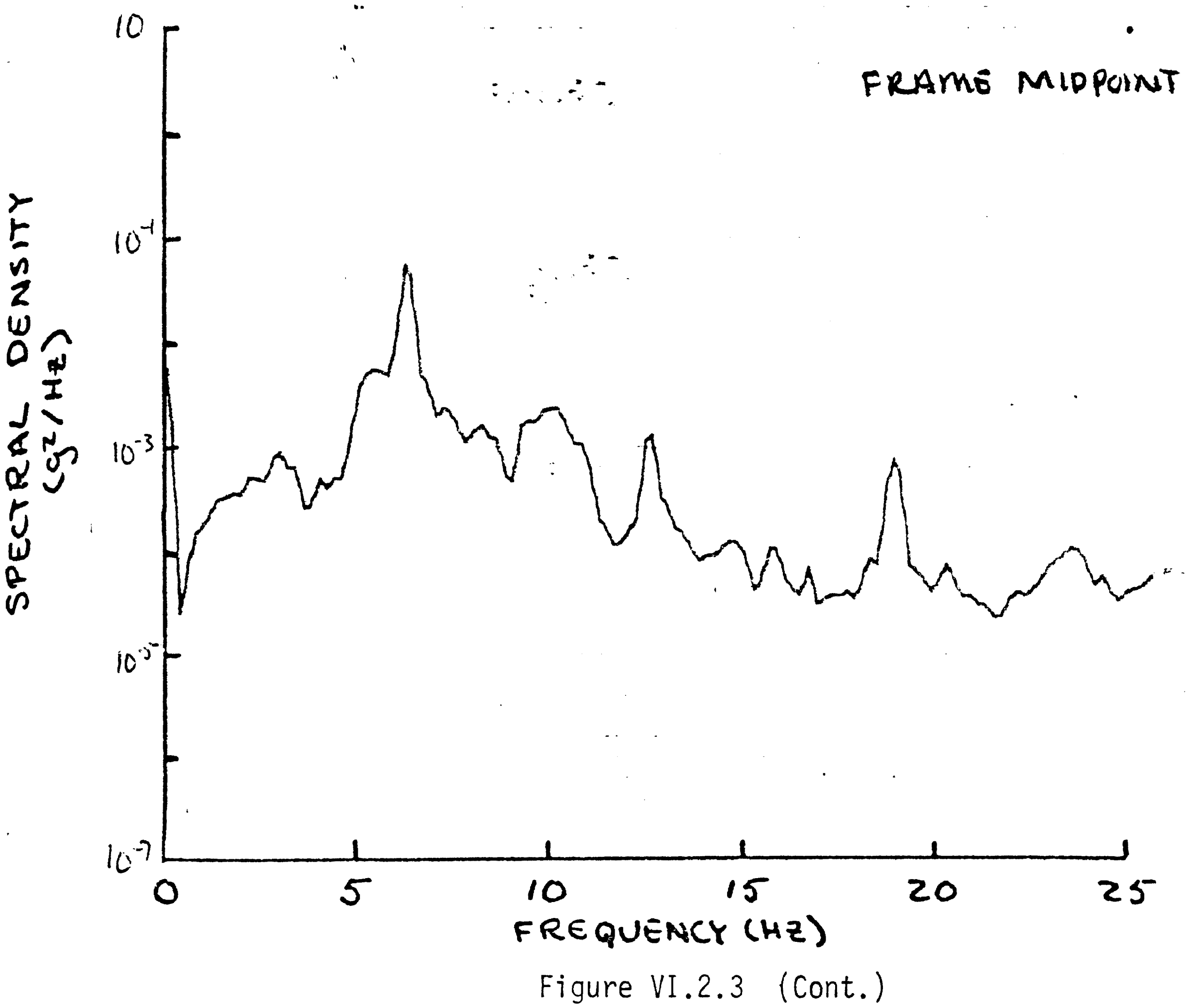

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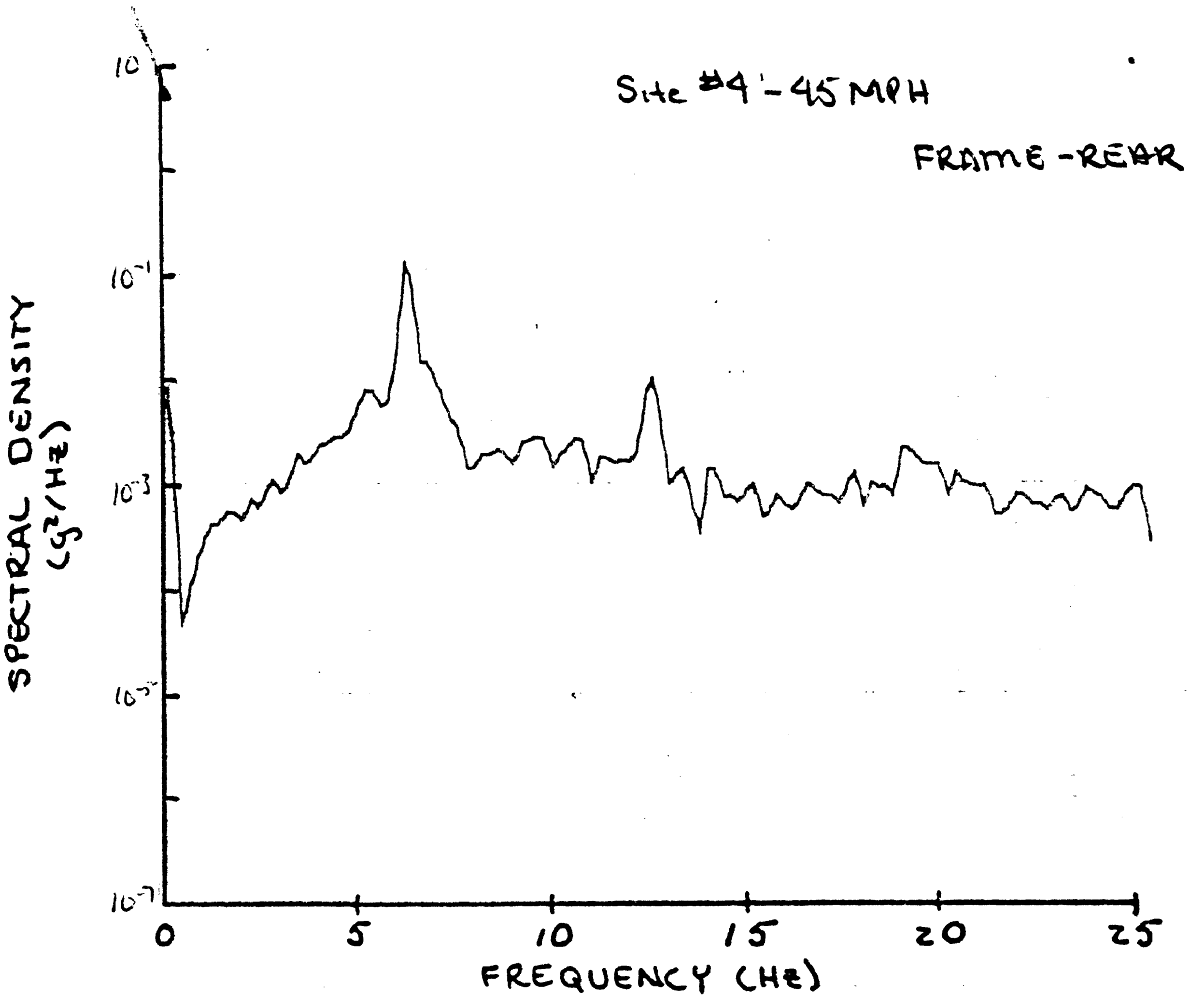

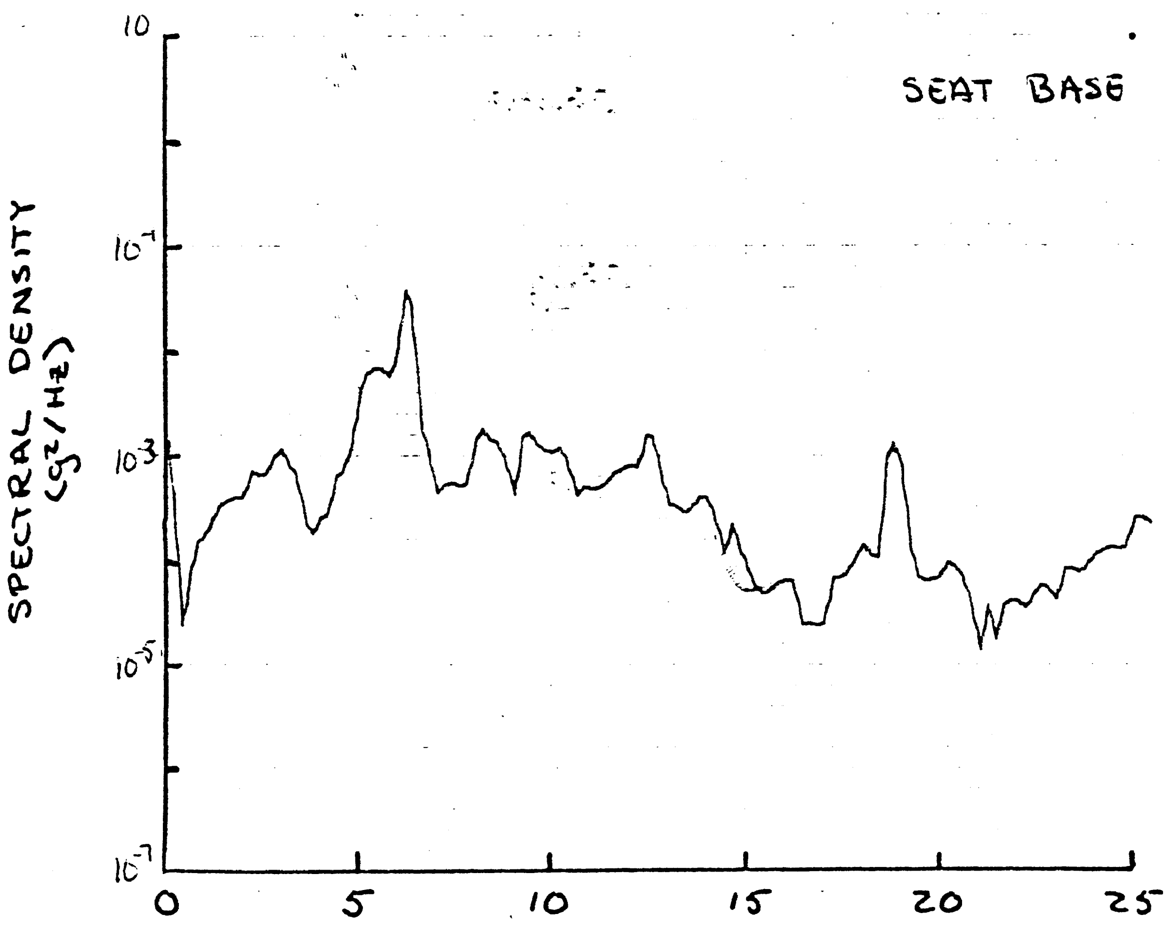

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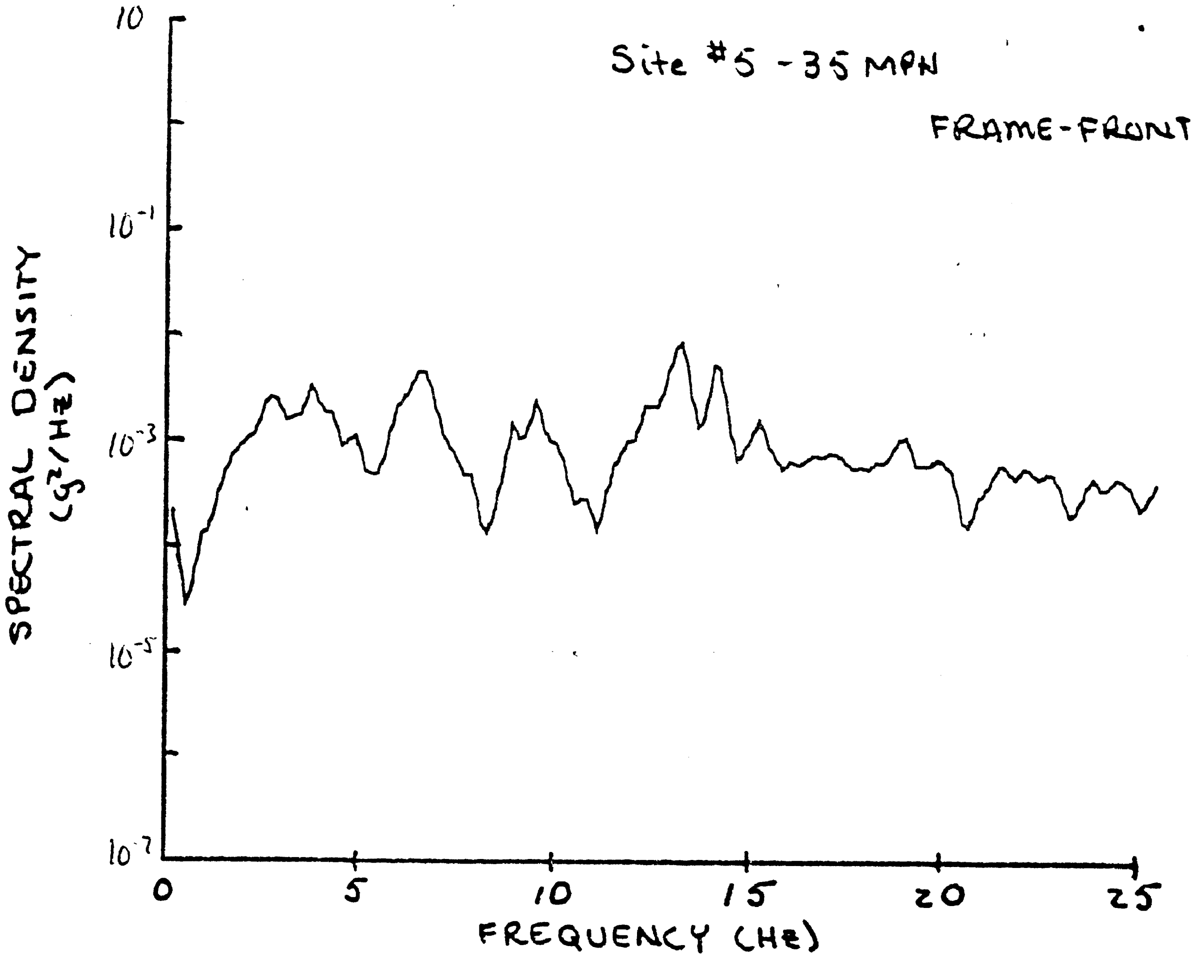

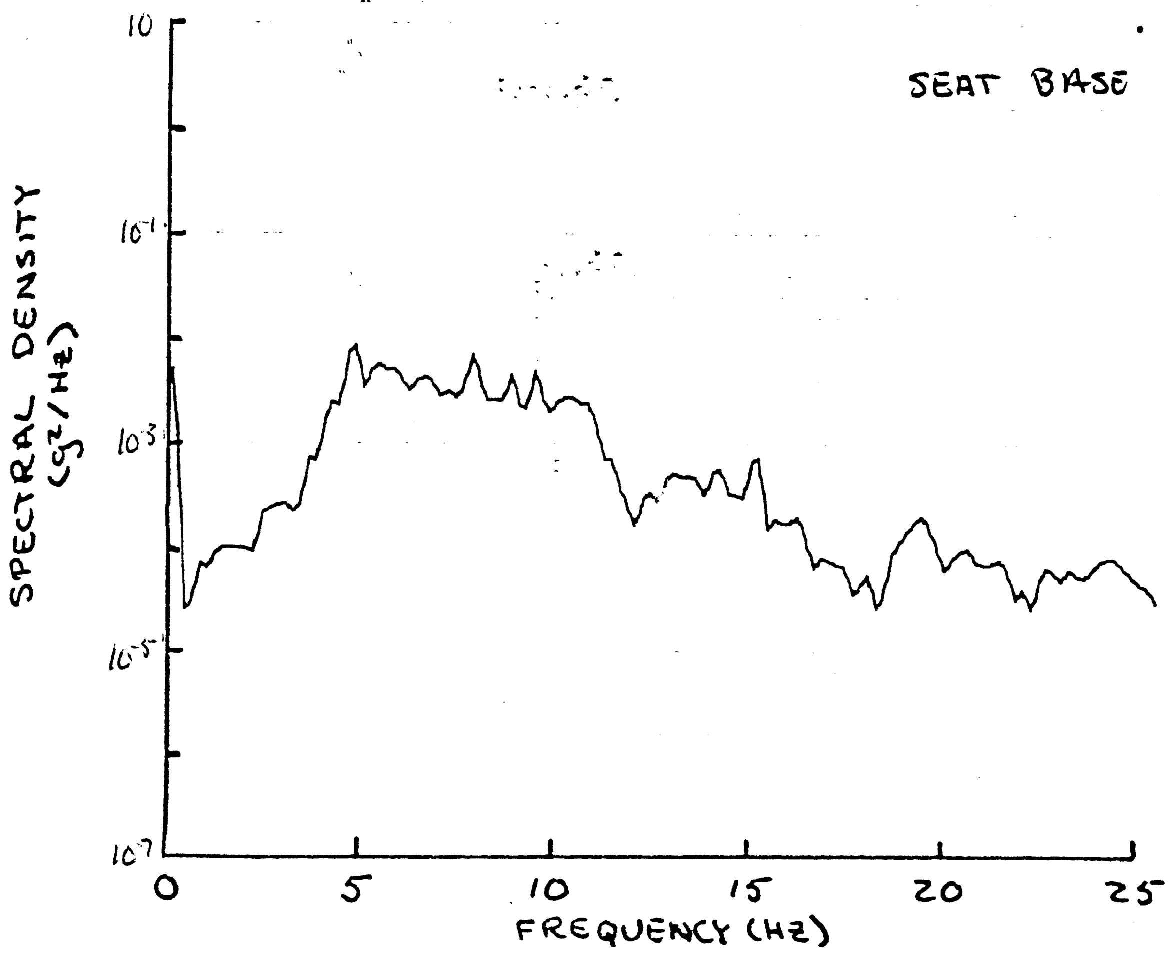

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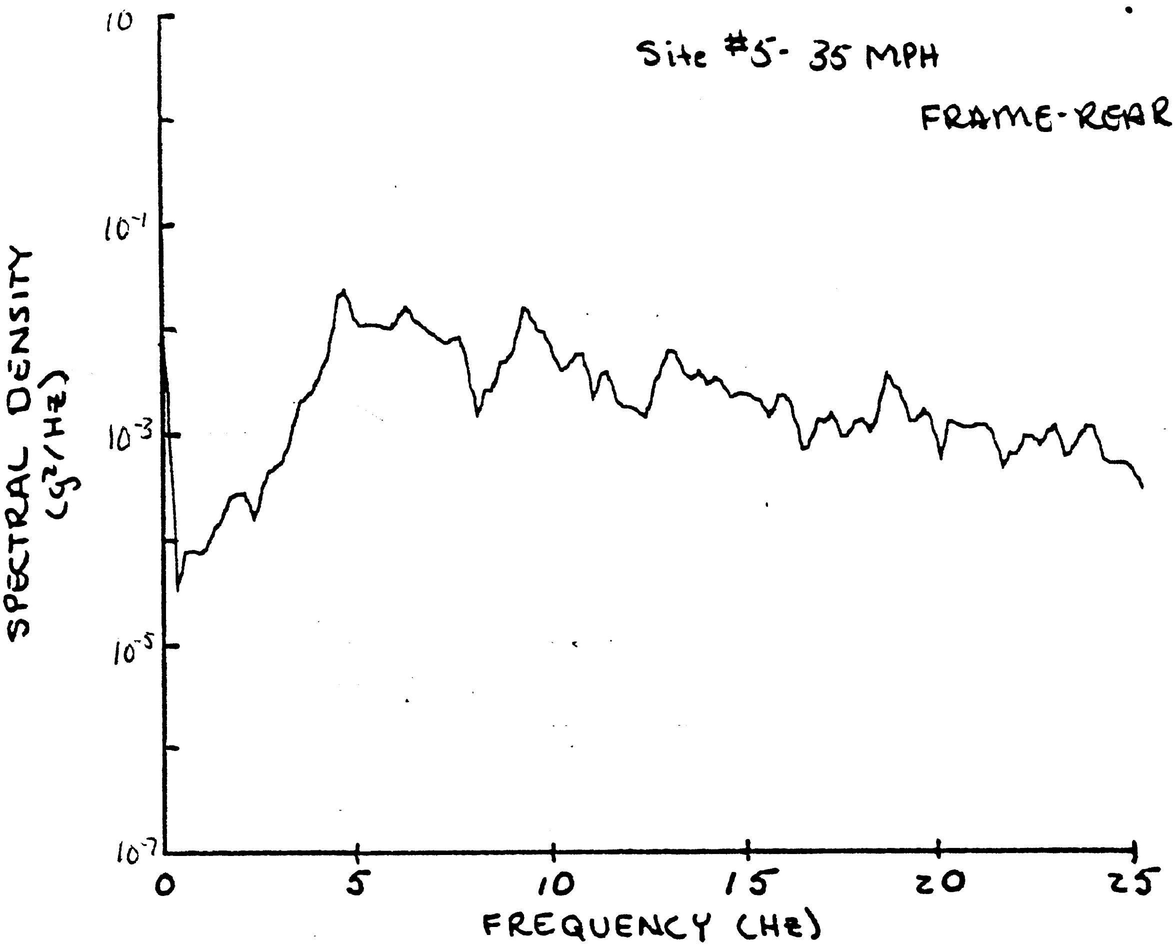

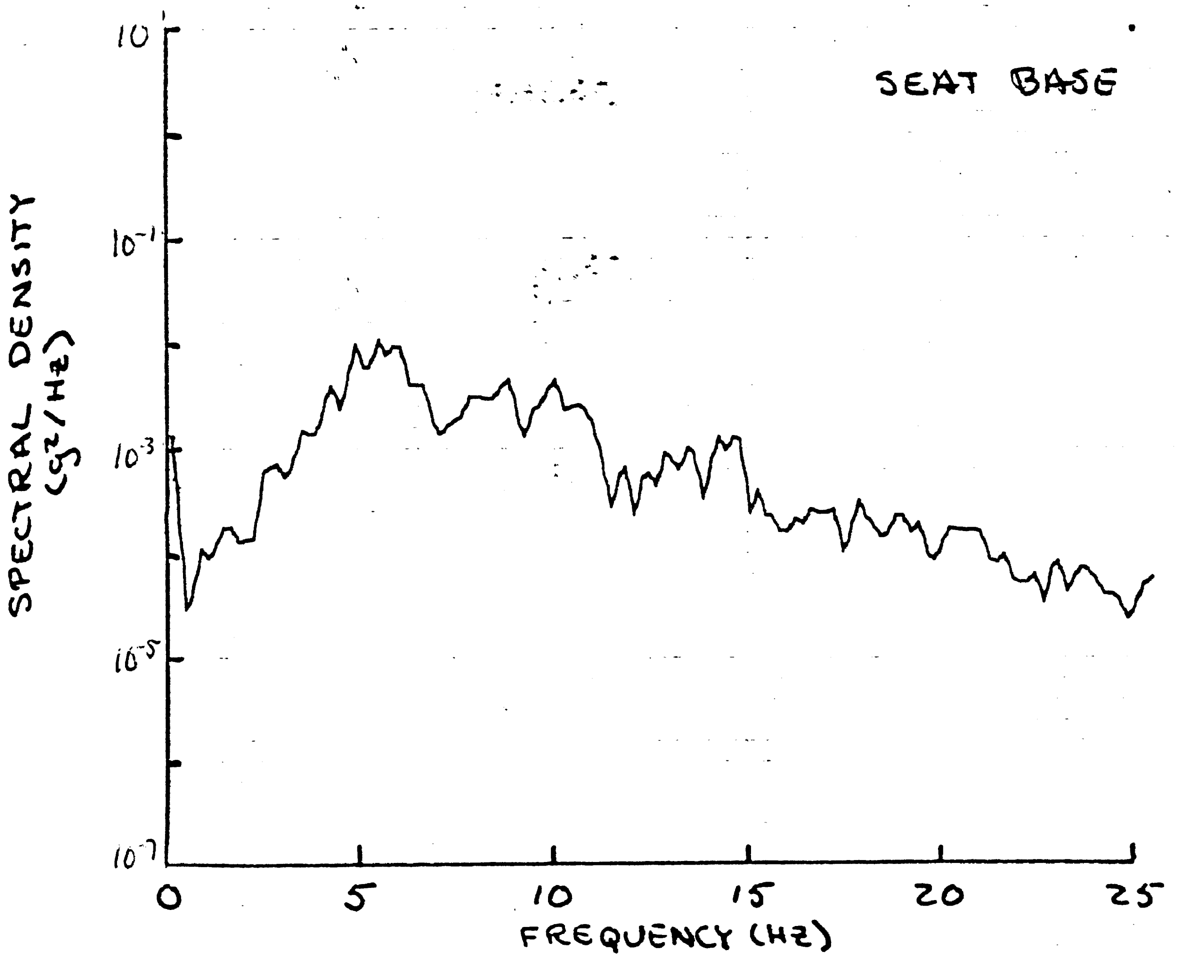

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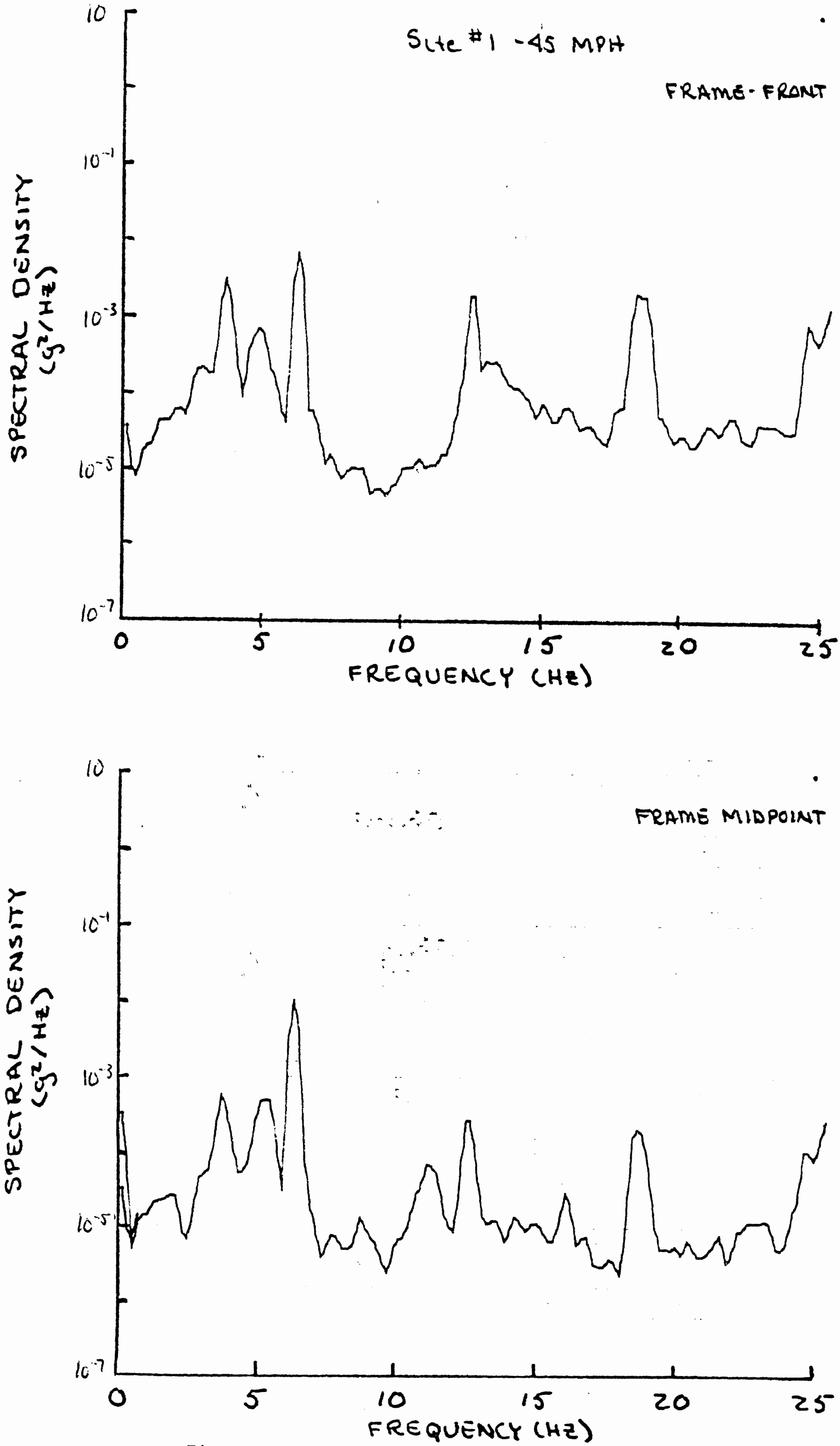
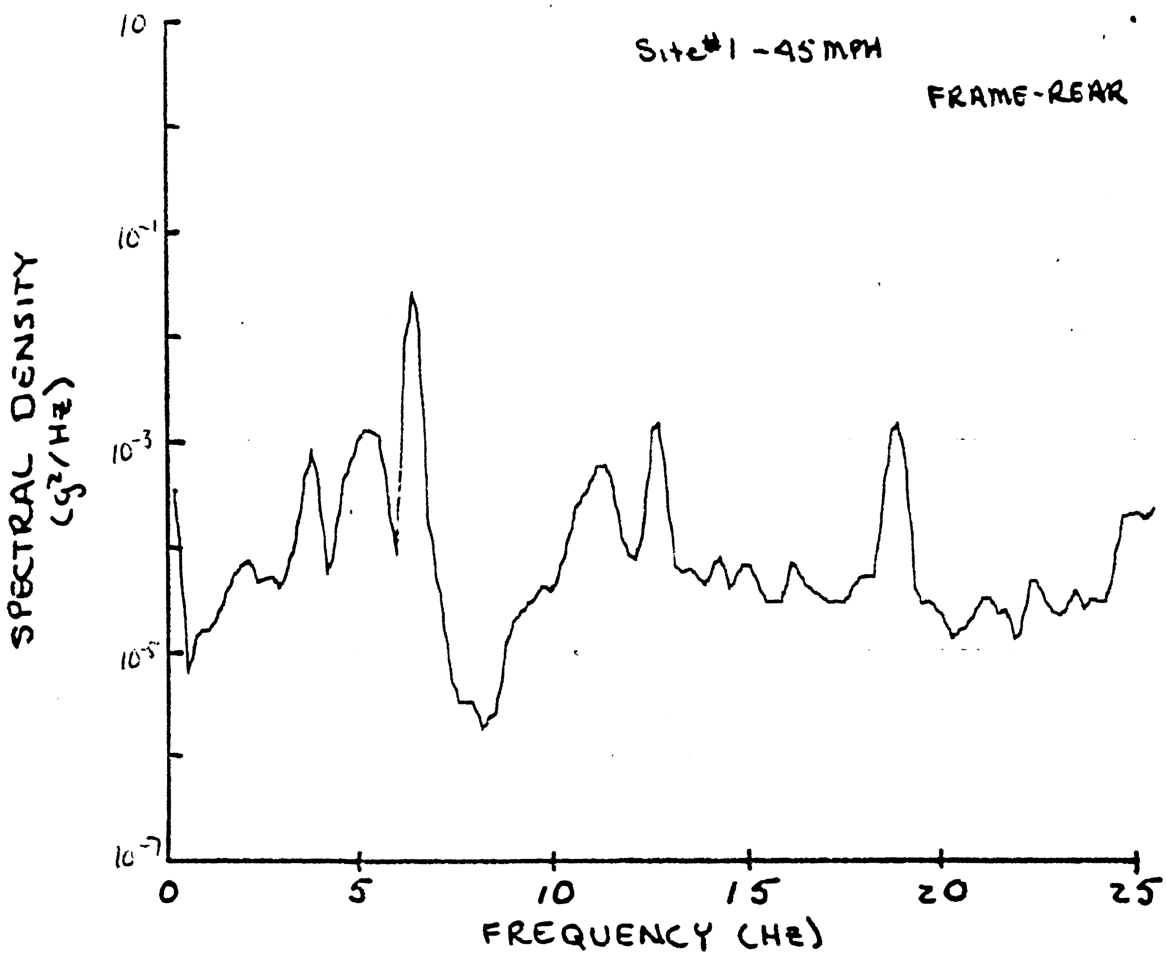
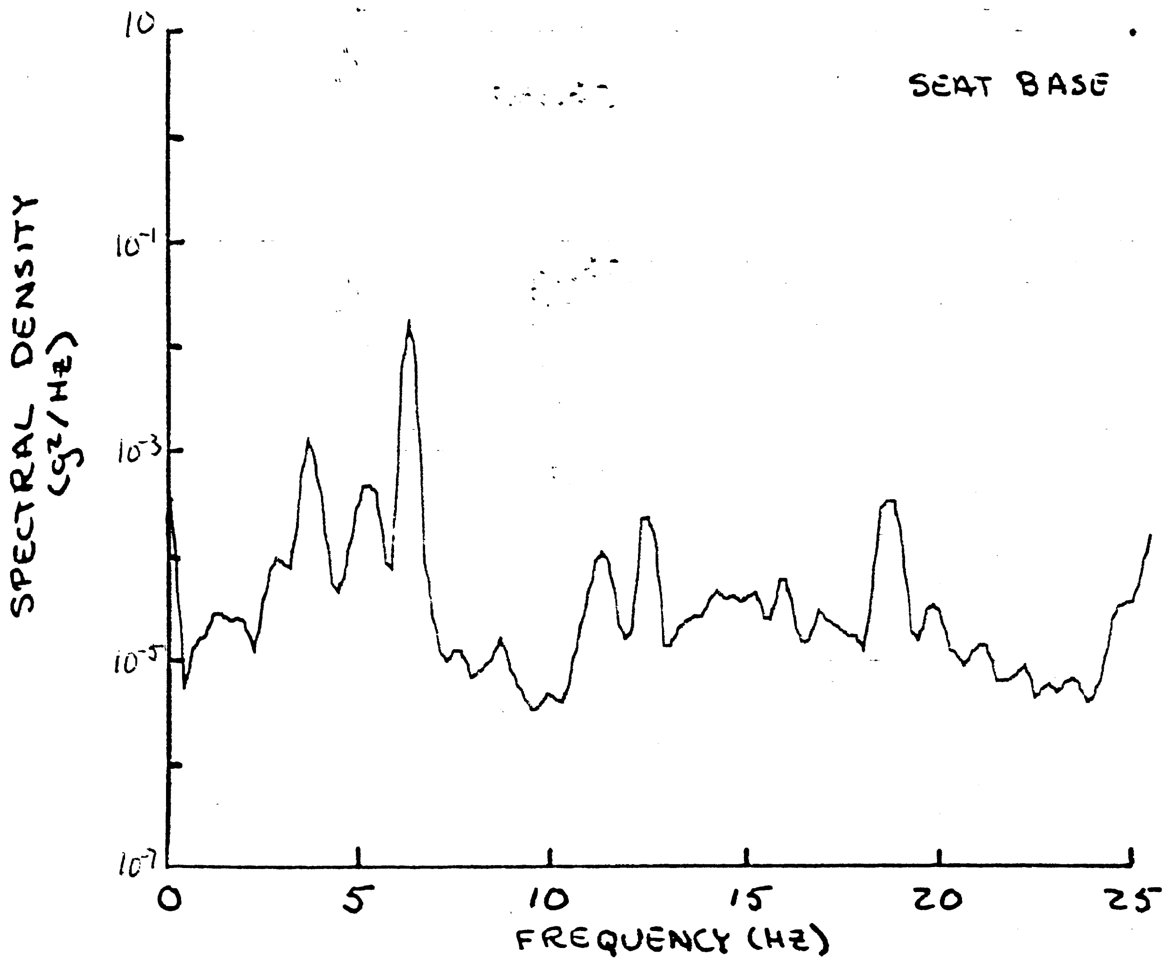


Figure VI.2.4. Loaded conventional tractor.





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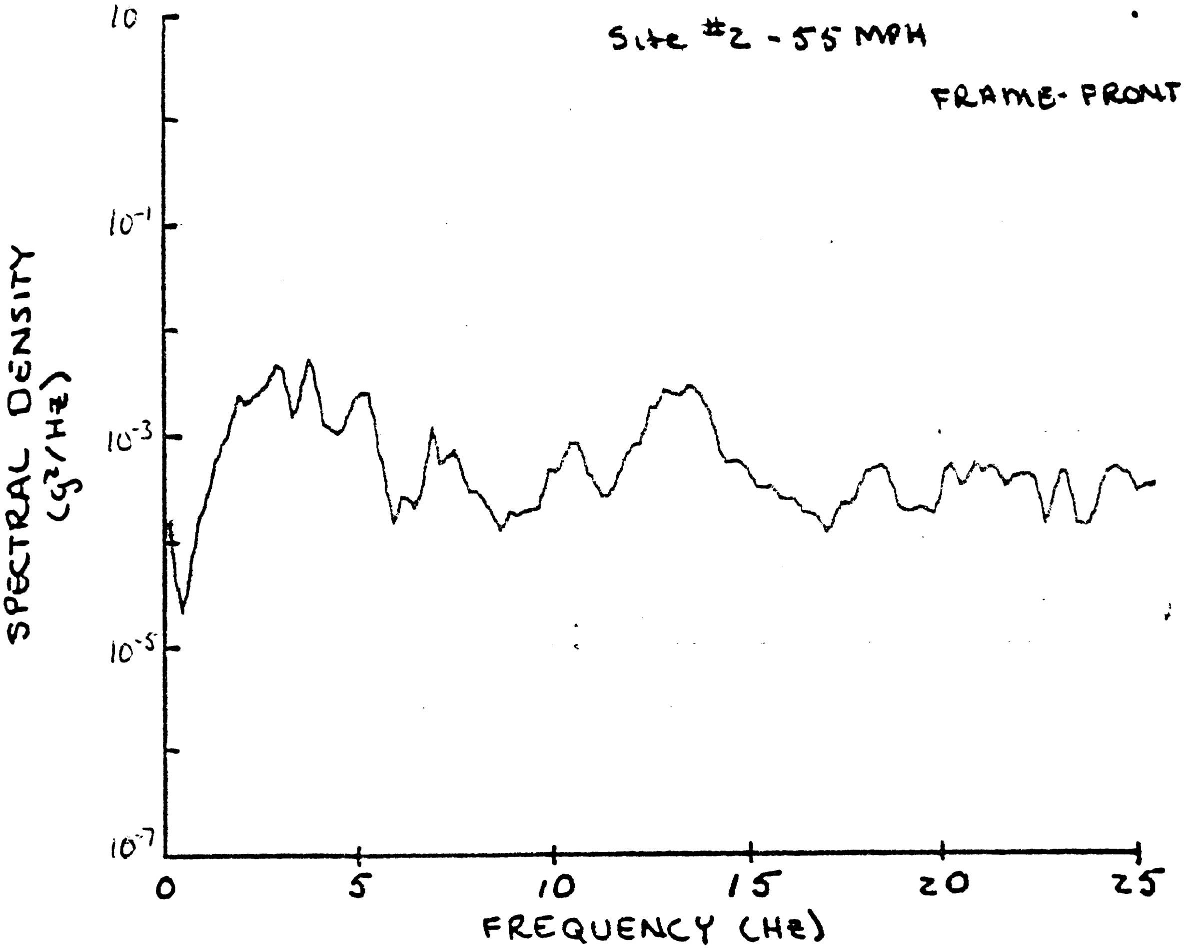

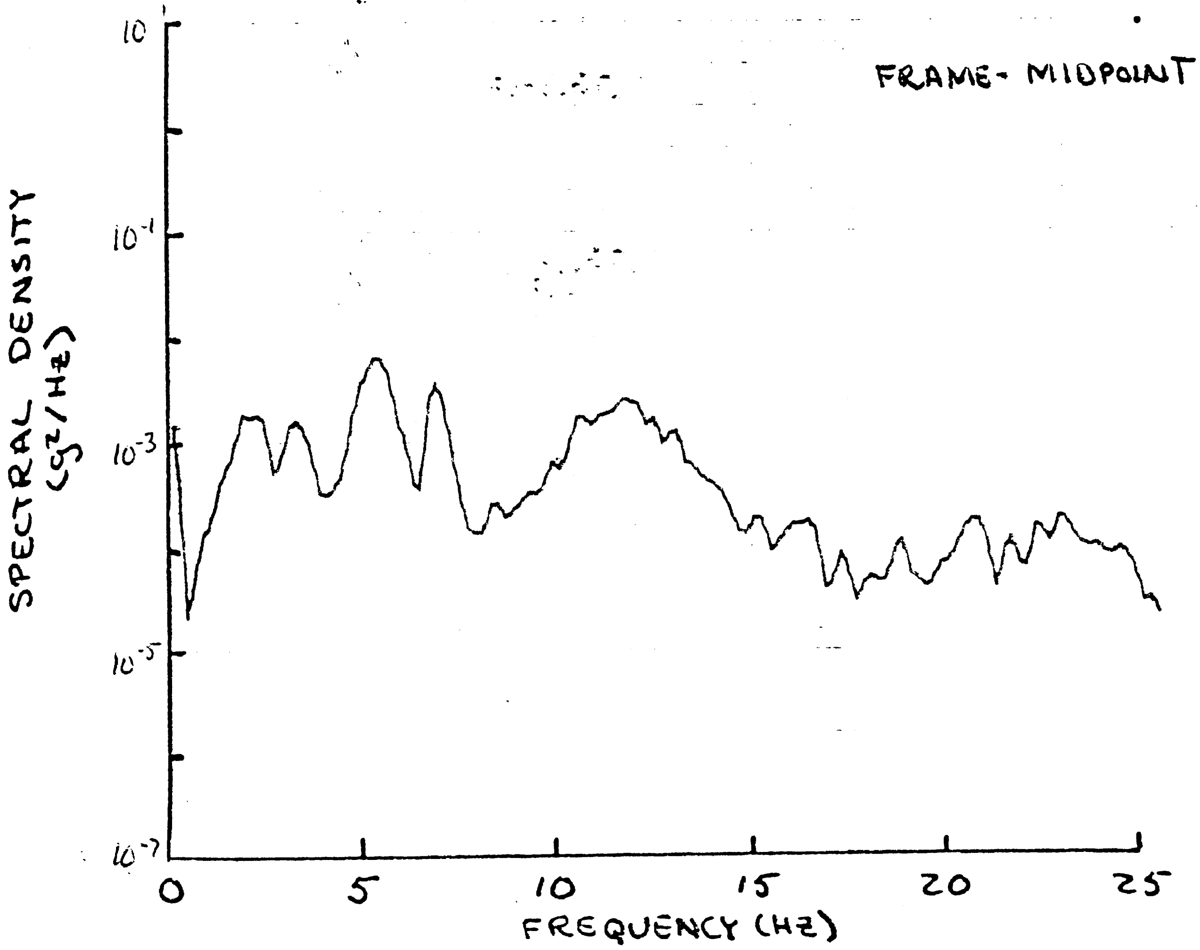

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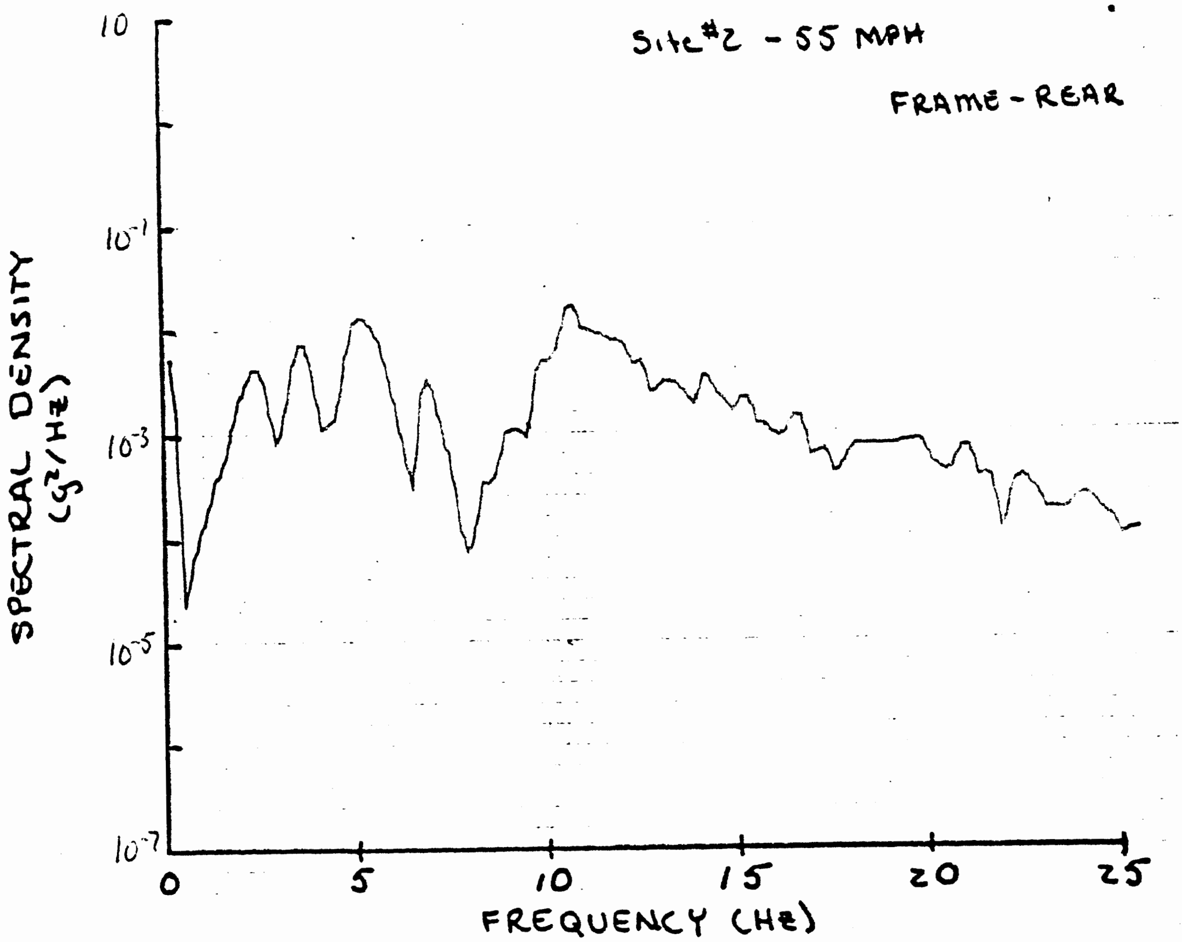

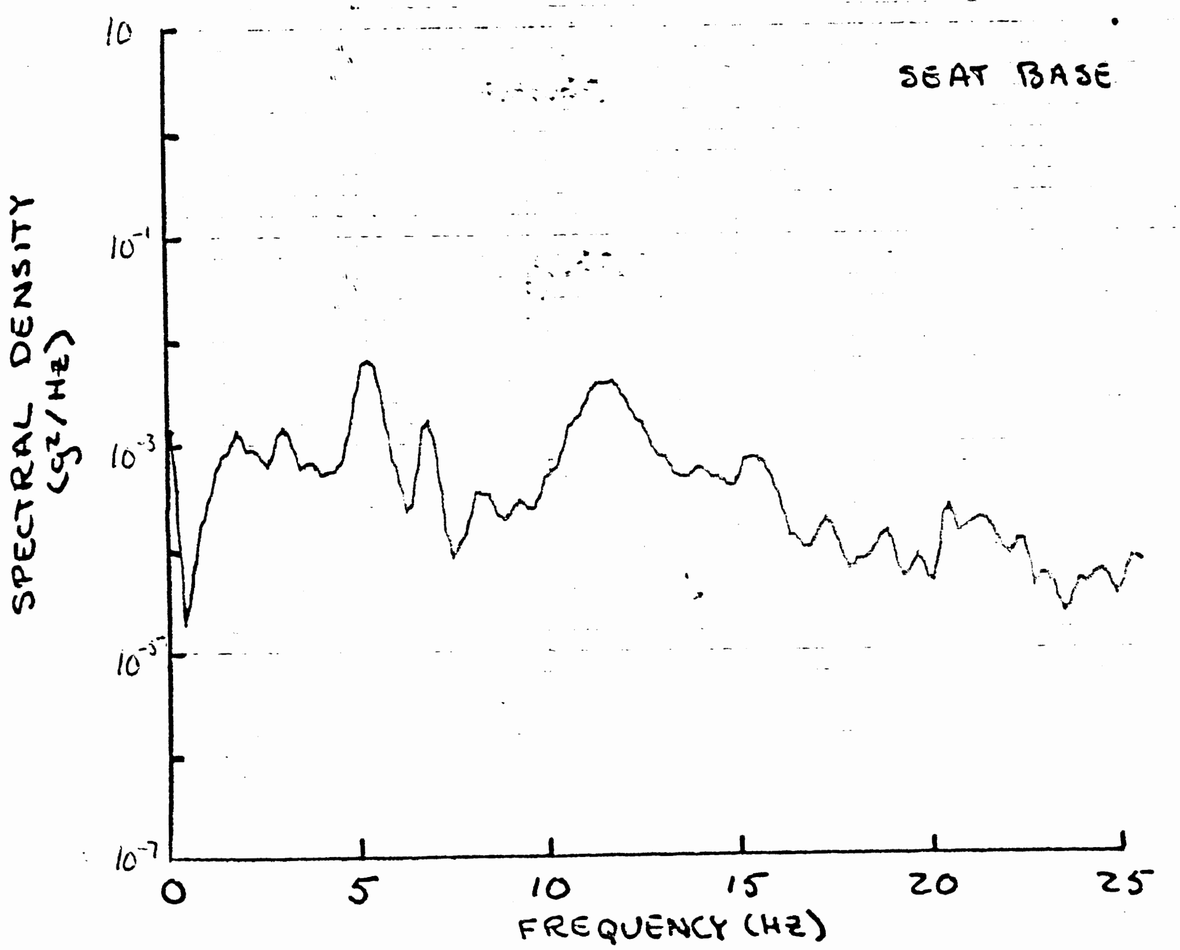

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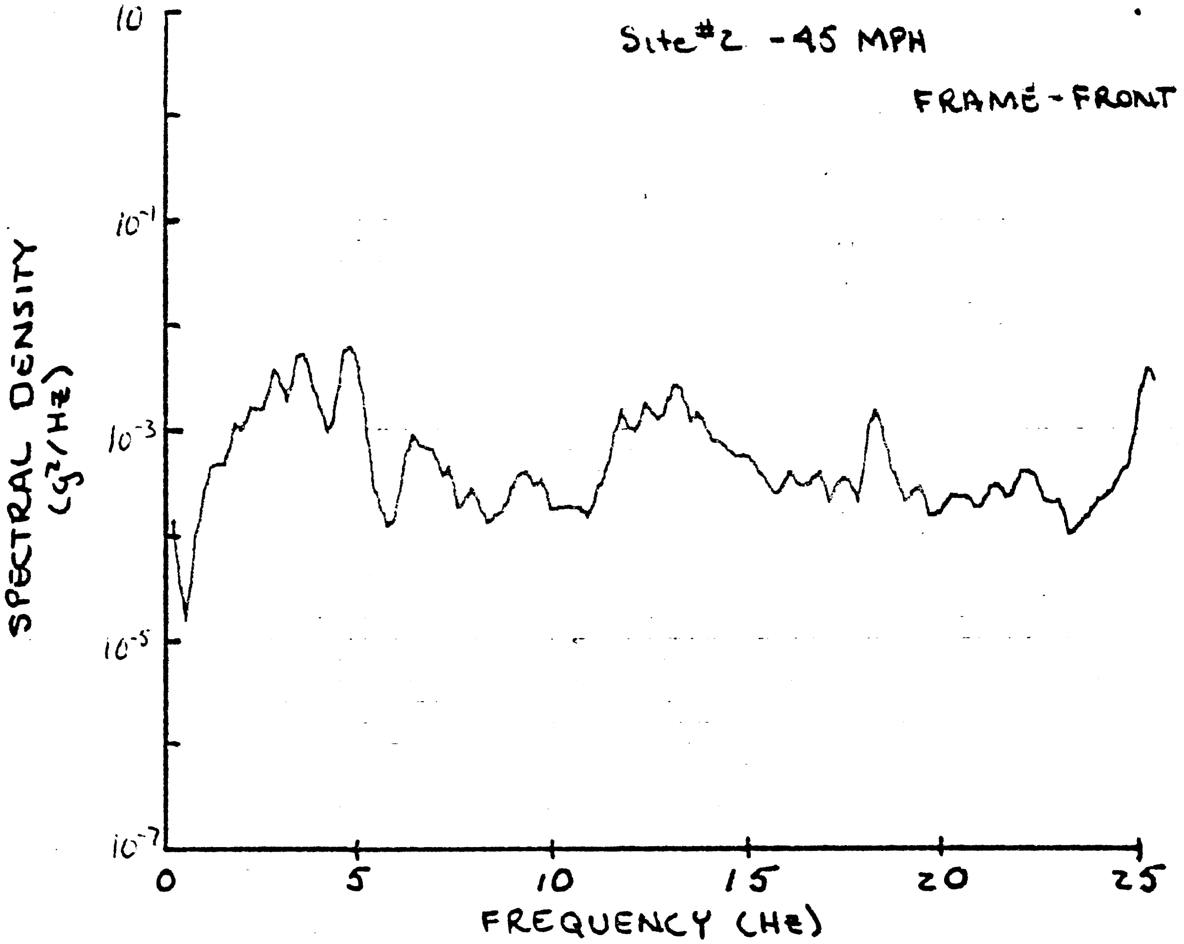

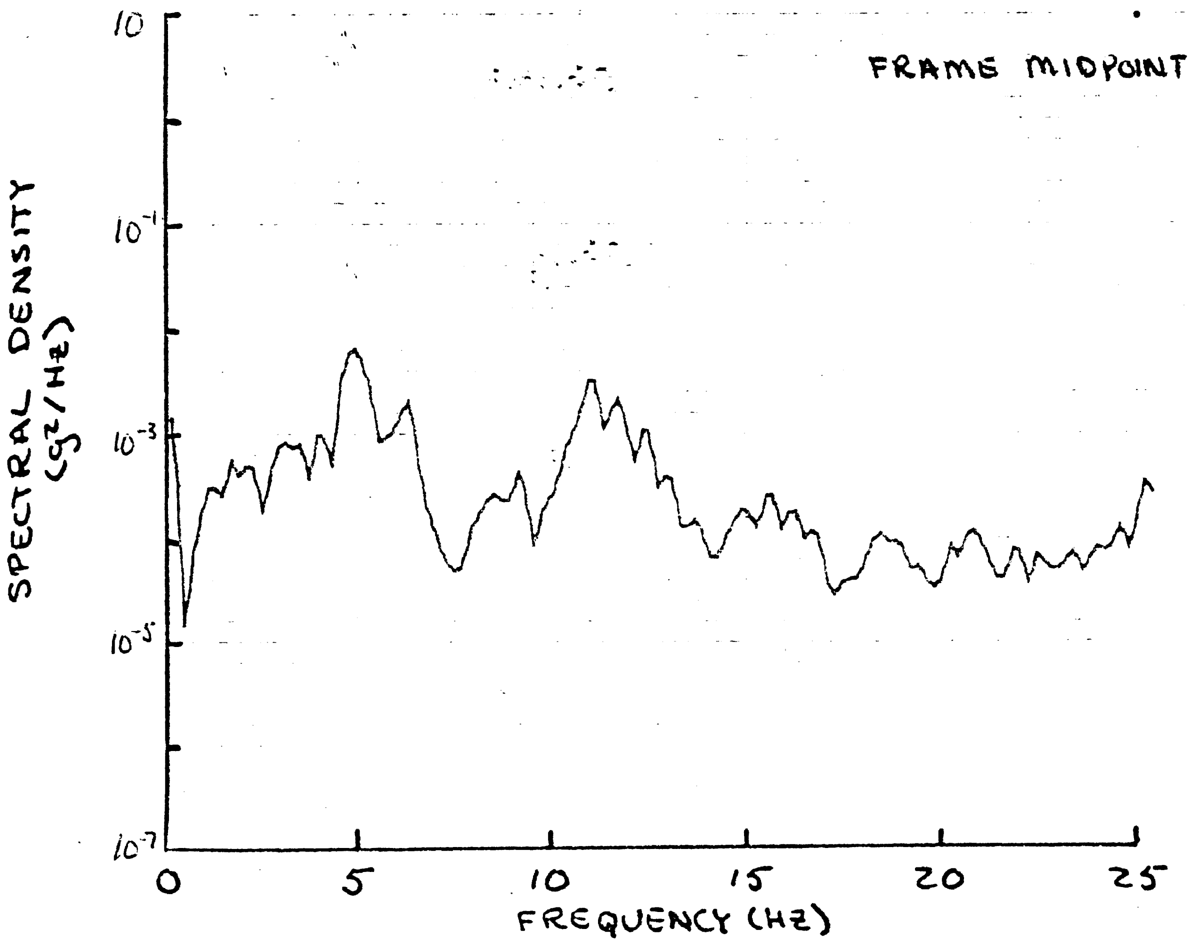

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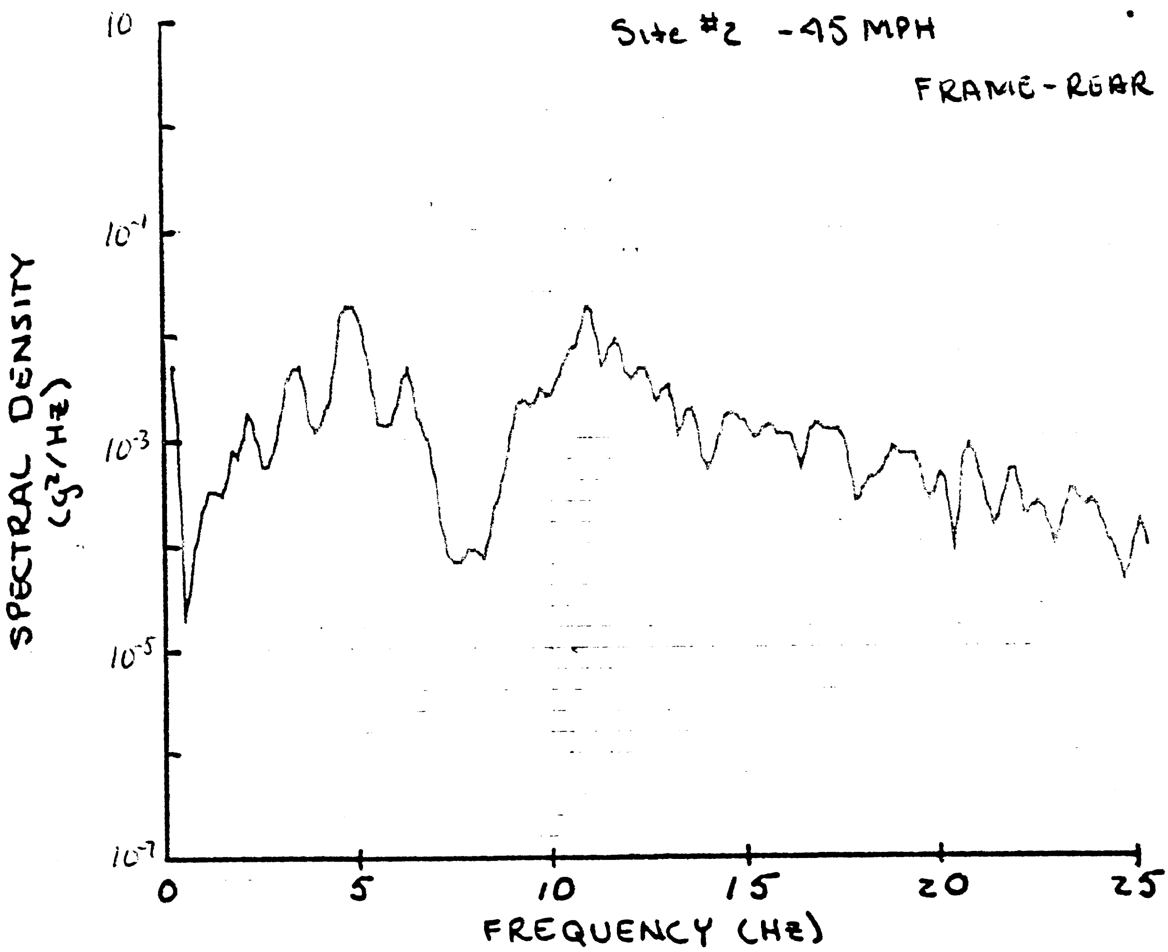

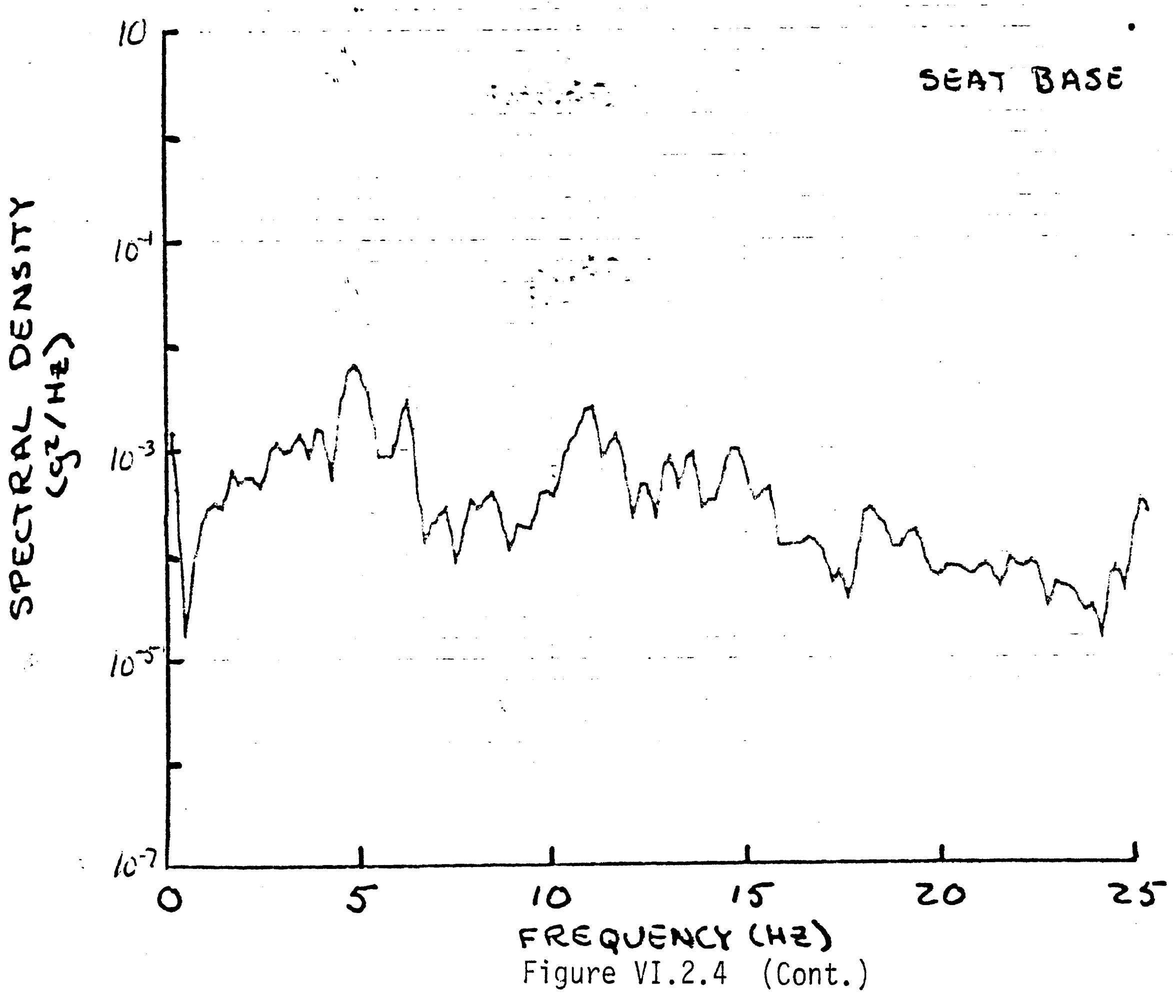

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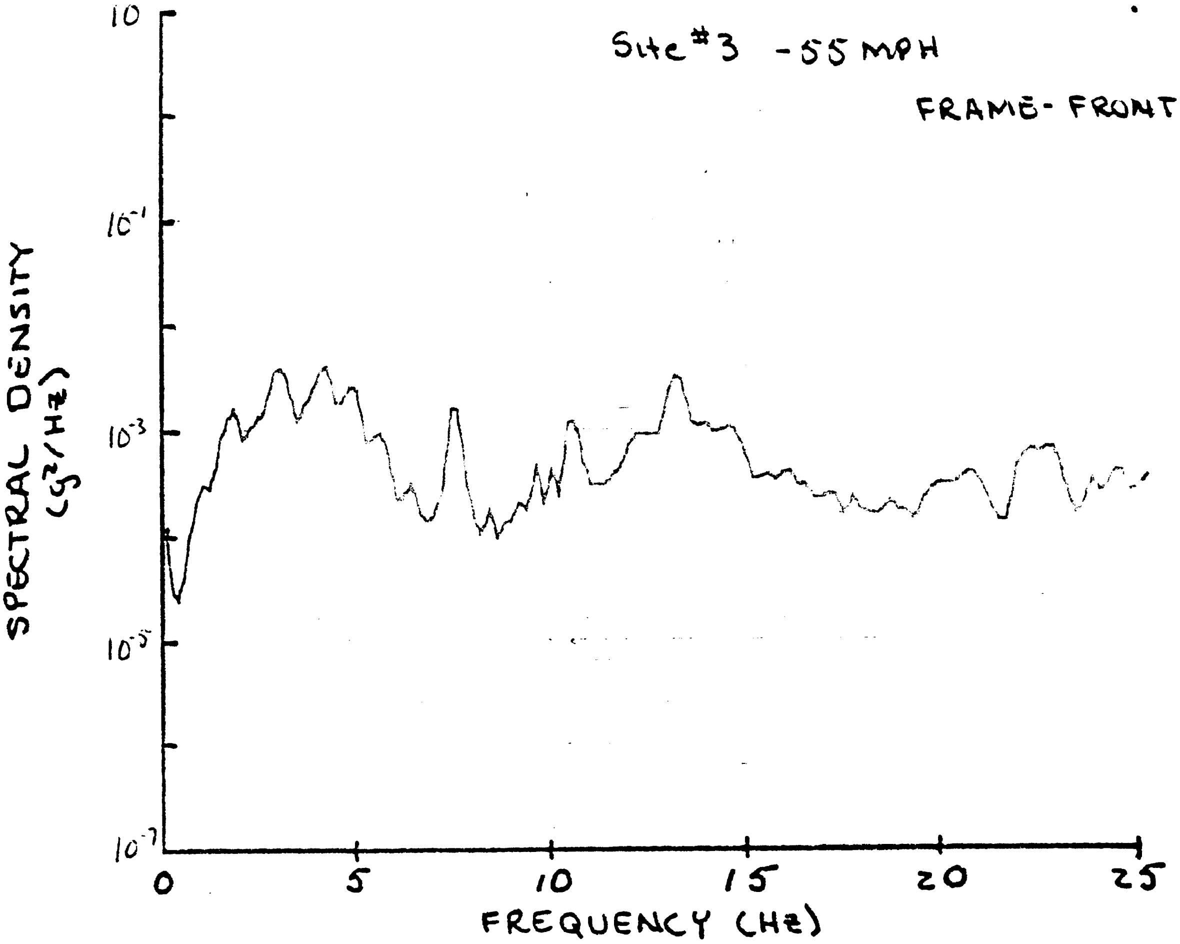

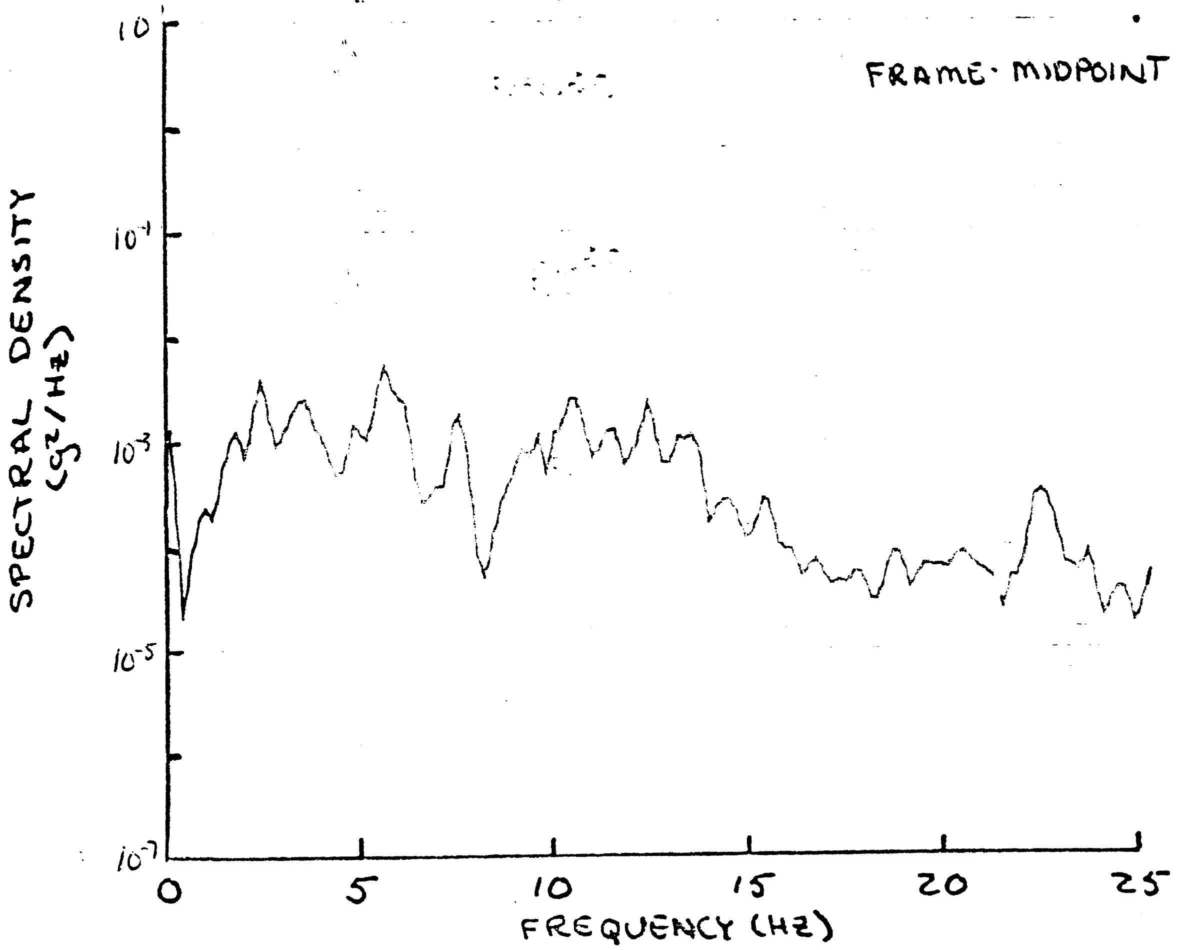

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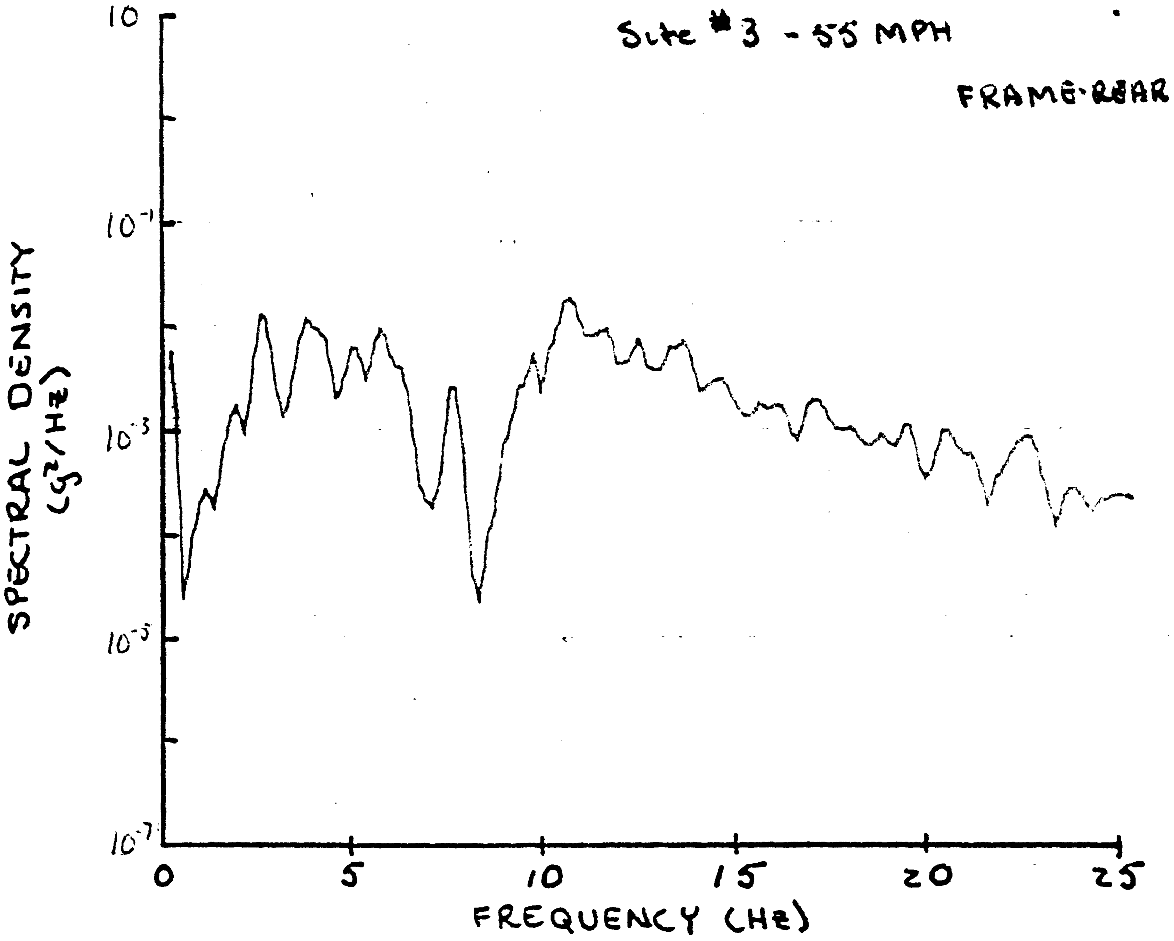

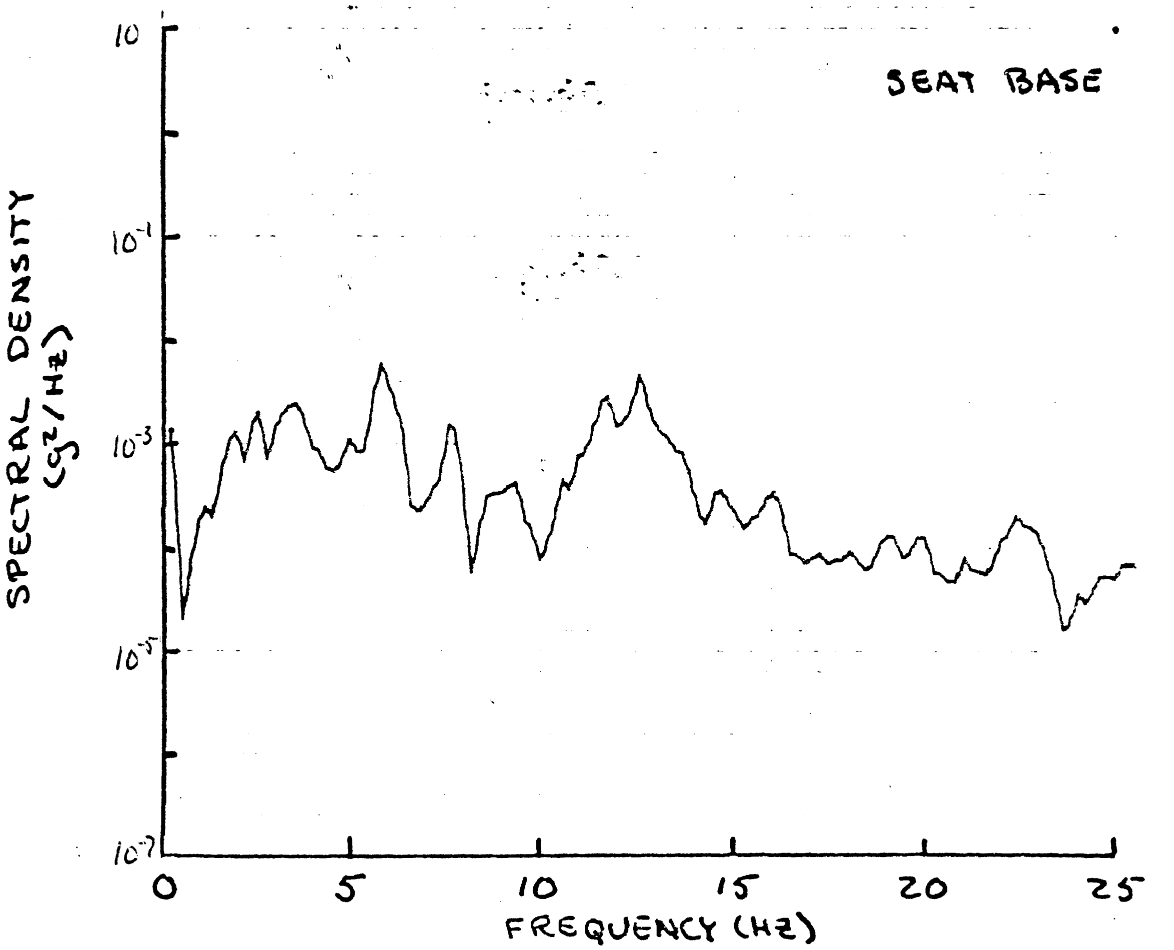

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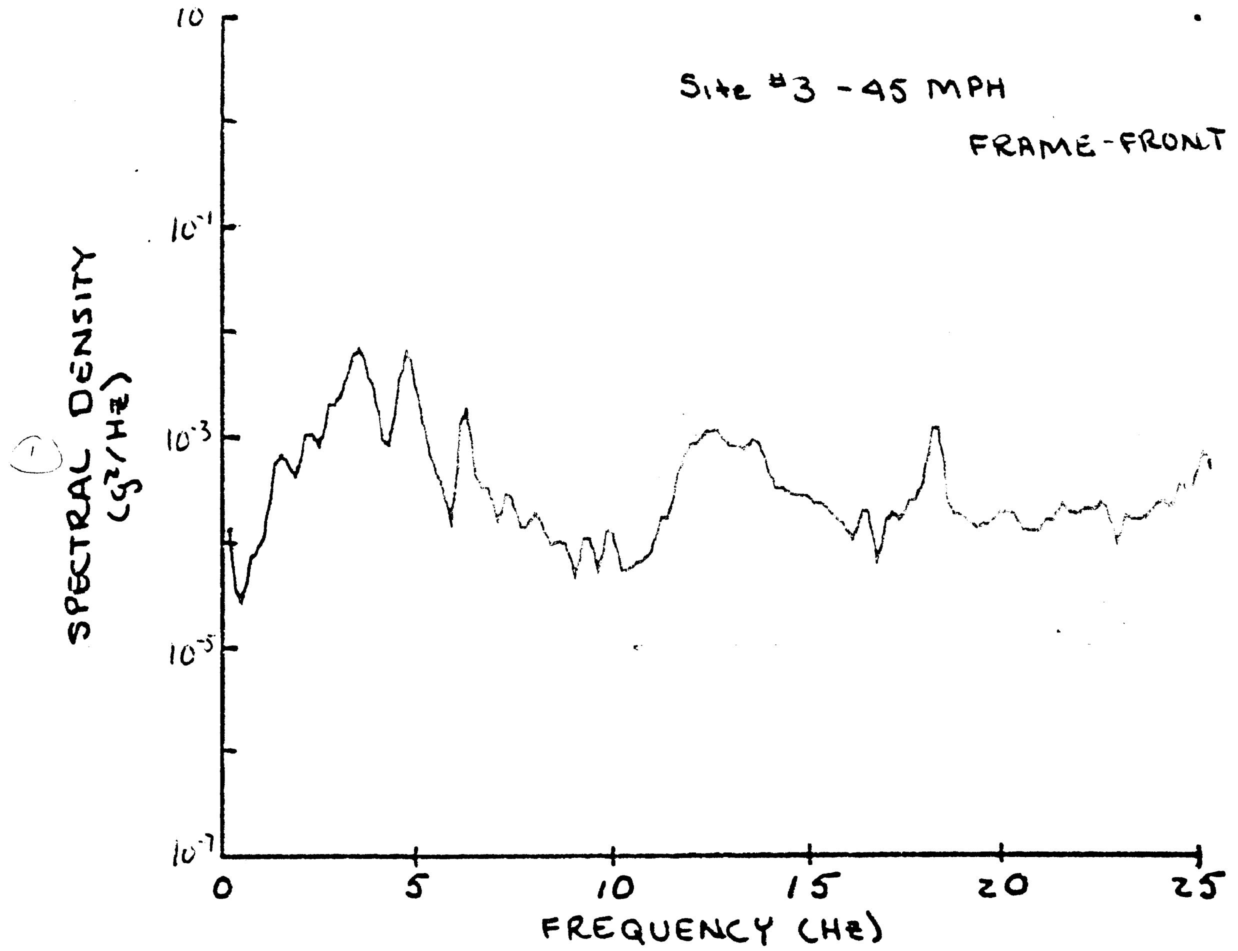
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10^{-1}
10^{-3}
10^{-5}
10^{-7}
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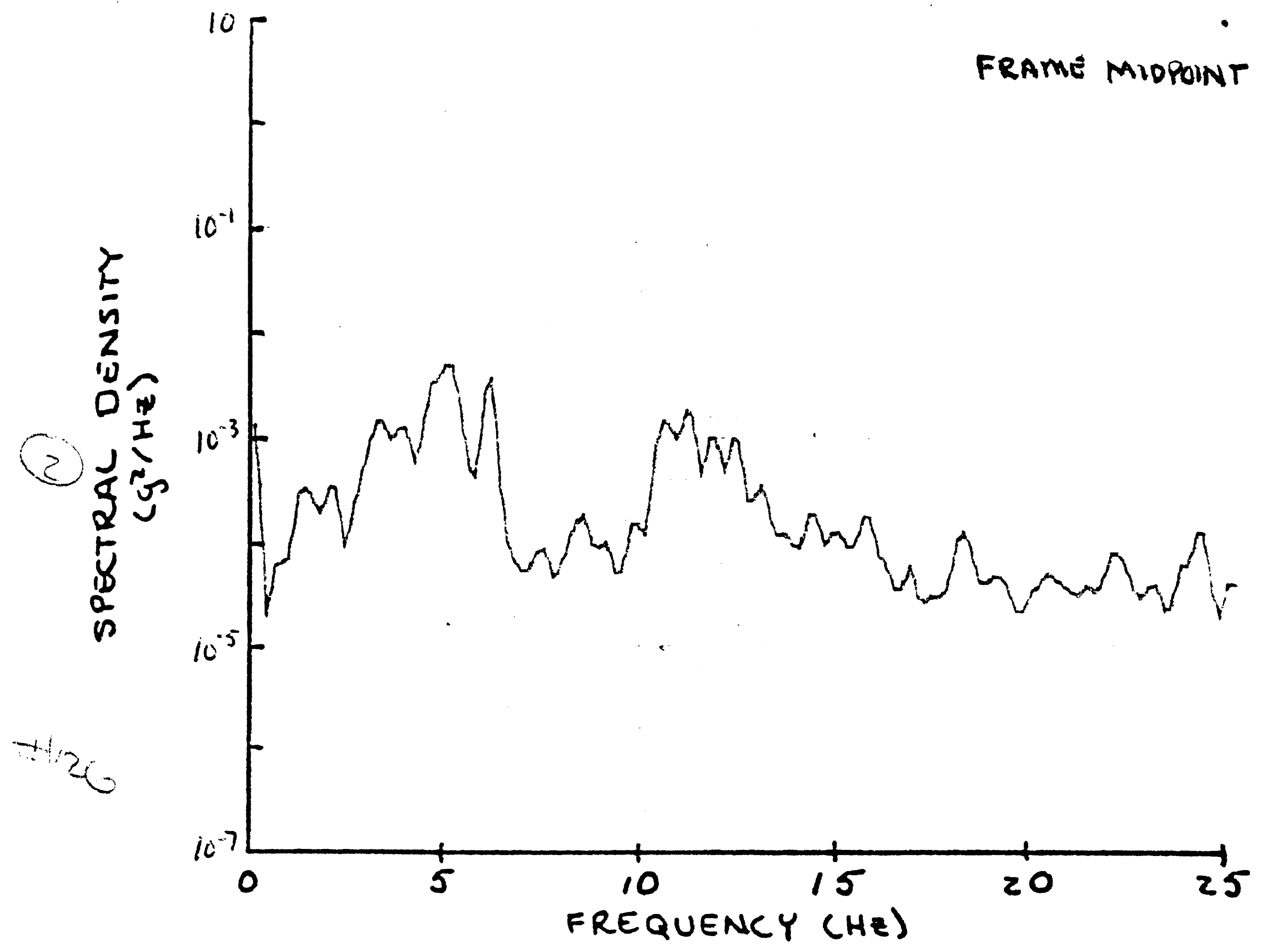
20
25
FREQUENCY (Hz)


FRAME MIDPOINT
SPECTRAL DENSITY (g^2/Hz)
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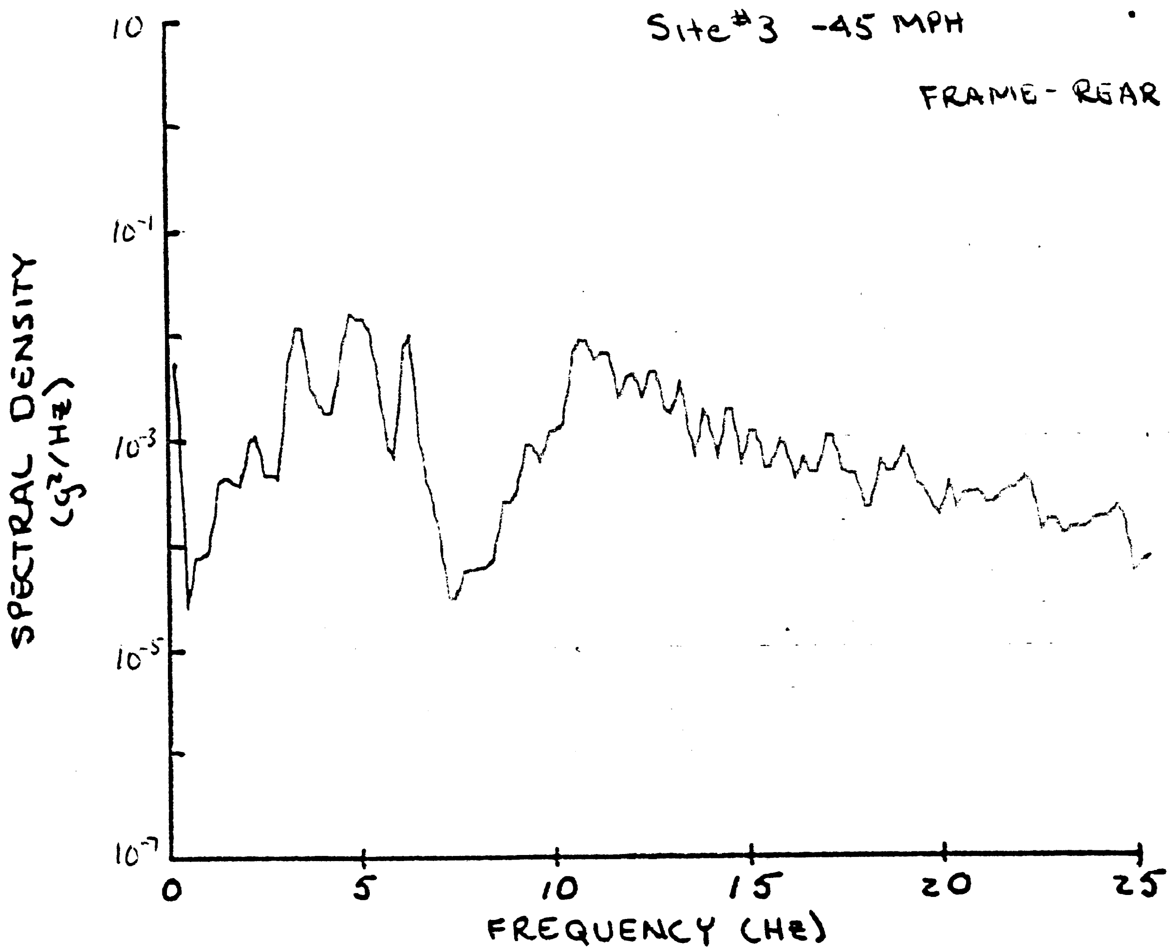
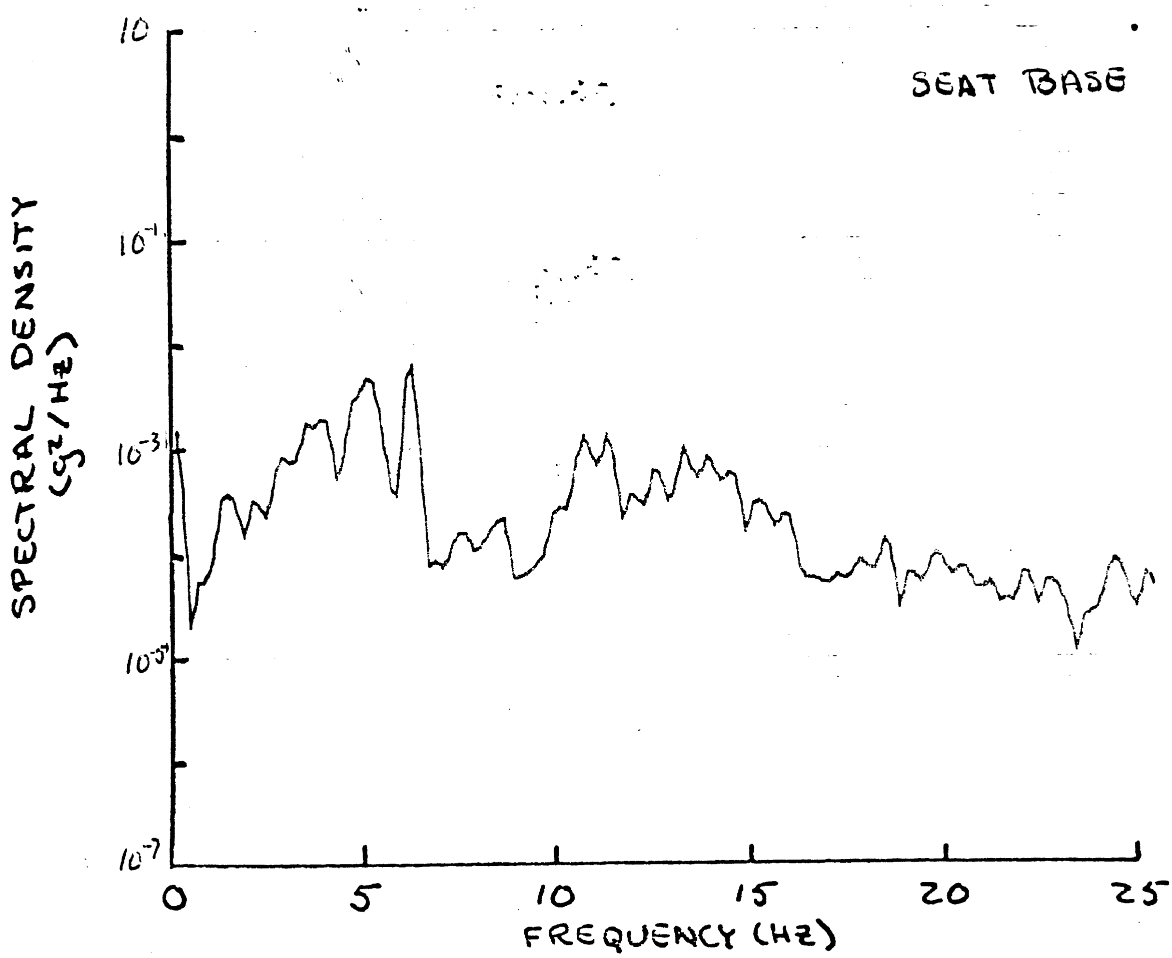
10^{-1}
10^{-3}
10^{-5}
10^{-7}
0
5
10
15
20
25
FREQUENCY (Hz)

Figure VI...4 (...d.)





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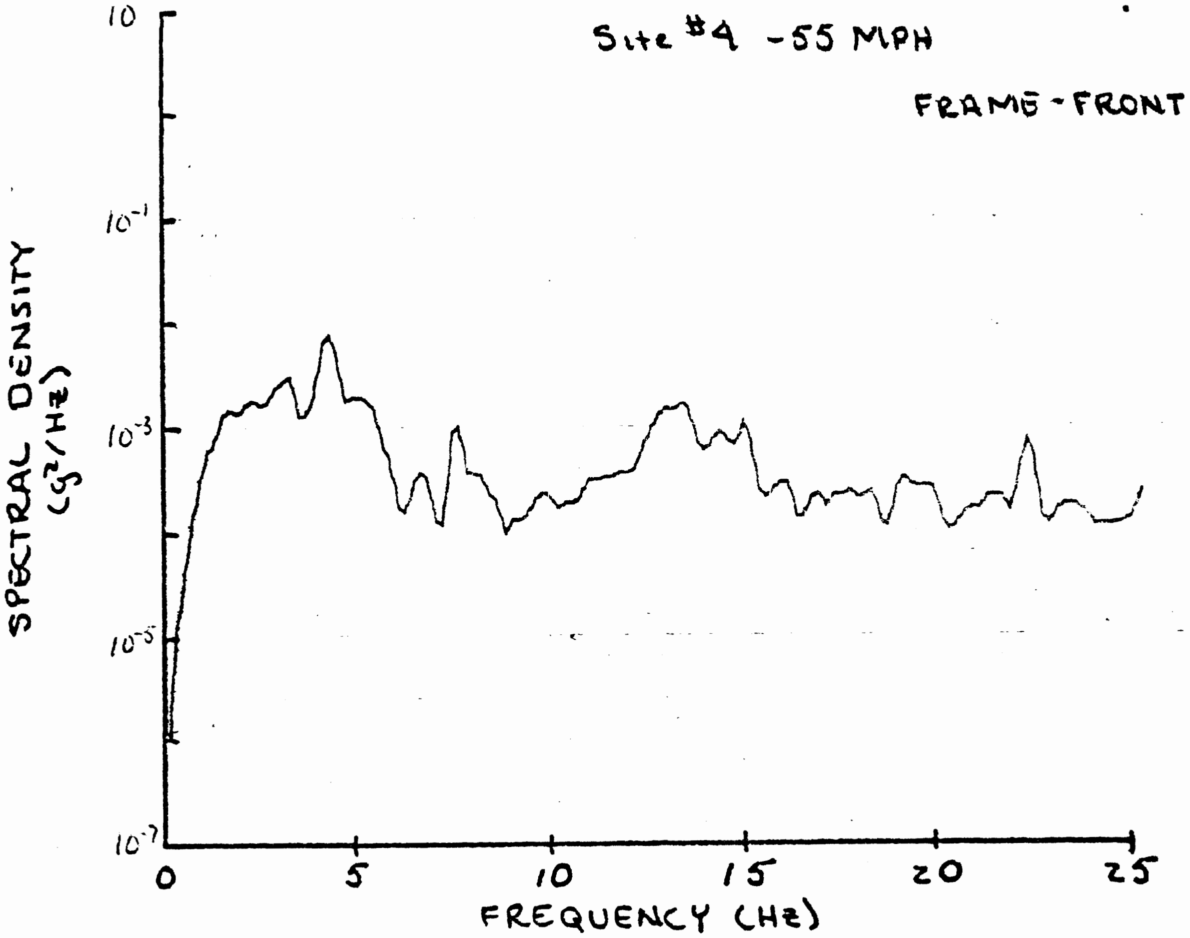

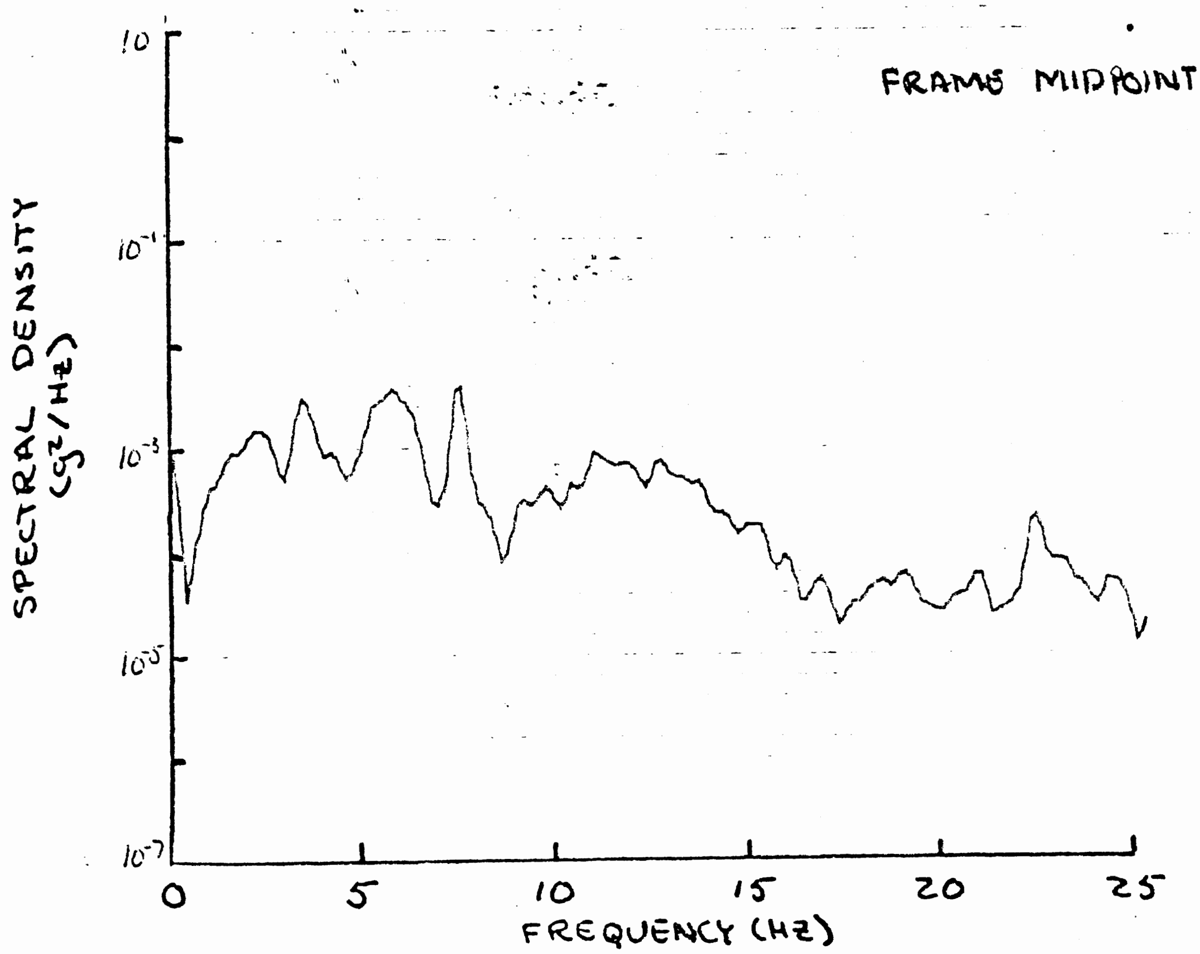

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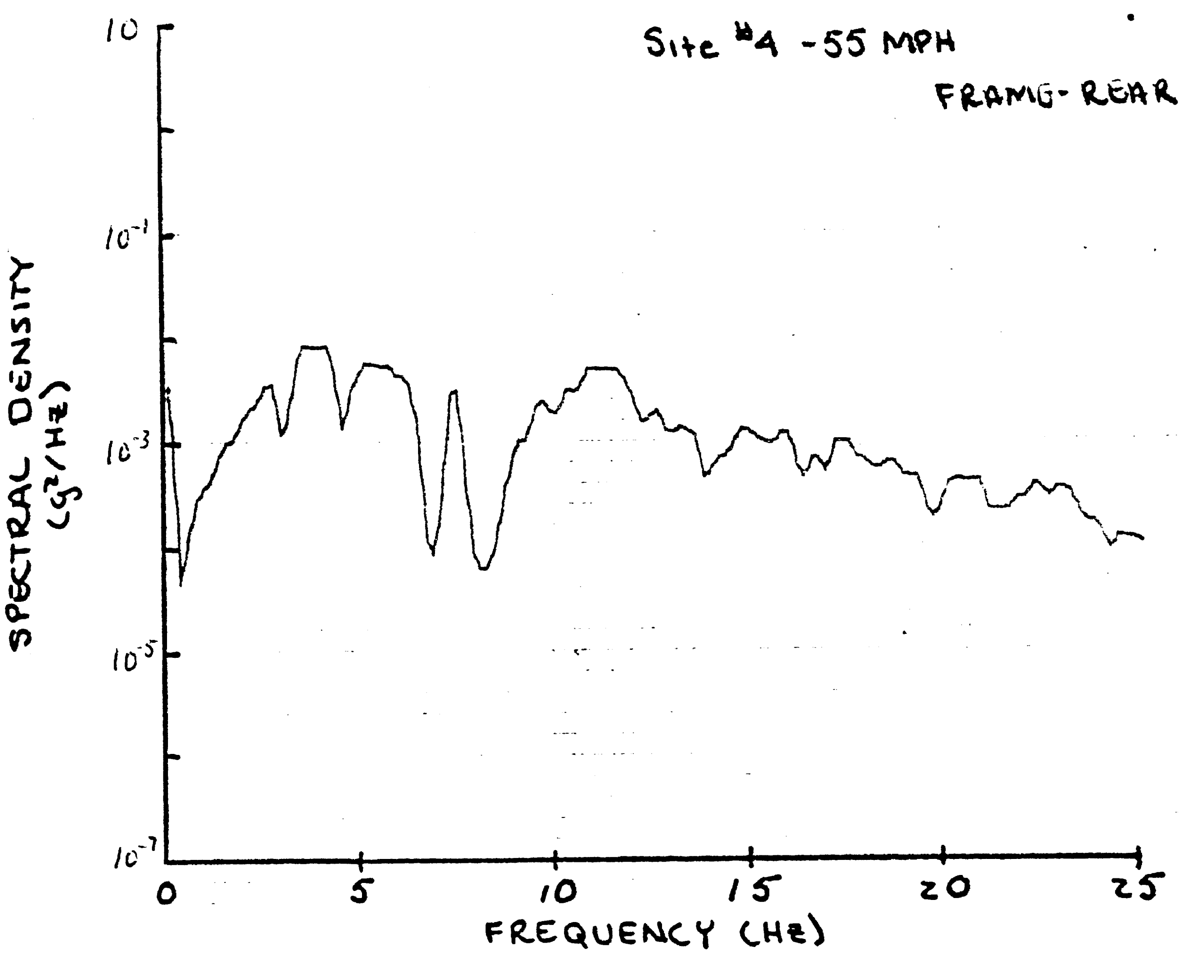

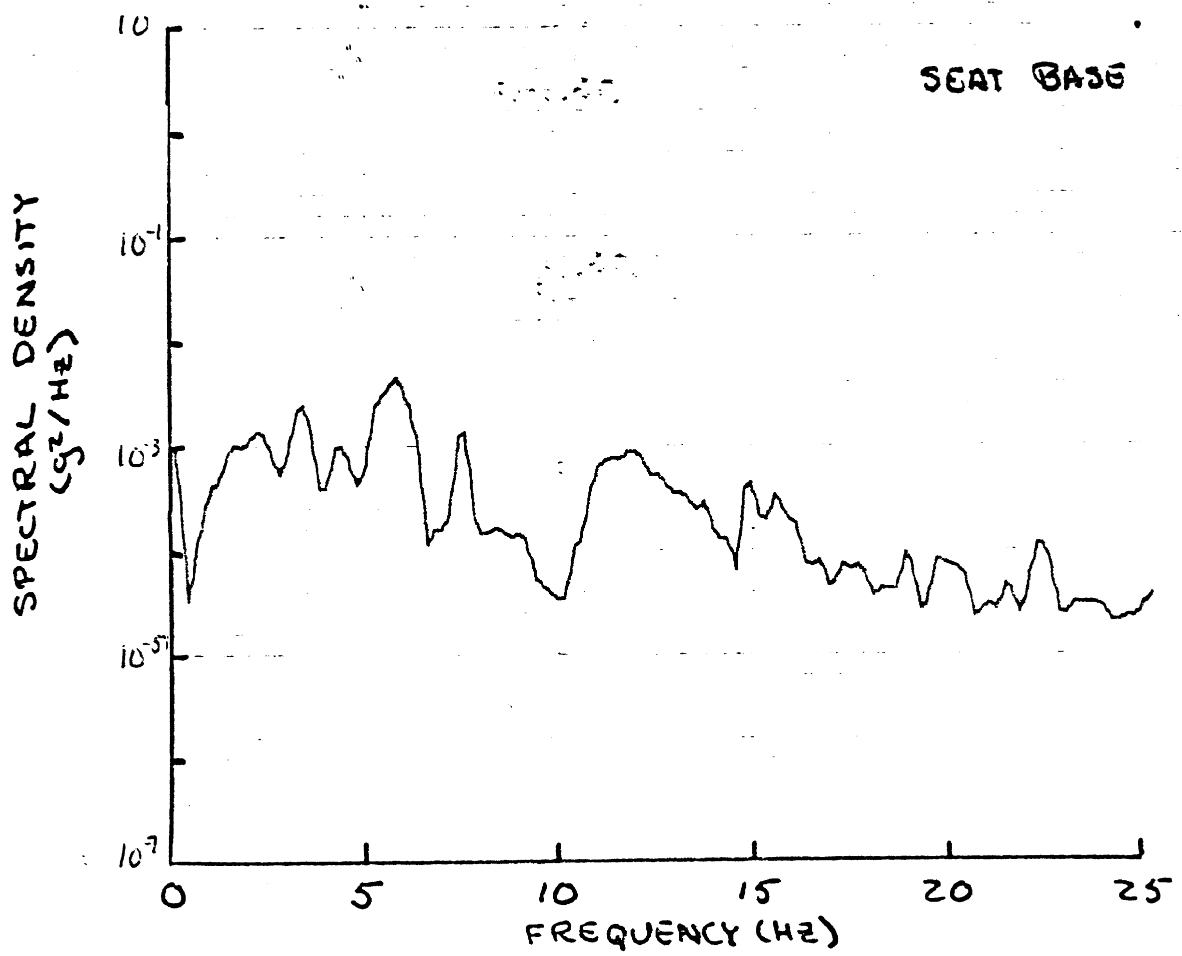

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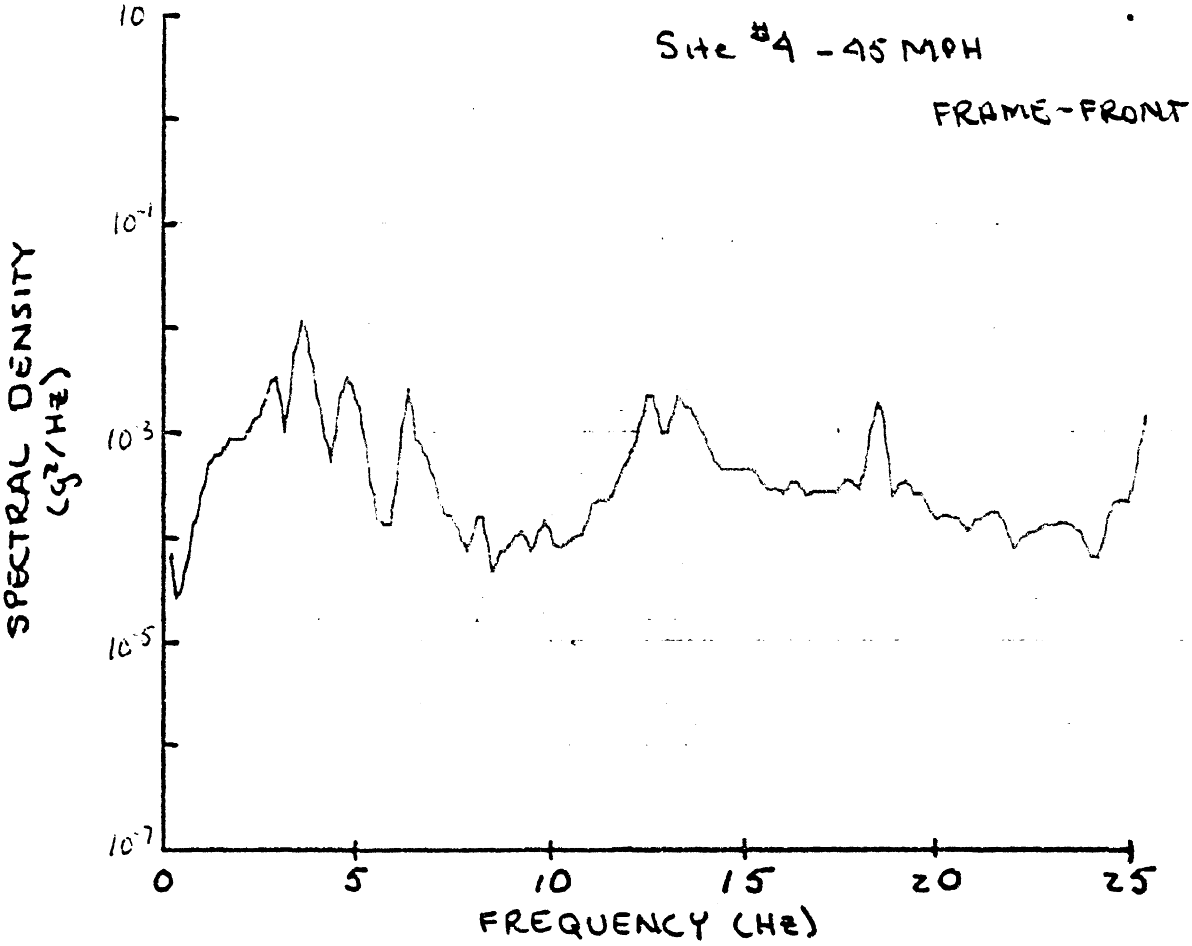


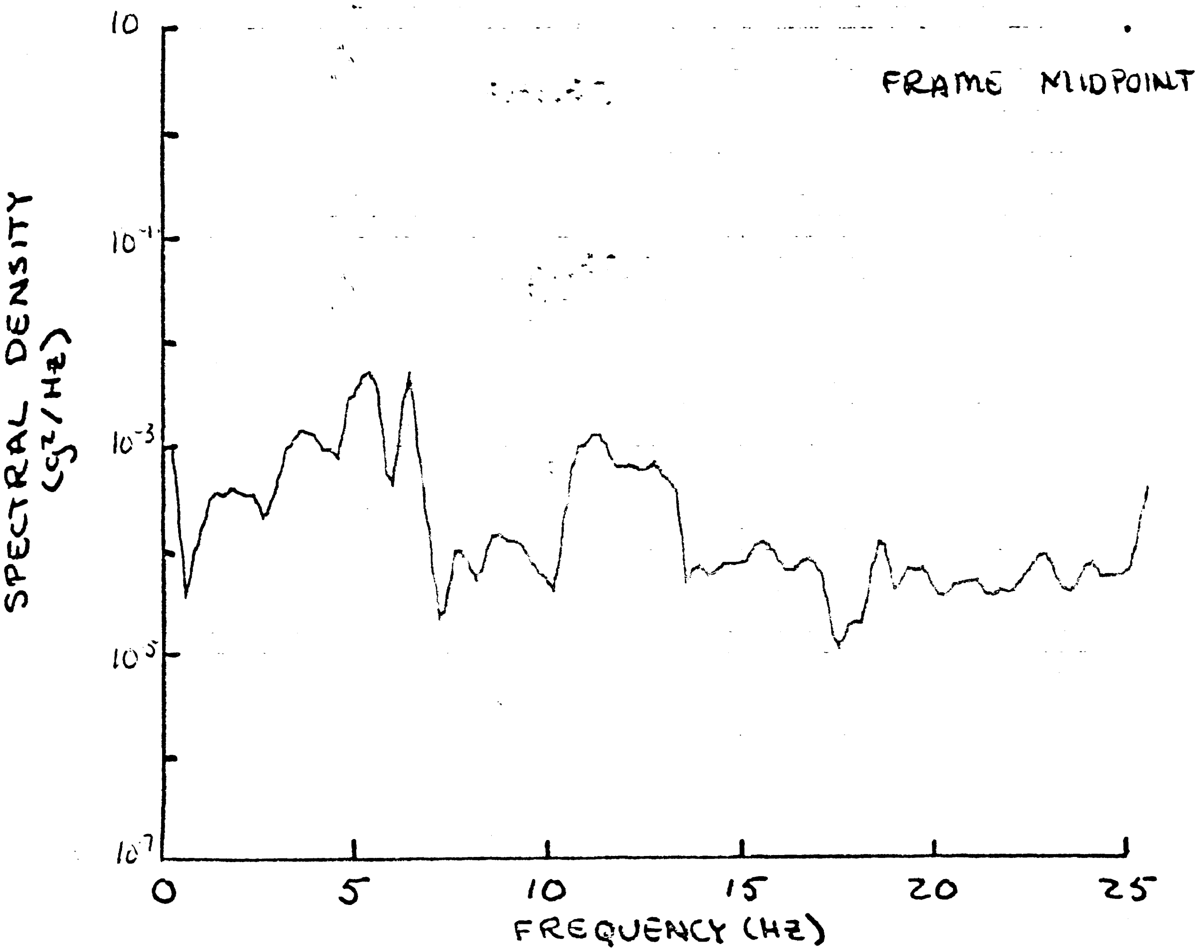
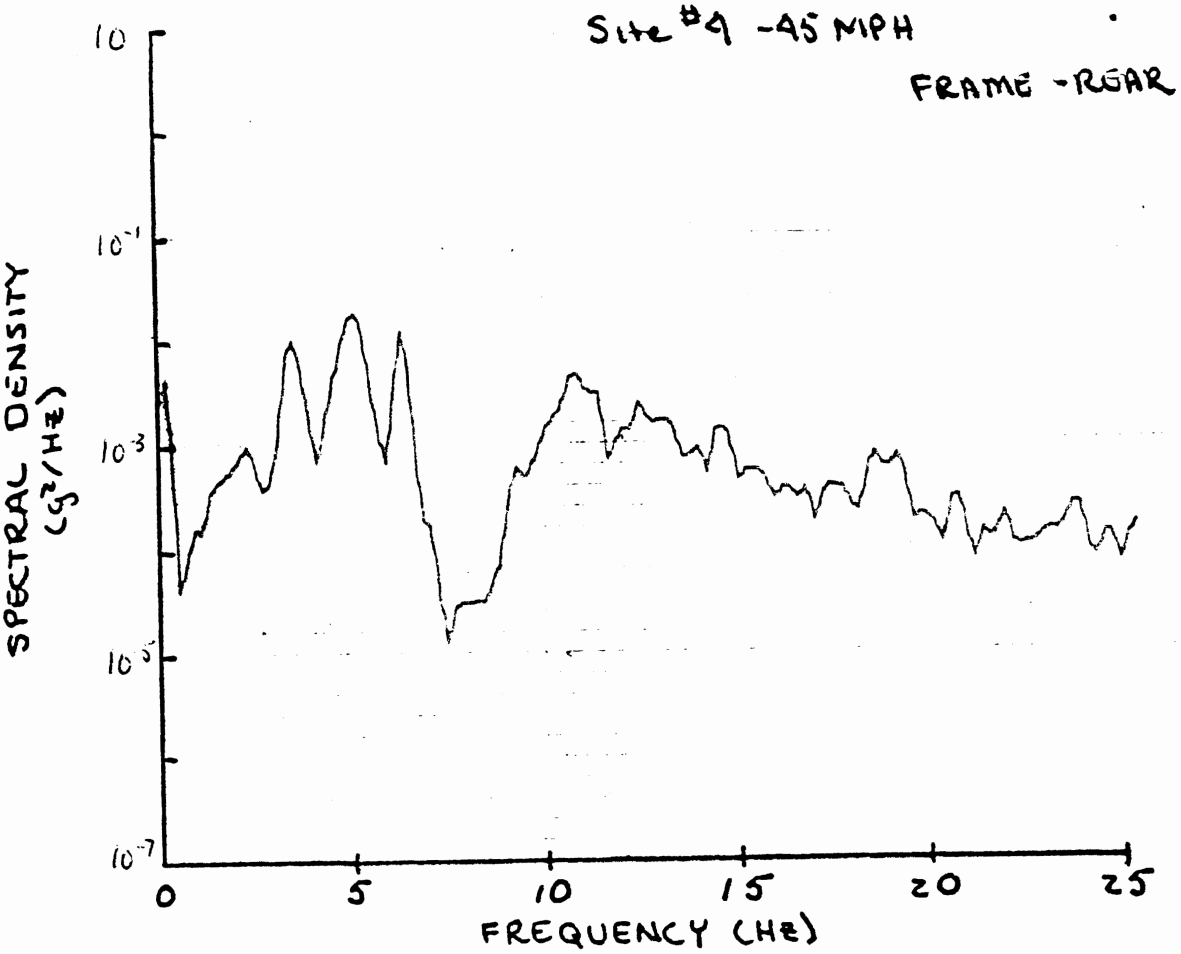


Figure VI.2.4 (Cont.)



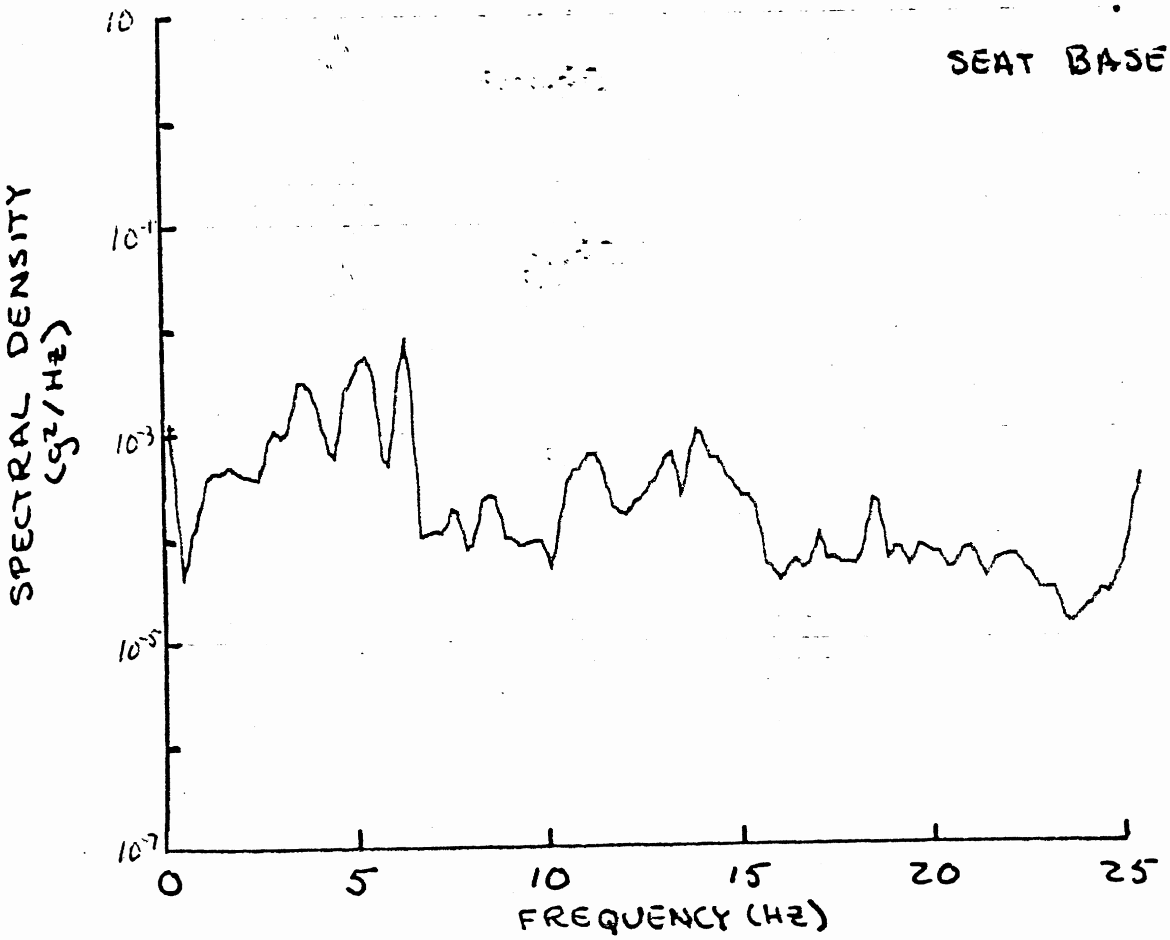
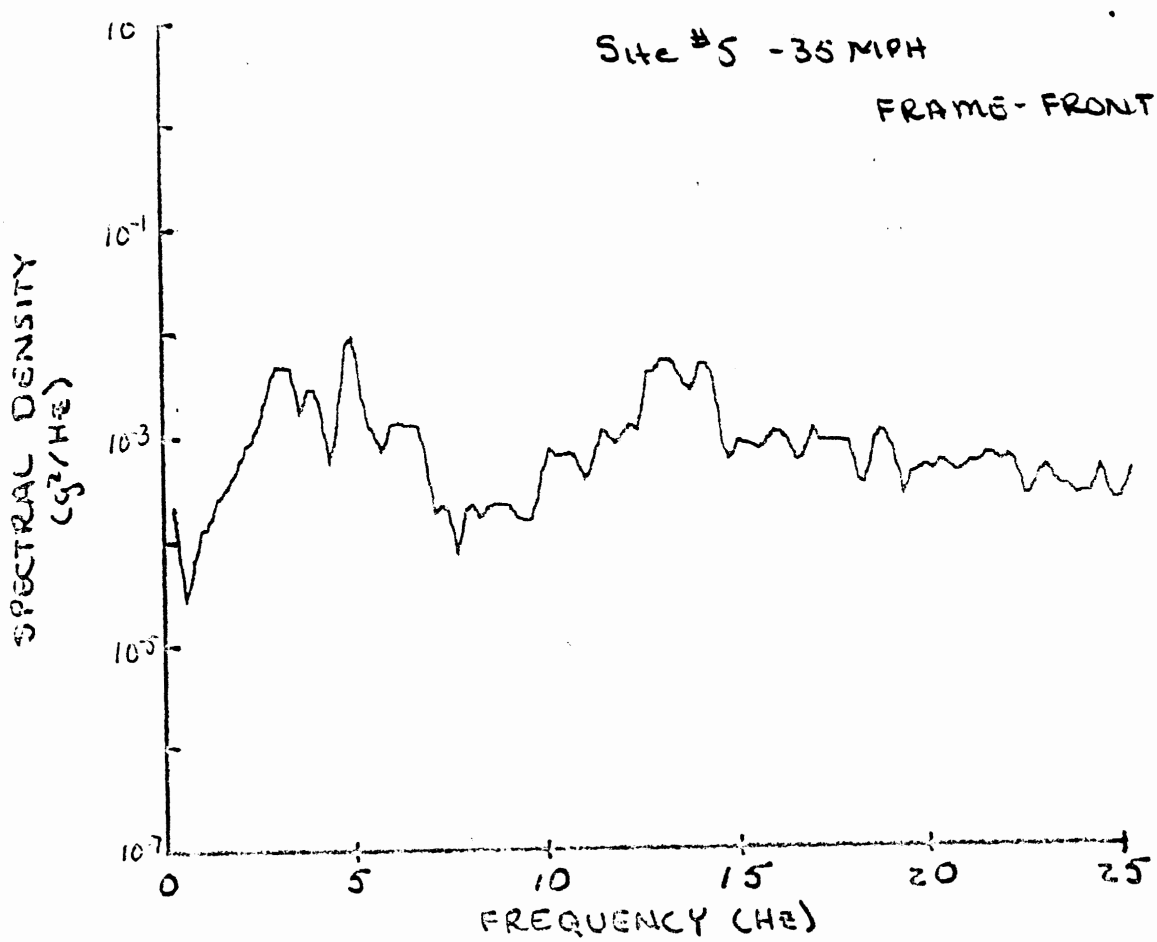


Figure VI.2.4 (Cont.)



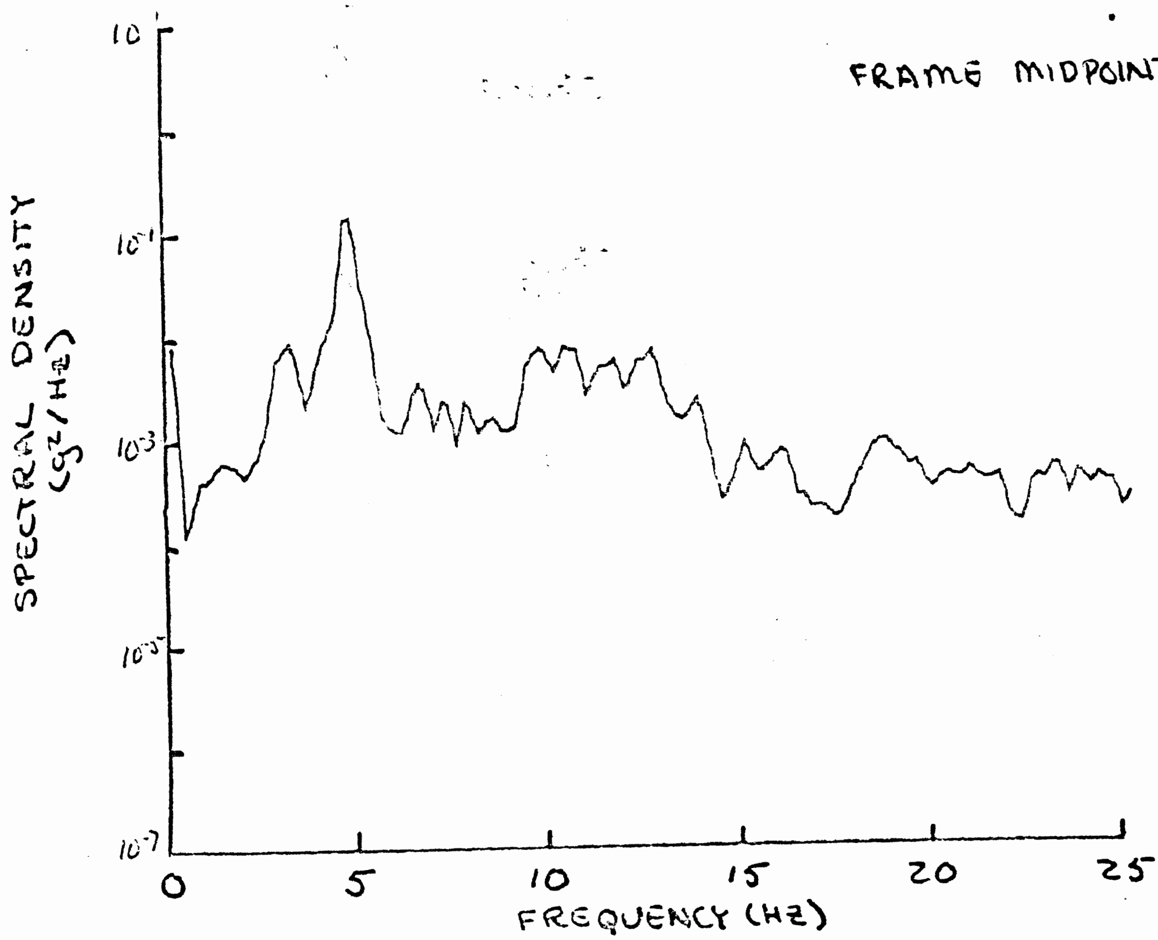
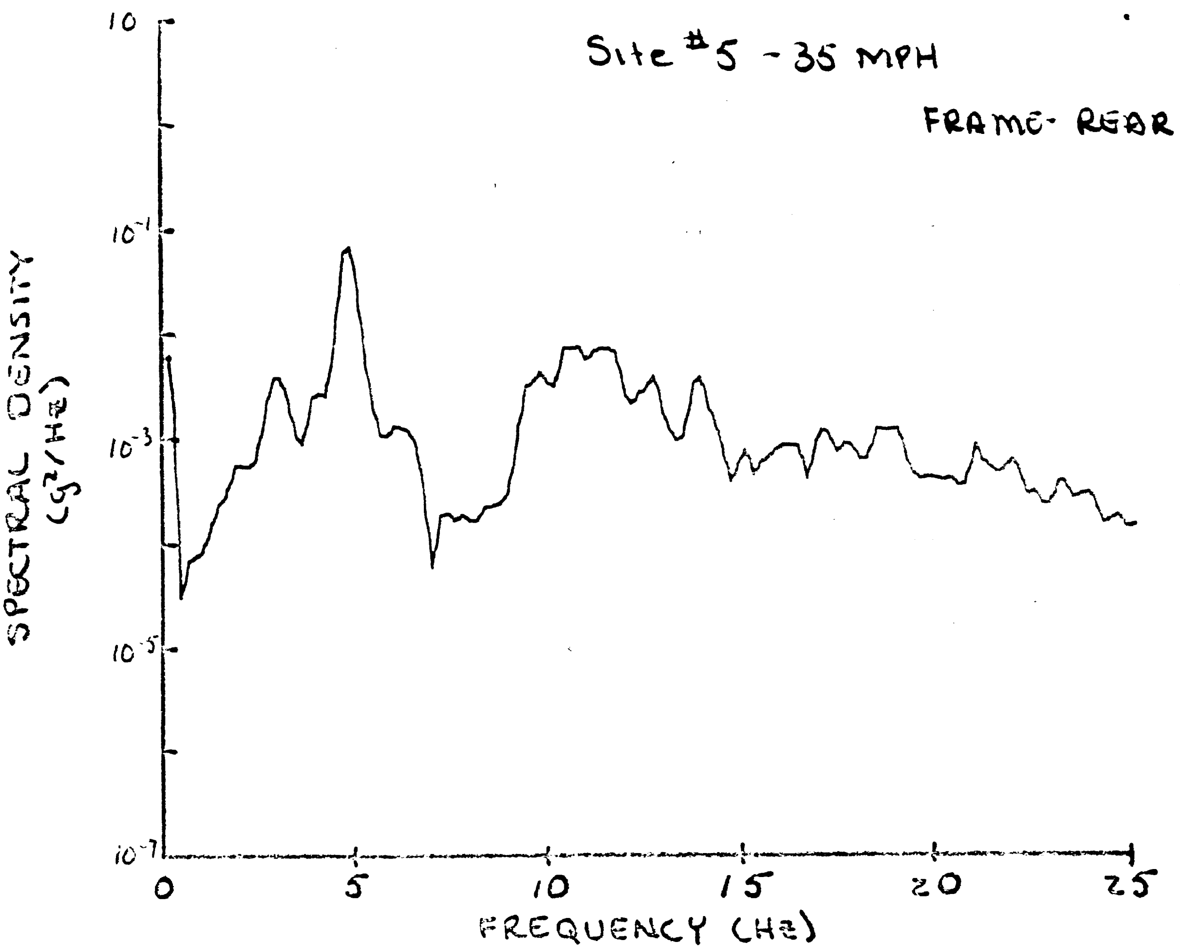


Figure VI.2.4 (Cont.)



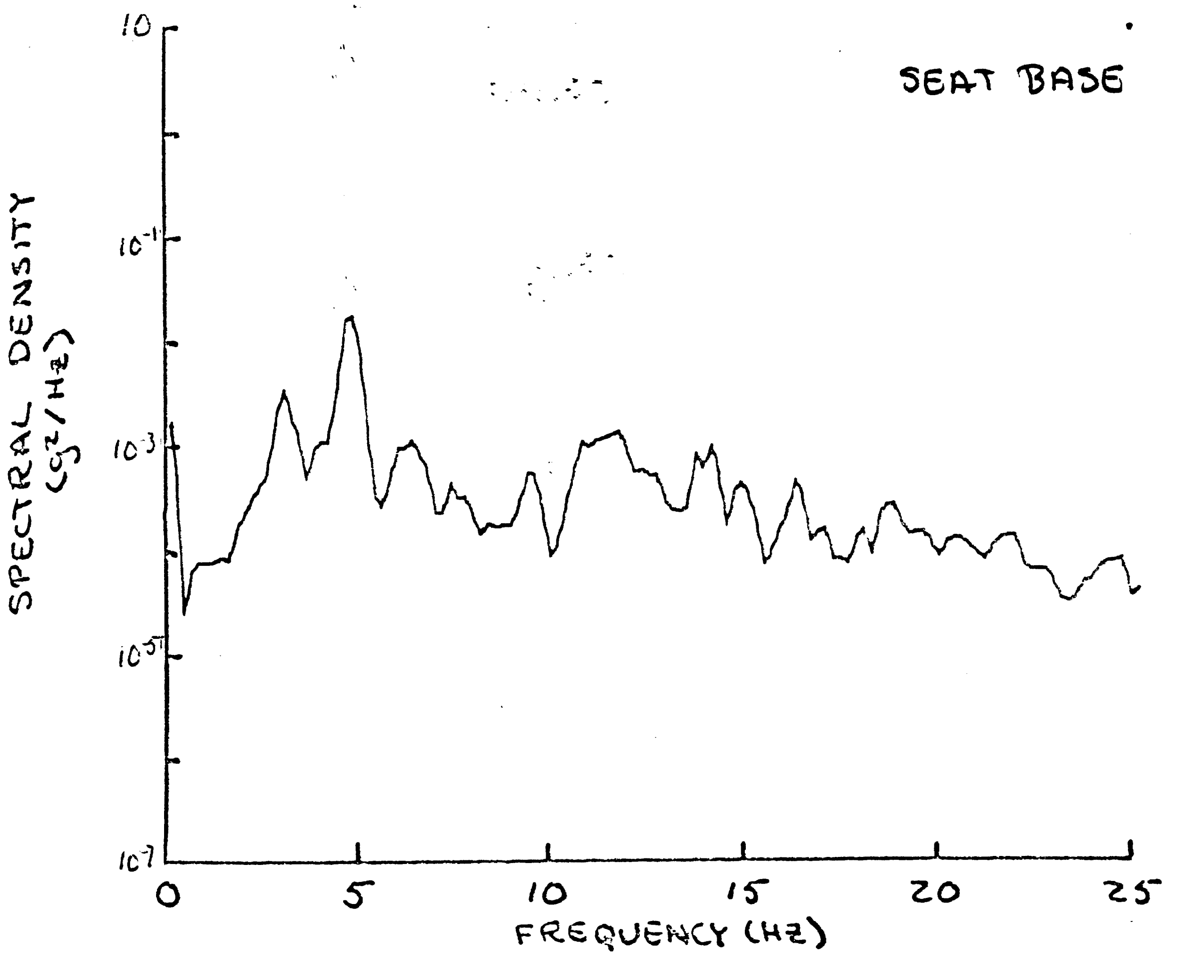


Figure VI.2.4 (Cont.)

APPENDIX VII

APPROXIMATE ANALYSIS OF TIRE SIDE FORCES ARISING DURING A TRANSIENT MANEUVER

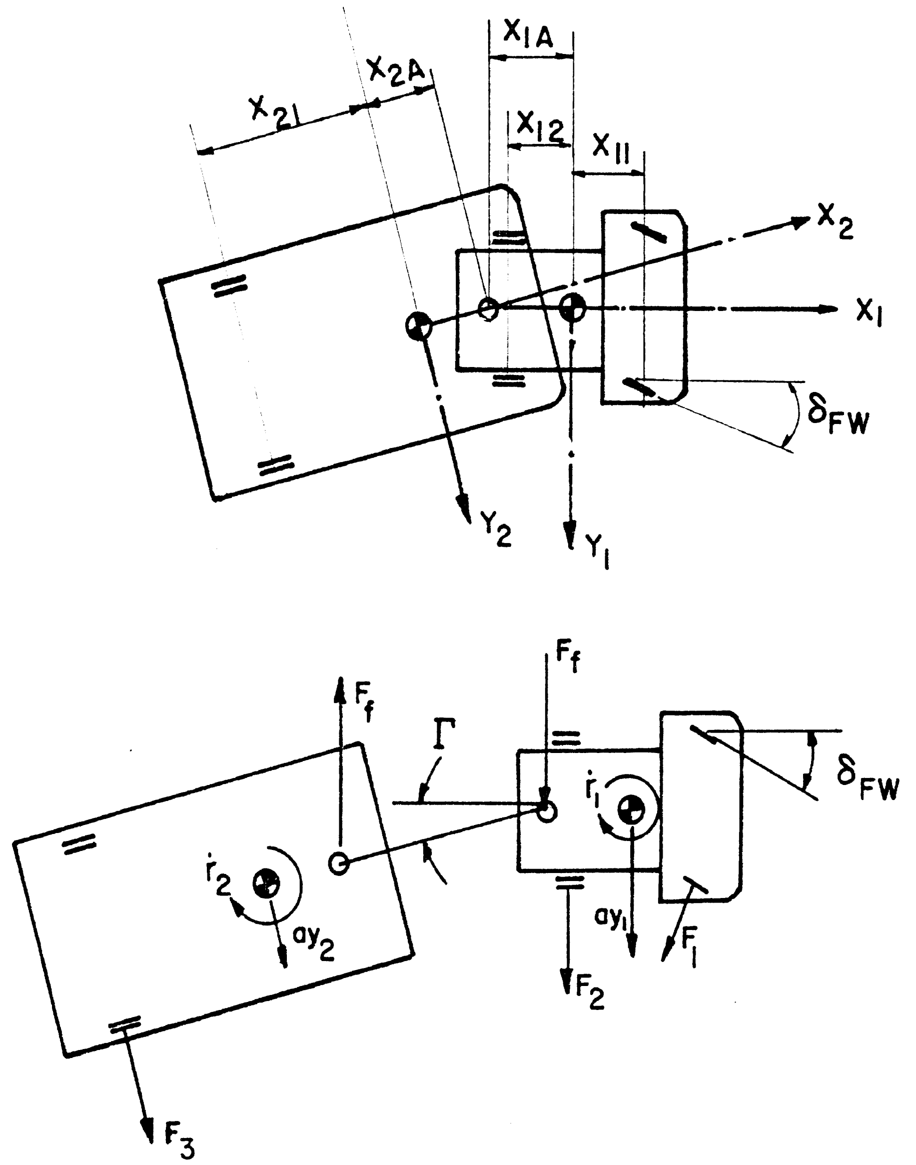
In this appendix, a simplified analysis is derived for identifying the terms which make up the expression for tire side forces prevailing at each of the three nominal axle positions of a tractor-semitrailer. The purpose of the analysis is to permit an assessment of the extent to which the mere presence of a non-steady turning condition could influence the tractor's yaw stability at a given operating point.

In particular, the analysis aided in identifying the mechanisms by which tractor-trailers appear more stable in the ramp-steer transient maneuver than in a steady-state turn. While previous discussion, in Section 6.2, showed that a lagging trailer response in the transient turn promotes tractor yaw stability indirectly through a roll mechanism, the presently derived expressions further indicate two contributions to tractor tire side force which work in opposing directions to influence tractor stability directly through a yaw plane mechanism.

A plan view of a two-axle tractor/single-axle trailer combination, along with the free-body diagrams (in the yaw plane) of the tractor and semitrailer units, is shown in Figure VII.1. If the assumption of small steering-wheel angles and articulation angles is valid, and, if there are no accelerating or braking forces present in the longitudinal direction, simple equations relating the tire side forces to the yaw angular acceleration and lateral acceleration of the tractor and trailer units can be derived from an inspection of the free-body diagrams. The equations are as follows:

<u>Lateral force equilibrium of the tractor</u>

$$F_1 + F_2 - F_f = m_1 a_{y1} \tag{1}$$



NOTE: $a y_1 = \dot{v}_1 + u r_1$

$$a y_2 = \dot{v}_1 + u r_1 - X_{1A}\dot{r}_1 - X_{2A}\dot{r}_2$$

Figure VII.1

Yaw moment equilibrium of the tractor

$$F_1 X_{11} - \dot{F}_2 X_{12} + F_f X_{1A} = I_1 \dot{r}_1 \tag{2}$$

Lateral force equilibrium of the trailer

$$F_f + F_3 = m_2 a_{y2} \tag{3}$$

Moment equilibrium of the trailer

$$F_f X_{2A} - F_3 X_{21} = I_2 \dot{r}_2 \tag{4}$$

Upon eliminating the lateral force at the fifth wheel, F_f from Equations (1) - (4), the tire side forces, F_1, F_2, and F_3 can be expressed in terms of $\dot{r}_1$, $\dot{r}_2$, a_{y1}, and a_{y2} and are of the form:

$$F_1 = \frac{X_{12} m_1 a_{y1}}{(X_{11}+X_{12})} + \frac{(I_2 \dot{r}_2 + m_2 X_{21} a_{y2})(X_{12}-X_{1A})}{(X_{2A}+X_{21})(X_{11}+X_{12})} + \frac{I_1 \dot{r}_1}{(X_{11}+X_{12})} \tag{5}$$

$$F_2 = \frac{X_{11} m_1 a_{y1}}{(X_{11}+X_{12})} + \frac{(I_2 \dot{r}_2 + m_2 X_{21} a_{y2})(X_{11}+X_{1A})}{(X_{2A}+X_{21})(X_{11}+X_{12})} - \frac{I_1 \dot{r}_1}{(X_{11}+X_{12})} \tag{6}$$

$$F_3 = \frac{m_2 X_{2A} a_{y2} - I_2 \dot{r}_2}{(X_{2A}+X_{21})} \tag{7}$$

When the fifth wheel is located directly over the tractor rear axle, $X_{1A} = X_{12}$, and Equations (5), (6), and (7) reduce to a simpler form:

$$F_1 = \frac{X_{12} m_1 a_{y1}}{L} + \frac{I_1 \dot{r}_1}{L} \qquad (8)$$

$$F_2 = \frac{X_{11} m_1 a_{y1}}{L} + \frac{m_2 X_{21}}{L_T} a_{y2} + \frac{I_2 \dot{r}_2}{L_T} - \frac{I_1 \dot{r}_1}{L} \qquad (9)$$

$$F_3 = \frac{m_2 X_{2A} a_{y2}}{L_T} - \frac{I_2 \dot{r}_2}{L_T} \qquad (10)$$

If we compare these instantaneous tire forces, F_i, to the forces $F_i)_{ss}$ during a steady turn of lateral acceleration, a_{y1}, we find

$$F_1 - F_1\Big)_{ss} = \frac{I_1 \dot{r}_1}{L} \qquad (11)$$

$$F_2 - F_2\Big)_{ss} = \frac{I_2 \dot{r}_2}{L_T} - \frac{I_1 \dot{r}_1}{L_T} - \frac{m_2 X_{21}}{L_T}(a_{y1} - a_{y2}) \qquad (12)$$

$$F_3 - F_3\Big)_{ss} = \frac{-I_2 \dot{r}_2}{L_T}$$

The factors which contribute to the deviation of the yaw response of the tractor during ramp-steer-type transient maneuvers from the steady turning behavior can be explained with the aid of Equations (11) and (12).

During the ramp-steer transient maneuver, the lateral acceleration of the trailer lags behind the lateral acceleration of the tractor and the yaw rates r_1 and r_2 increase with time. From Equation (12) we find that a lag in the trailer acceleration will lower the side force, F_2, and therefore will provide a stabilizing effect on the tractor. The tractor yaw angular acceleration term ($I_1 \dot{r}_1$) causes an increase in F_1 and a decrease in F_2, and therefore also has a stabilizing effect. The trailer angular acceleration term ($I_2 \dot{r}_2$), on the other hand, tends to increase F_2 and hence has a destabilizing effect. For typical tractor-trailer vehicles, the influence of trailer lag dominates and the result is the contribution of a net stabilizing effect (during ramp-steer-type maneuvers) for those tractors which have a tendency to exhibit yaw divergence.