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INTERTIAL AND SUSPENSION PARAMETER DATA FOR VRTC

Final Report

Contract Number DTNH22-82-C-07373

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R.L. Nisonger

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16. Abstract

Inertial and suspension parameters were measured on two heavy vehicles. Center-of-gravity position, pitch-plane moment of inertia of the whole vehicle, and polar moment of inertia of front and rear tire/wheel/brake assemblies were measured for both vehicles. Unsprung front and rear masses were measured for one vehicle. A variety of suspension properties, including vertical and roll rates, roll steer, and compliance steer properties, were measured for each of the four suspensions.

17. Key Words

Truck, parameters, center-of-gravity, moment of inertia, front suspension, rear suspension, tandem suspension

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1. INTRODUCTION

This document constitutes the final report of The University of Michigan Transportation Research Institute (UMTRI) on Contract Number DTNH22-82-C-07373, "Inertial and Suspension Parameter Data for VRTC." The purpose of this project was to measure inertial and suspension characteristics of a (1) Ford LNT 800 6x4 truck and of an (2) International Harvester S-1954 4x2 truck. The specific parameters to be measured are reviewed in Table 1.

The results of inertial parameter testing are presented in Section 2. Results for suspension parameter testing are given in Section 3.

Table 1

PROGRAM OF PARAMETER MEASUREMENTS FOR NHTSA

TASK NO.	NHTSA ITEM NO.	VEHICLE NO.	DESCRIPTION OF TASK
1	1	1	C. G. and Moment of Inertia in the Pitch Plane
2	2	1	Polar Moment of Inertia of 1 Front and 1 Dual Rear Wheel
3	3-7&9	1	Front Suspension: Vertical Force Deflection Roll Moment/Defelction Roll Steer Compliance Steer (Lateral Force and Aligning Moment) Brake Force Compliance Steer Vertical Deflection Steer
4	8	1	Roll Steer at + & - 1.5 deg Steer
5	10-15	1	Rear Suspension: Vertical Force/Deflection Roll Moment/Deflection Roll Steer Compliance Steer (Lateral Force and Aligning Moment) Vertical Load Distribution Interaxle Load Transfer
6	16	1	Load Distribution & Interaxle Load Transfer at -1 & -2 deg pitch
7	17	2	C. G. and Moment of Inertia in the Pitch Plane
8	18-23	2	Front Suspension: Vertical Force Deflection Roll Moment/Deflection Roll Steer Compliance Steer (Lateral Force and Aligning Moment) Brake Force Compliance Steer Vertical Deflection Steer

Table 1 (Cont.)

TASK NO.	NHTSA ITEM NO.	VEHICLE NO.	DESCRIPTION OF TASK
9	24&29	2	Front and Rear Unprung Mass Weight
10	25&26	2	Rear Suspension: Vertical Force/Deflection Roll Moment/Deflection
11	27&28	2	Roll Steer Compliance Steer (Lateral Force and Aligning Moment)

2. INERTIAL PROPERTIES

The pitch-plane inertial properties of the two test vehicles were measured on UMTRI's Pitch-Plane Inertial Properties Test facility (Figure 2.1). These properties are those of the whole vehicle and include total weight, c.g. height and fore/aft position, and pitch moment of inertia about the c.g. Results of these measurements are given in Figure 2.2. (Note that the c.g. height is located relative to the lower face of the vehicles' frame rails at the fore/aft position. We feel that locating the c.g. relative to the sprung mass is more reliable for reporting purposes than locating it relative to ground. The "height above ground" data given in the figure is for your convenience and may vary considerably with tire changes, etc.)

The weight and polar moment of inertia of the rotating masses for each truck were also measured. Weights were determined using a balance scale. The multi-filar pendulum technique was used to measure the moments of inertia. One rear and one front assembly from each vehicle was measured, where an assembly includes all the major rotating elements, viz., tire, wheel, hub, and brake rotor (drum or disc). The results appear in Figure 2.3.

Finally, the front and rear unsprung masses of the IH truck were weighed using a strain gauge load cell. In each case, the springs were included in the measurement and the shock absorbers were not included. For the rear alxes, no portion of the drive shaft weight was included. For the front axle, the steering drag link was not included. For these conditions, the front unsprung mass weighs 1,093 lbs and the rear unsprung mass weighs 2,133 lbs.

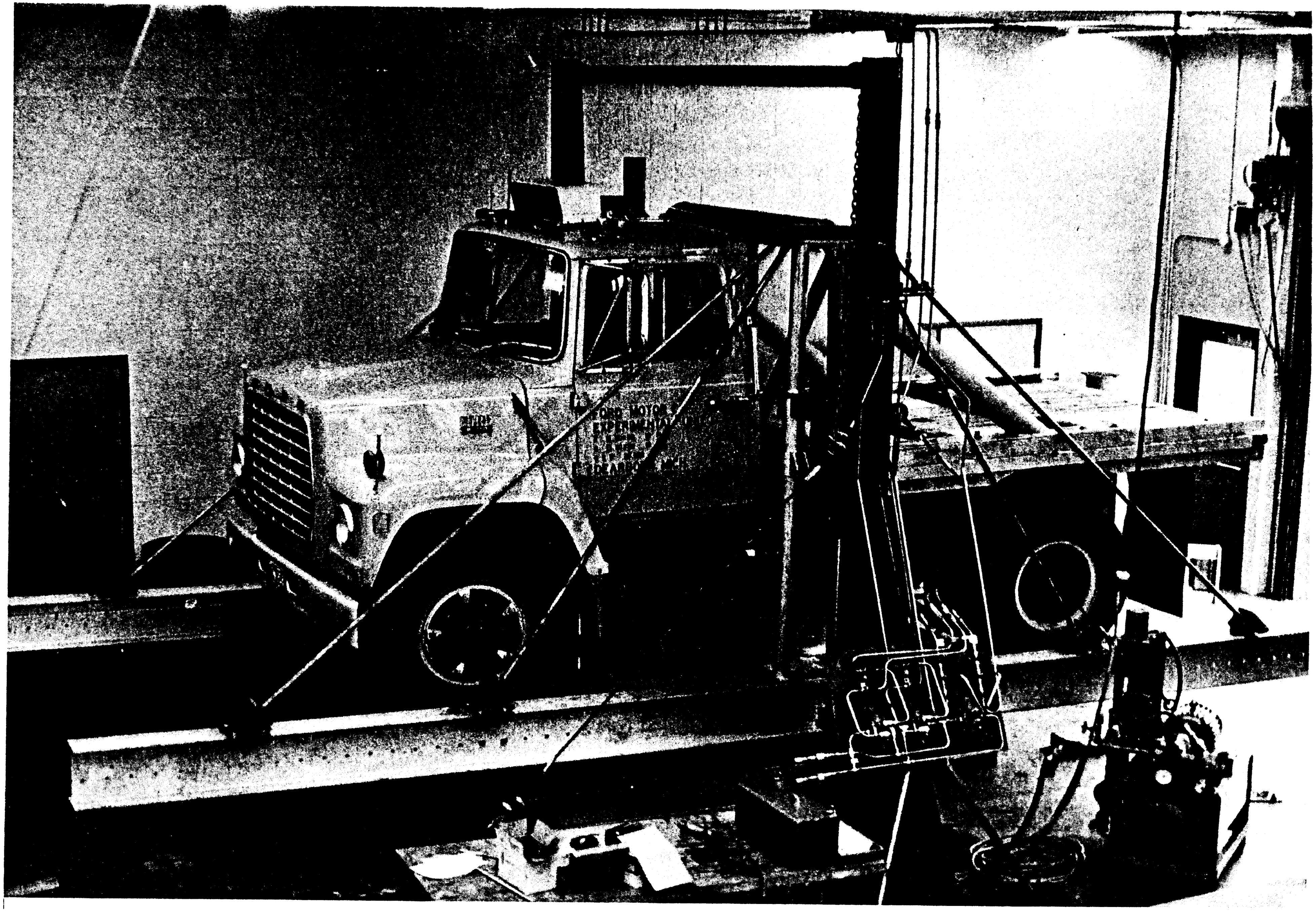


Figure 2.1. Pitch-Plane Inertial Properties Test Facility.

HSRI PITCH PLANE INERTIAL

PROPERTIES TEST

TEST NO. NHTSA - 1

DATE 11/10/82 TIME__________ OPERATOR Winkler

I. VEHICLE ID

MANUFACTURER Ford (T) tandem WHEELBASE 150

MODEL NO. 800 (429-FV) SERIAL NO. 1FDRS50K1DV543734

II. BODY ID

MANUFACTURER None DESCRIPTION__________________

MODLE NO.__________________

SERIAL NO.__________________

III. VEHICLE CONDITION

GAS Full LOADING None

IV. RESULTS

	TEST 1	TEST 2	TEST 3	AVG
C.G. POSITION (INCHES)				
AFT OF FRONT AXLE	81.81	81.81	81.80	81.80
EXPECTED ERROR	0.150	0.150	0.151	
STANDARD DEVIATION				0.006
HEIGHT ABOVE VEHICLE REFERENCE*	0.81	0.80	0.84	0.82
EXPECTED ERROR	0.347	0.337	0.326	
STANDARD DEVIATION				0.015
HEIGHT ABOVE GROUND				30.82
PITCH MOMENT OF INERTIA ABOUT CG (IN-LB-SEC**2)	161714.	161076.	161250.	161347.
EXPECTED ERROR	2293.	2286.	2288.	
STANDARD DEVIATION				269.
WEIGHT (LBS)	11383.			

* REFERENCE POINT IS LOWER FACE OF FRAME AT CG

Figure 2.2a

HSRI PITCH PLANE INERTIAL

PROPERTIES TEST

TEST NO. NHTSA-2

DATE 11/30/82 TIME PM OPERATOR [illegible]

I. VEHICLE ID

MANUFACTURER IH WHEELBASE 140

MODEL NO. 1954 SERIAL NO. [illegible]

II. BODY ID

MANUFACTURER None DESCRIPTION

MODLE NO.

SERIAL NO.

III. VEHICLE CONDITION

GAS Full LOADING None

IV. RESULTS

	TEST 1	2	3	AVG
C.G. POSITION (INCHES)				
AFT OF FRONT AXLE	55.04	55.04	55.05	55.04
EXPECTED ERROR	0.143	0.143	0.143	
STANDARD DEVIATION				0.003
HEIGHT ABOVE VEHICLE				
REFERENCE*	5.95	5.79	5.80	5.84
EXPECTED ERROR	0.580	0.577	0.579	
STANDARD DEVIATION				0.073
HEIGHT ABOVE GROUND				32.34
PITCH MOMENT OF INERTIA				
ABOUT CG (IN-LB-SEC**2)	88585.	87969.	88022.	88192.
EXPECTED ERROR	2060.	2048.	2049.	
STANDARD DEVIATION				279.
WEIGHT (LBS)	9656.			

* REFERENCE POINT IS LOWER FACE OF FRAME AT CG

Figure 2.2b

	4x6 Ford Truck		2x4 IH Truck	
	Front	Rear	Front	Rear
Weight, lb.	319.5	569.5	294.5	513.5
Polar Moment of Inertia in-lb/sec^2	115	241	99	211

Figure 2.3. Rotating Masses.

3. SUSPENSION PARAMETER MEASUREMENTS

Front and rear suspensions of the two subject vehicles were measured on the UMTRI Heavy Vehicle Suspension Parameter Measurement Facility (Fig. 3.1). This facility exercises the suspension by the application of forces and moments to the tire contact patches of the suspension while the vehicle frame is held fixed. The parameters measured were:

- Vertical rate
- Roll rate
- Bounce steer (front only)
- Roll steer
- Aligning moment compliance steer
- Lateral force compliance steer
- Brake force compliance steer (front only)
- Interaxle load transfer due to brake force (tandem suspensions only)
- Load equalization (tandems only)

All tests that do not involve a sweeping of vertical load (i.e., vertical rate and bounce steer) are performed at three loads to provide information on the influence of geometric changes due to vertical deflection on the measured parameters. These loads were chosen to be 12,000, 9,000, and 6,000 lbs for the front suspensions, 19,000, 14,250, and 9,500 lbs for the single-axle rear, and 32,000, 24,000, and 16,000 lbs for the tandem suspension. Control of the axle motion was accomplished with two different schemes, depending on the requirements of the test being performed. For those parameter measurements that require bounce or roll motion of the axle, the axle is controlled by commanding total vertical load and the load differential between the right and left sides. This allows the suspension to respond to the application of vertical loads imposed at the tire contact patches. For those tests involving the application of shear forces and moments, the axle position is controlled directly to avoid the inclusion of motion-related responses in the compliance measurement.

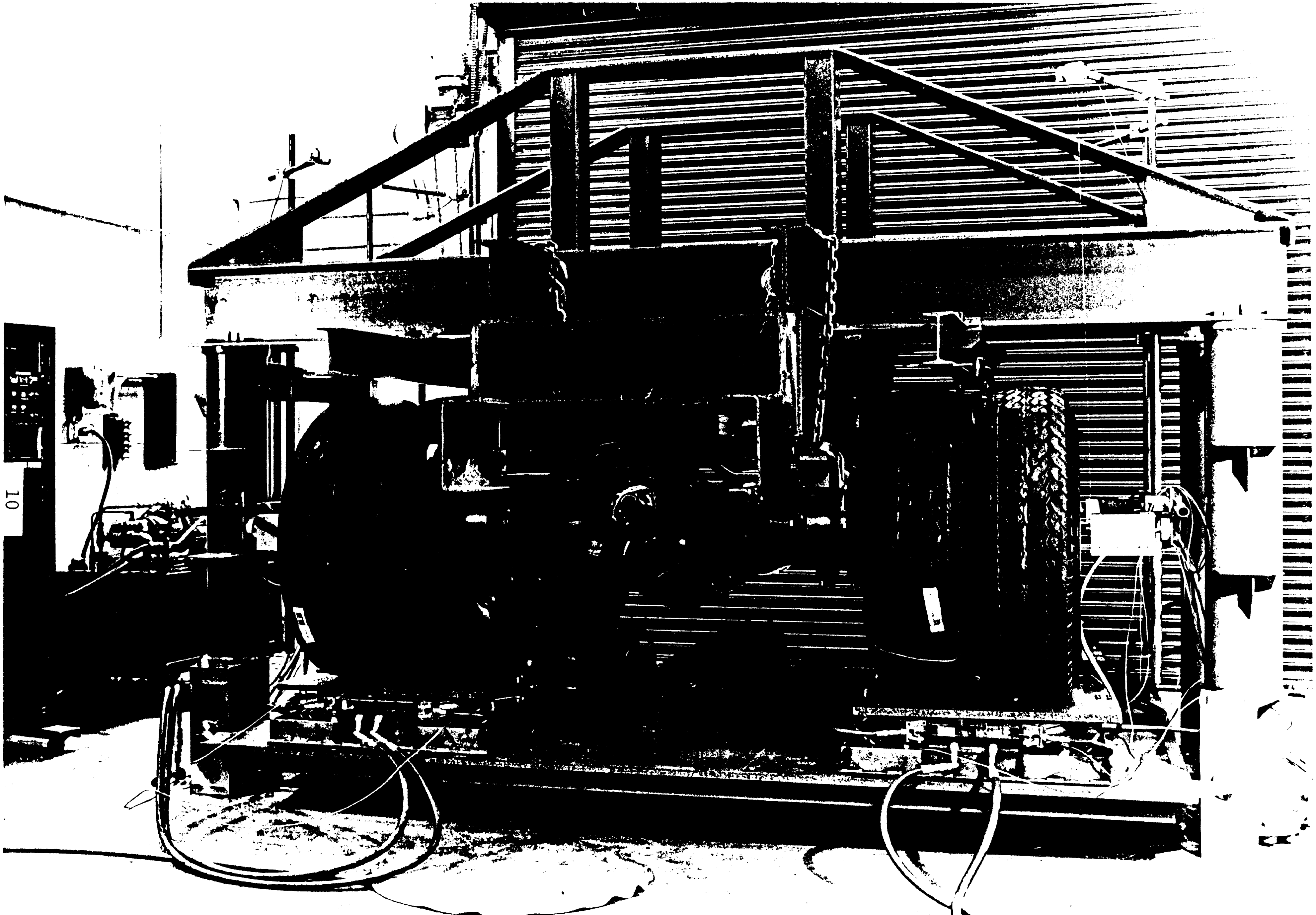


Figure 3.1. Heavy Vehicle Suspension Parameter Measurement Facility.

Results are presented graphically following this text.

3.1 Notes and Comments

Vehicle 1 (Ford)

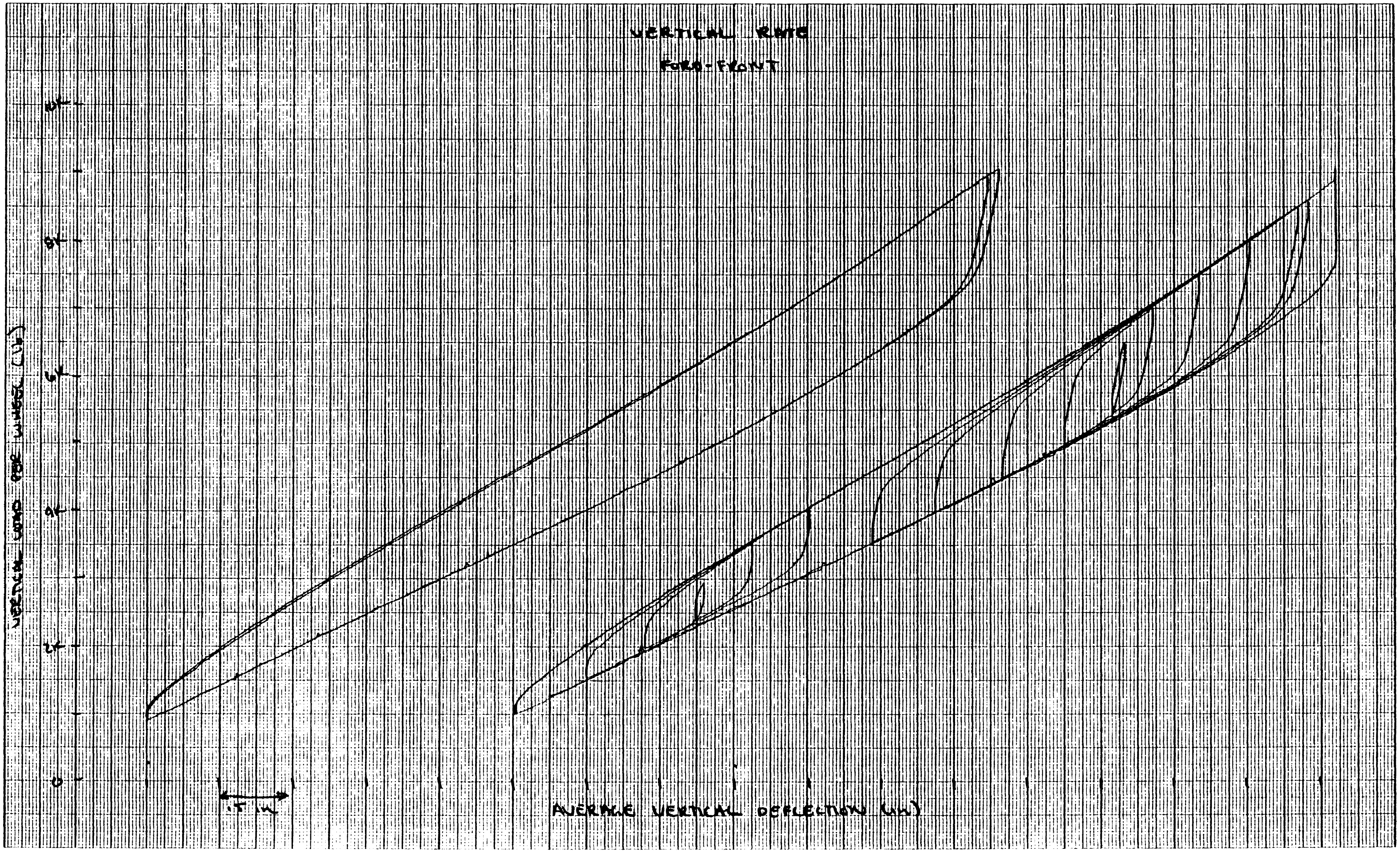
The front suspension of this vehicle is typical of other heavy vehicles measured on the facility. Roll steer measurements made at three nominal steer angles (0, 1.5, and -1.5 degrees) show very slight differences with the off-center conditions exhibiting marginally greater roll steer. Bounce steer measurements indicate that this parameter is not significant relative to the other parameters, resulting in steer angles that are still in the lash of the steering system. Aligning moment compliance steer has the shape characteristic of truck steering systems, with a very large compliance evident around zero moment and steer, and less compliance once the lash has been passed through. It is of interest to note that these measurements (and those made on vehicle 2) were made with the engine running to charge the power steering system. Without the engine running, the steering system had on the order of five degrees of lash. The results of lateral force compliance tests are questionable for the 9,000 and 6,000 lbs cases due to difficulty in aligning the center of force application with the kingpin axis. The data collected at 12,000 lbs axle load reflects the more typical response observed when the force is accurately applied.

The Hendrickson suspension used at the rear of this vehicle is very stiff, approximately 8,000 lb/in per wheel set, with significant coulomb friction at higher suspension loads. The most notable characteristics of this suspension are its ability to equalize loads on the two axles and its negligible interaxle load transfer in response to brake force. This applies to all pitch angles tested.

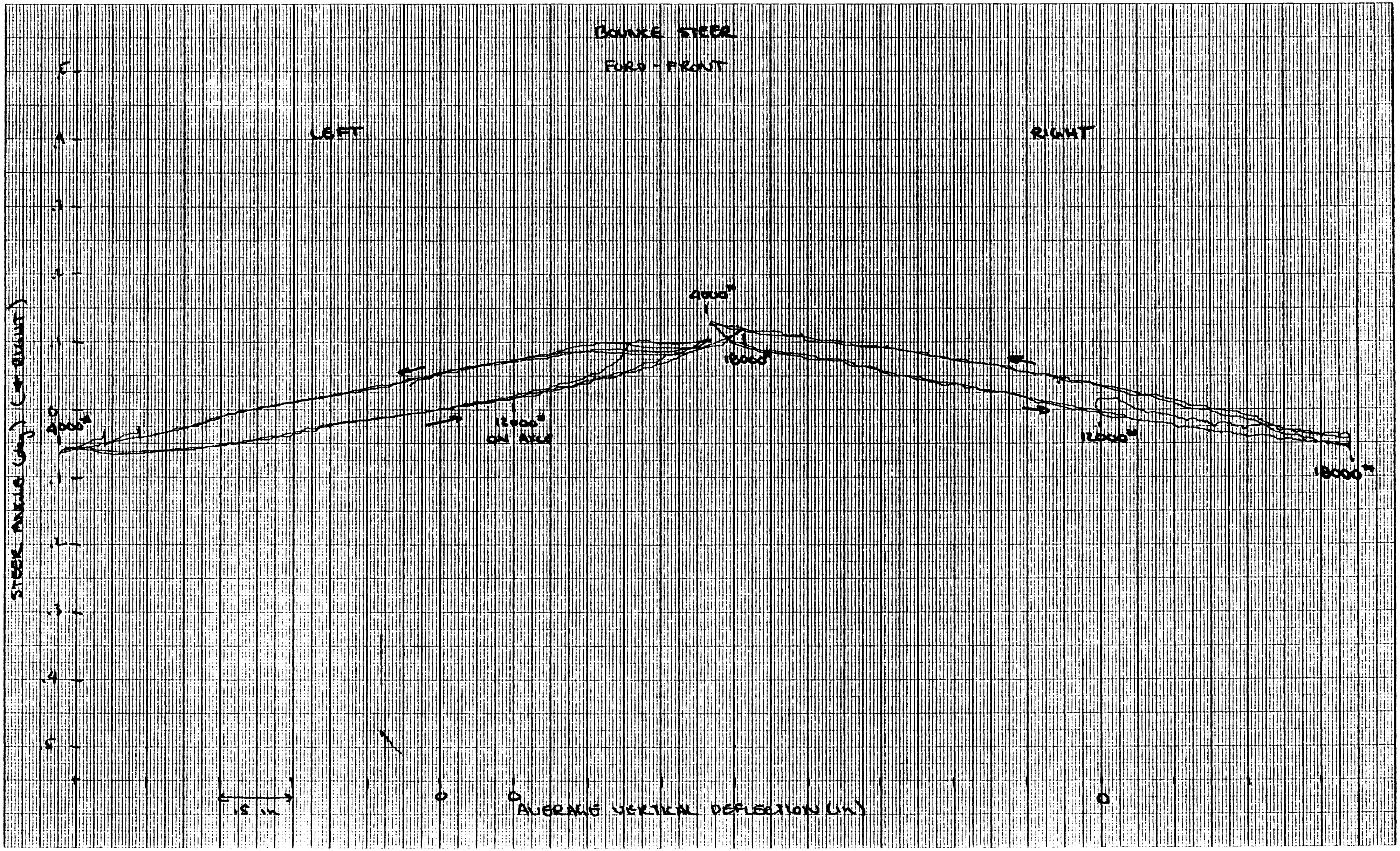
Vehicle 2 (International Harvester)

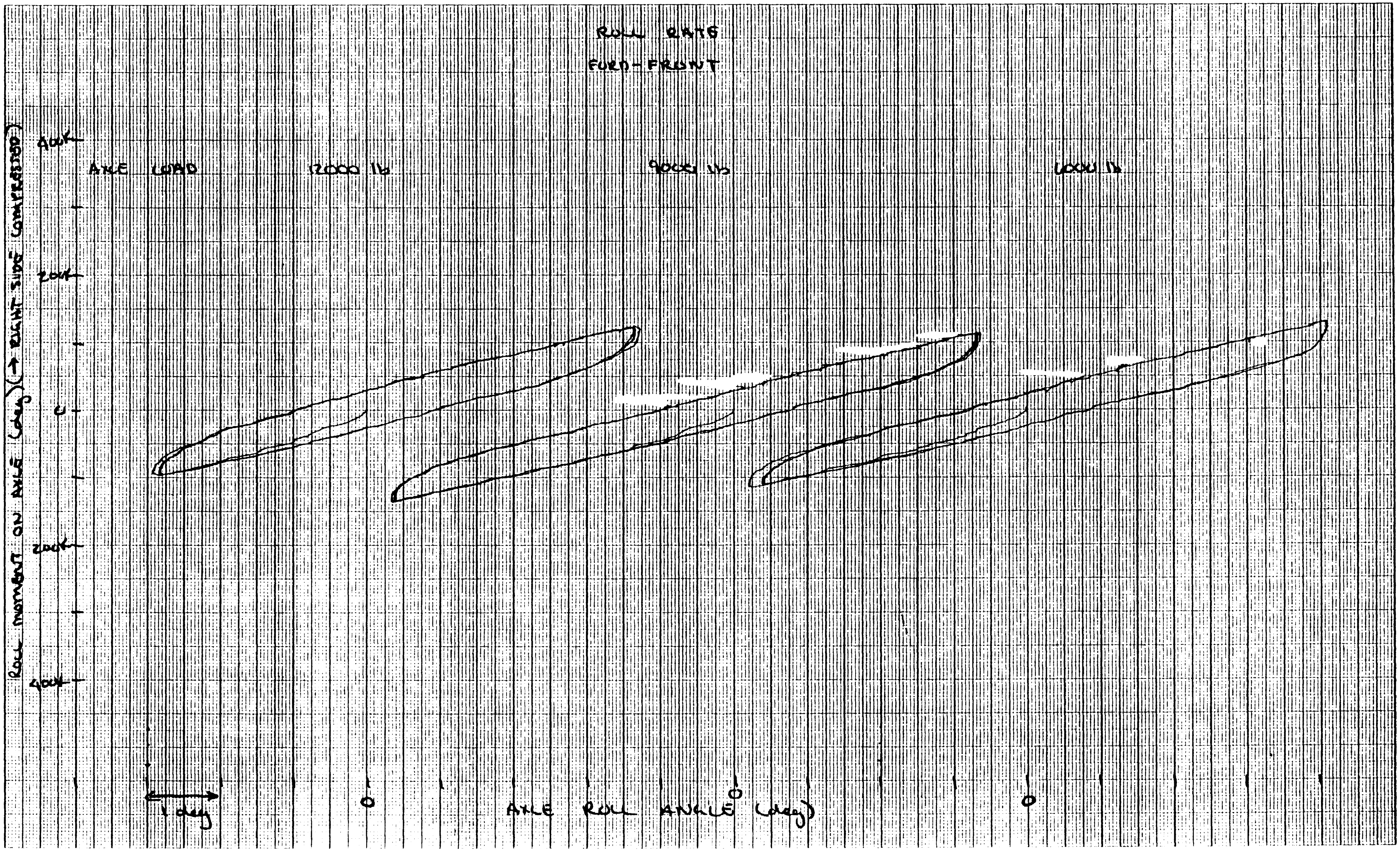
The front suspension on this vehicle is quite limited in its stroke by the bump stops grounding on the frame rails. This occurs with approximately 14,000 lb on the axle. This is a metal-to-metal contact and therefore there is no transition through a compliant bump stop. The roll steer of this suspension is nearly zero at a 12,000-lb axle load, and increases as the load is decreased and the steering linkage geometry moves away from the design condition. Again, the bounce steer measured is proably due to the steering linkage moving in its lash.

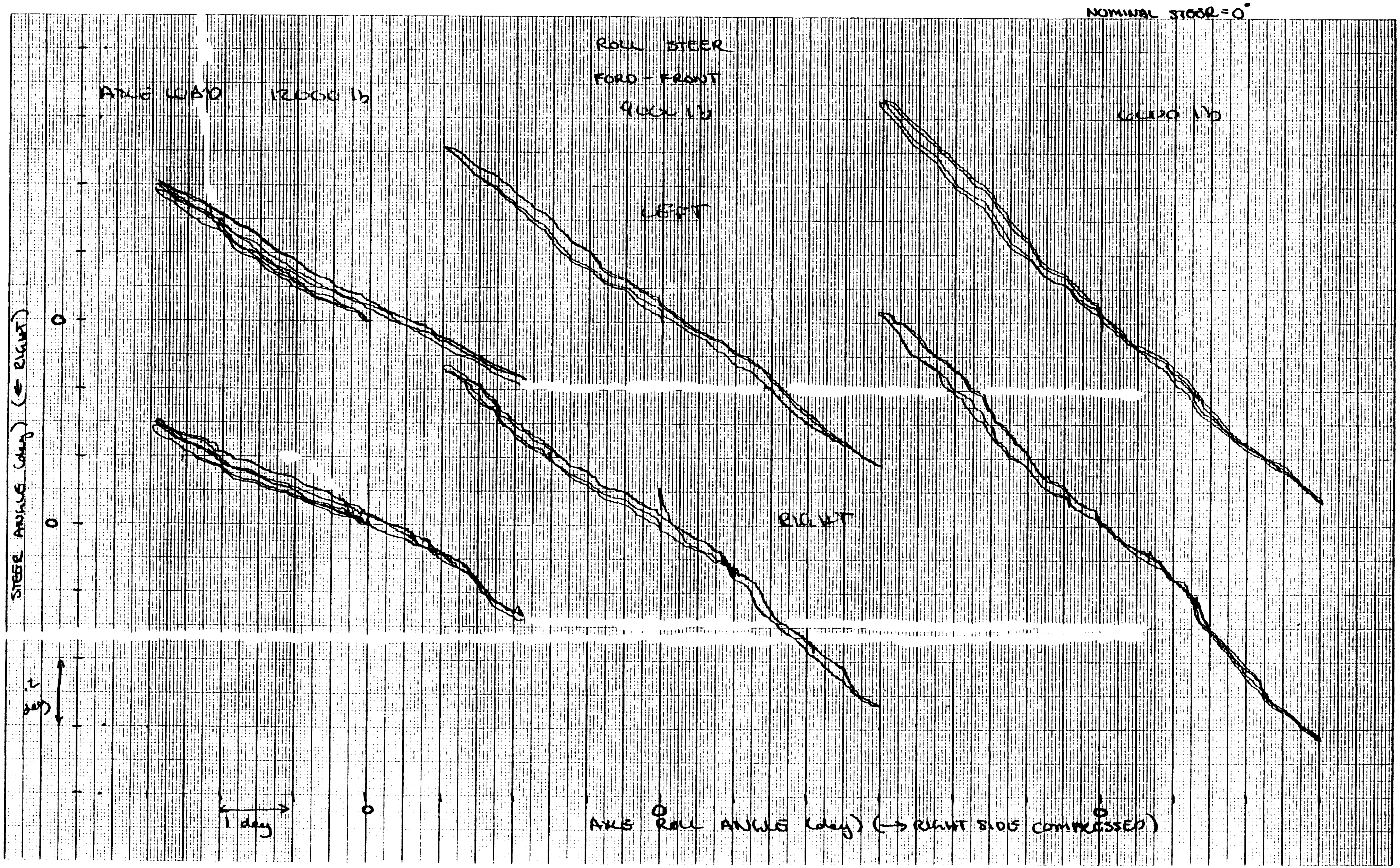
The single-axle rear suspension of vehicle 2 is typical of this genre of suspensions in terms of vertical and roll stiffness and compliance to applied shear forces and moments. The roll steer is nearly zero at 19,000 lbs and increases at reduced loads, though the level is still low for a suspension of this type.

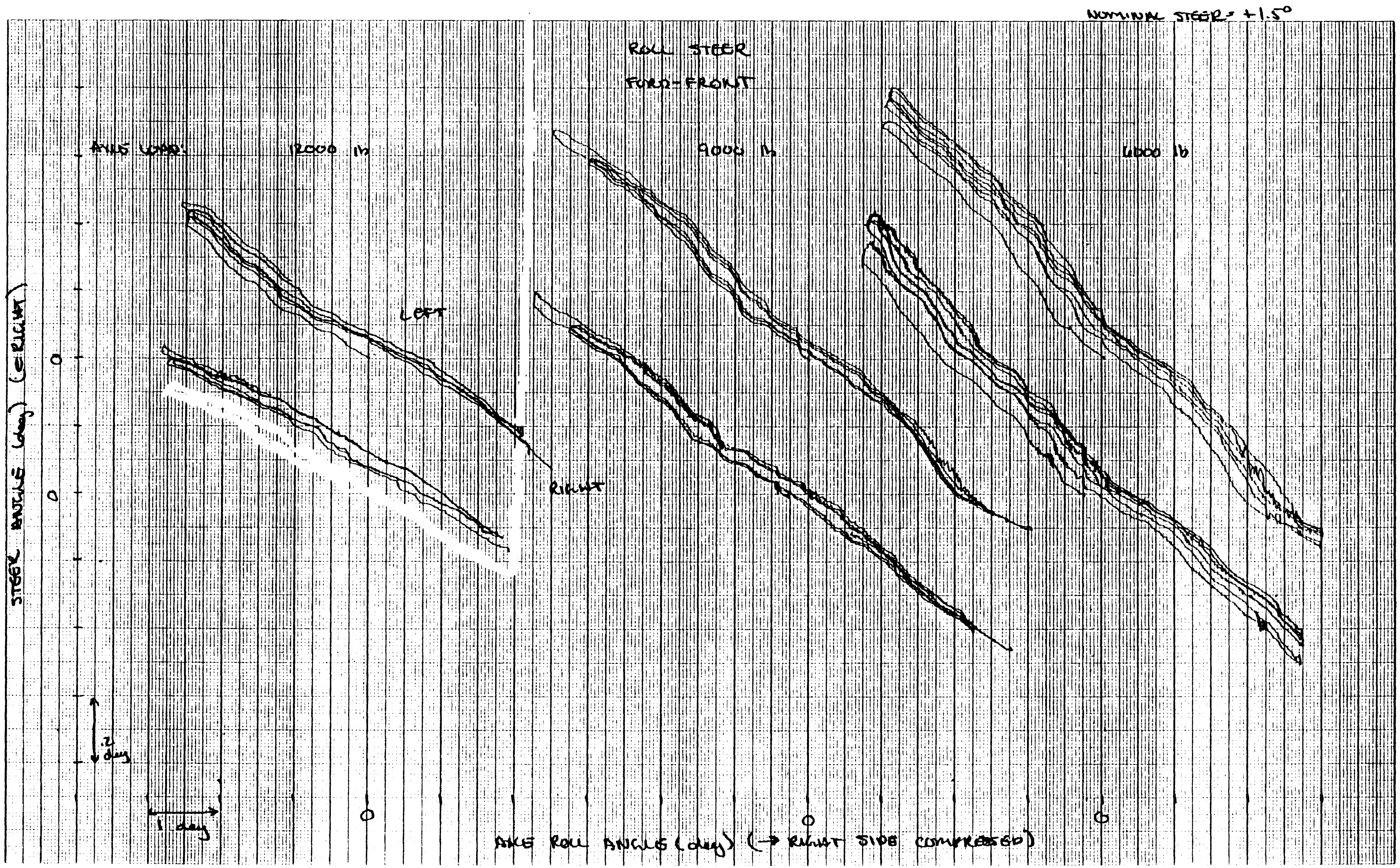


VERTICAL RATE
FORD-FRONT
VERTICAL LOAD PER WHEEL (LB)
0
2K
4K
6K
8K
10K
.1 IN
AVERAGE VERTICAL DEFLECTION (IN)


BOUNCE STEER
FORD - FRONT
LEFT
RIGHT
4000#
18000#
12000#
ON AXLE
12000#
18000#
4000#
STEER ANGLE (deg) (+ RIGHT)
.5
.4
.3
.2
.1
0
.1
.2
.3
.4
.5
.5 in
0
0
0
AVERAGE VERTICAL DEFLECTION (in)

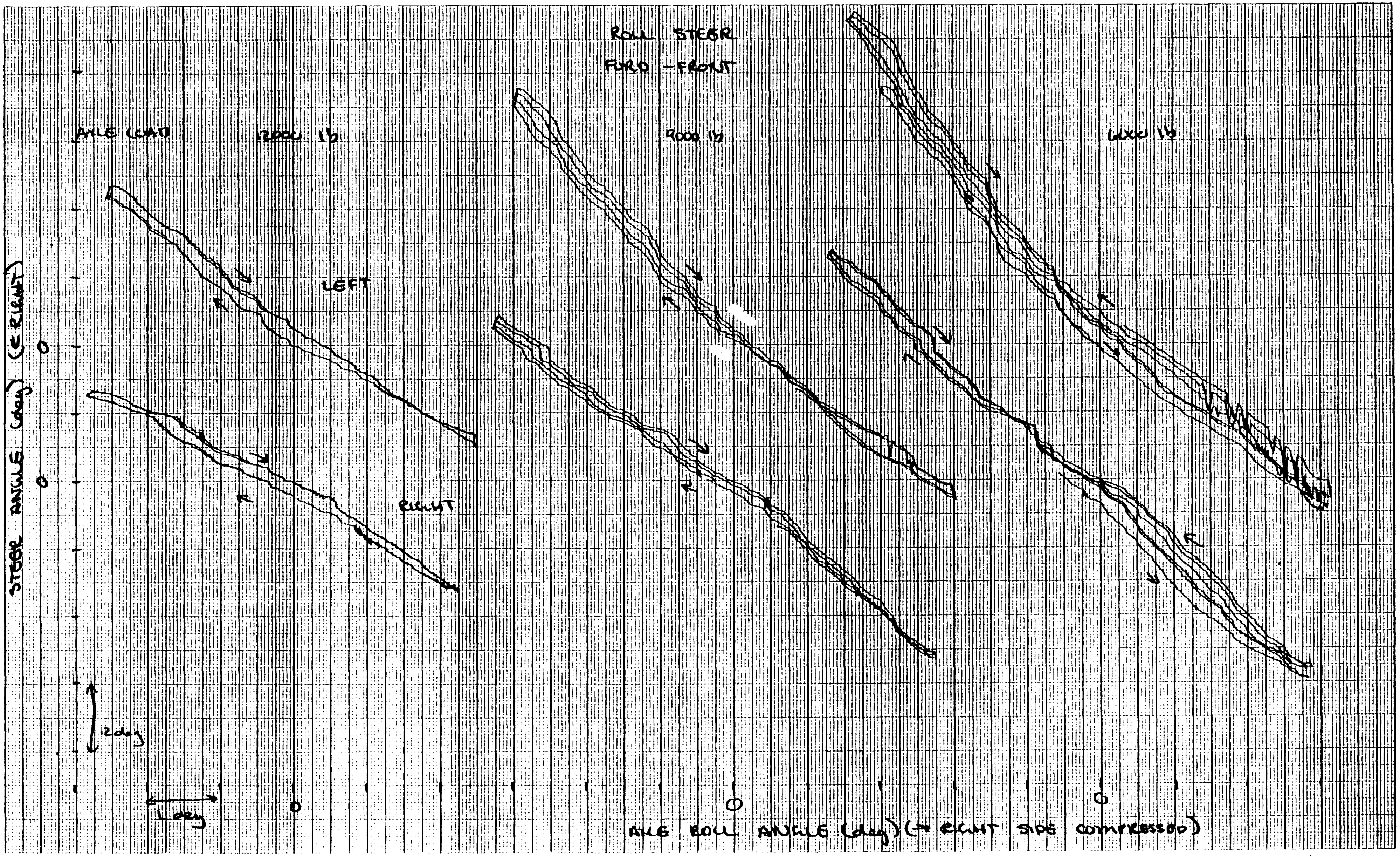

ROLL RATE
FORD-FRONT
AXLE LOAD
12000 lb
9000 lb
6000 lb
400k
200k
0
200k
400k
ROLL MOMENT ON AXLE
(→ RIGHT SIDE COMPRESSED)
1 deg
0
0
0
AXLE ROLL ANGLE (deg)


NOMINAL STEER = 0°
ROLL STEER
FORD - FRONT
AXLE LOAD 12000 lb
4000 lb
6000 lb
LEFT
RIGHT
STEER ANGLE (deg) (← RIGHT)
0
0
.2 deg
1 deg
AXLE ROLL ANGLE (deg) (→ RIGHT SIDE COMPRESSED)



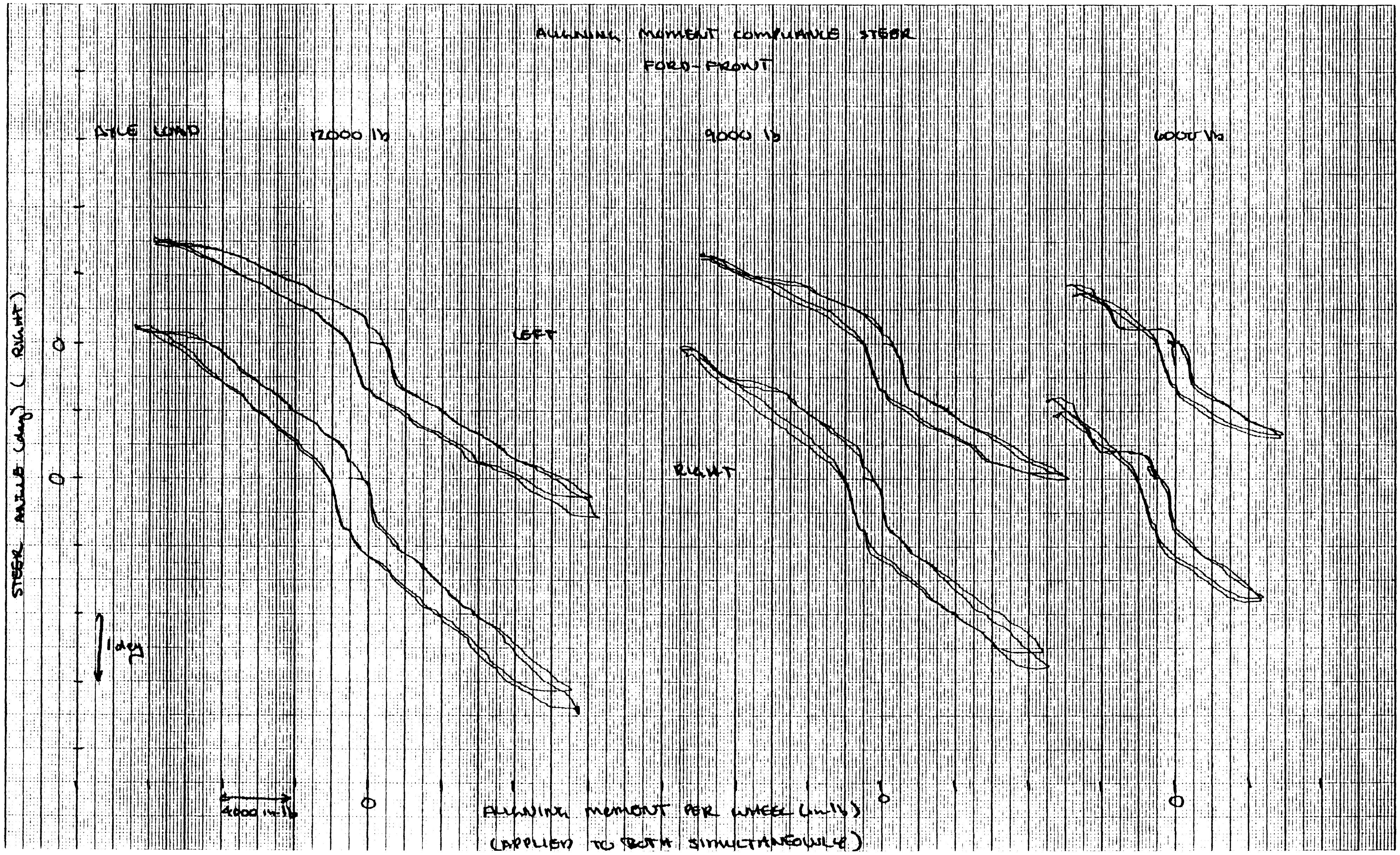
NOMINAL STEER = +1.5°
ROLL STEER
FORD-FRONT
AXLE LOAD:
12000 lb
9000 lb
6000 lb
LEFT
RIGHT
STEER ANGLE (deg) (→ RIGHT)
AXLE ROLL ANGLE (deg) (→ RIGHT SIDE COMPRESSED)
.2 deg
1 deg
0
0
0
0
0

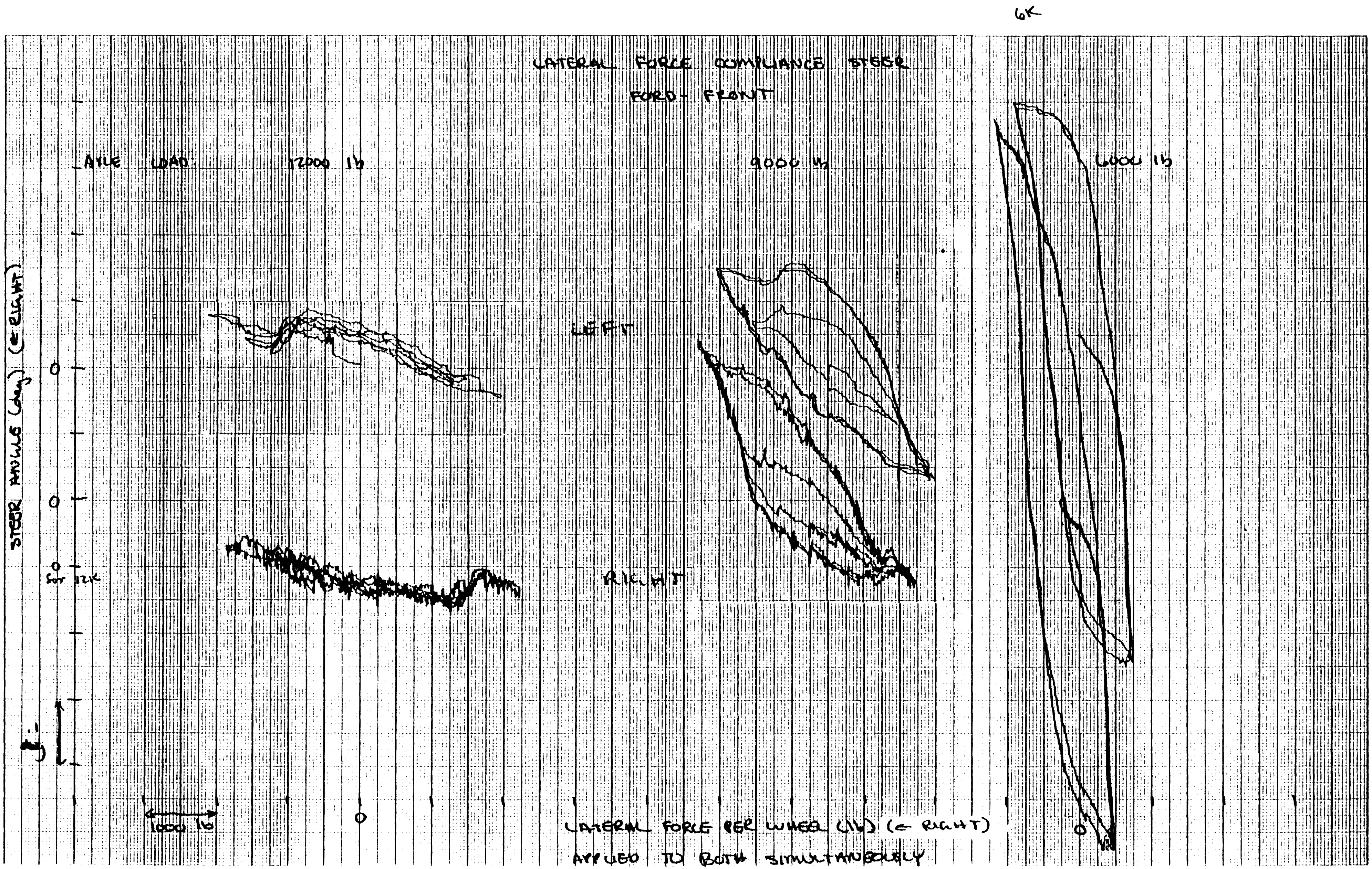
NOMINAL STEER = -1.5°



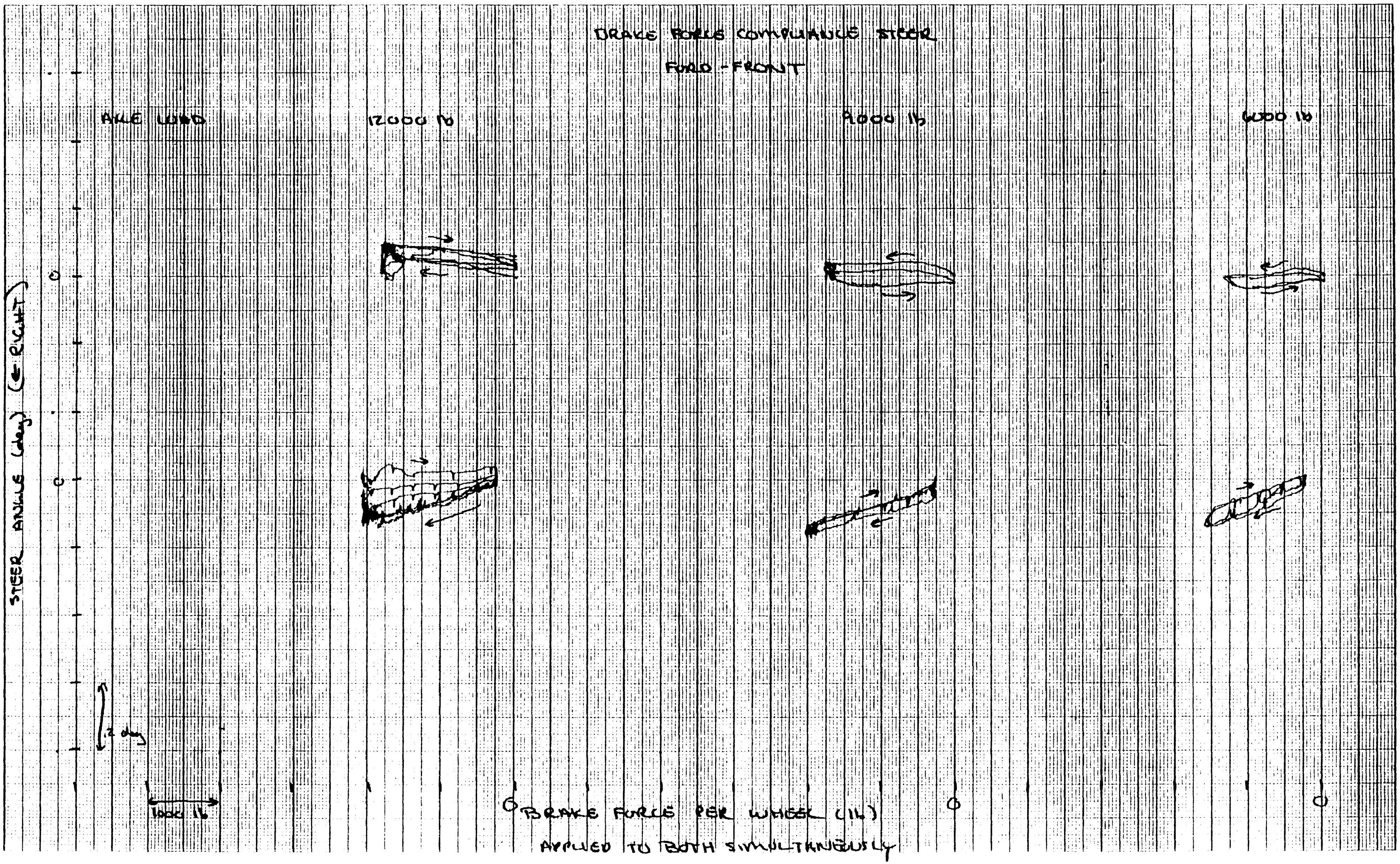
47 1510

K+E 10 X 10 TO THE CENTIMETER KEUFFEL & ESSER CO.


ALIGNING MOMENT COMPLIANCE STEER
FORD-FRONT
AXLE LOAD
12000 lb
9000 lb
6000 lb
LEFT
RIGHT
STEER ANGLE (deg) (RIGHT)
1 deg
4000 in-lb
0
ALIGNING MOMENT PER WHEEL (in-lb)
(APPLIED TO BOTH SIMULTANEOUSLY)

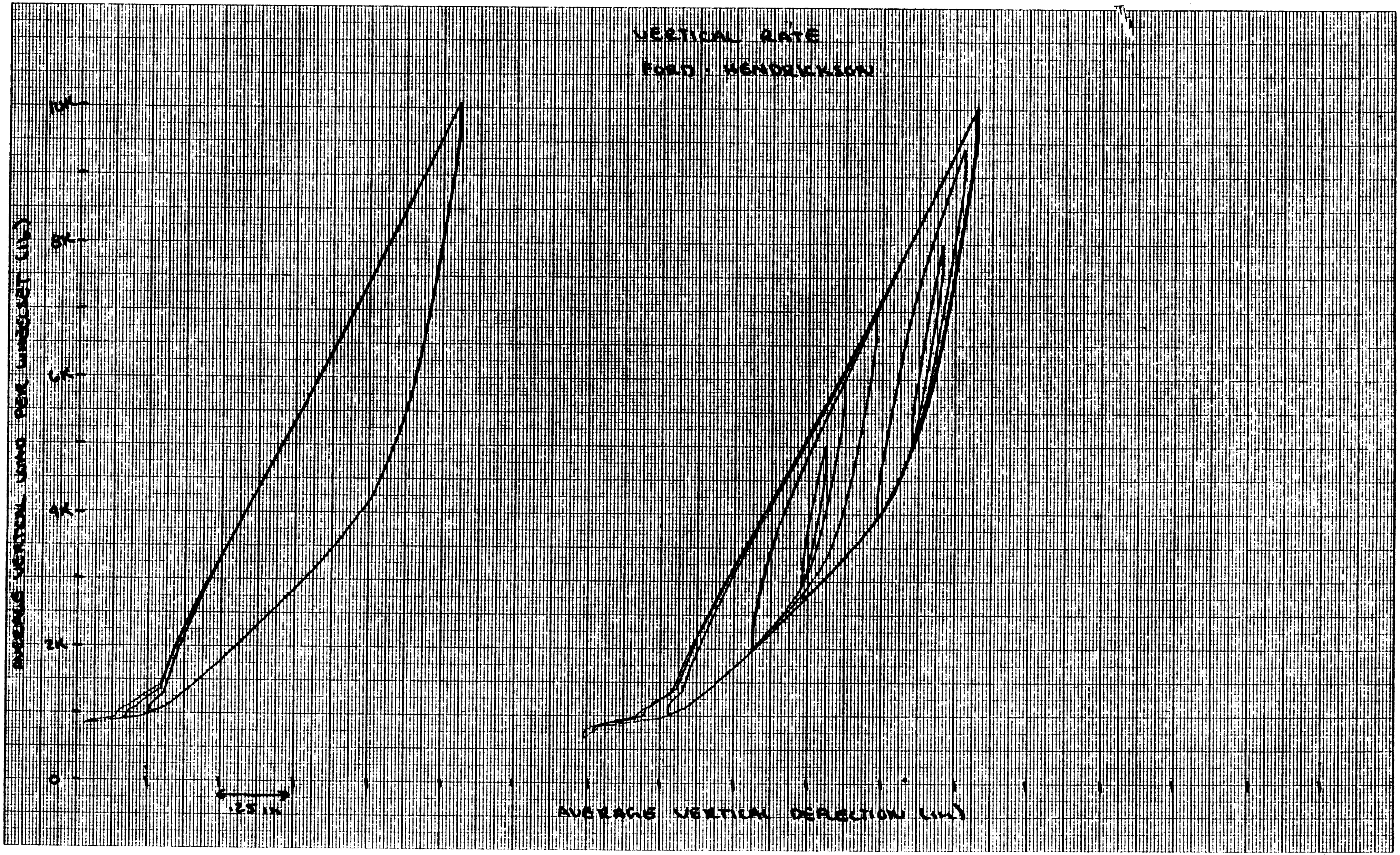

6K
LATERAL FORCE COMPLIANCE STEER
FORD - FRONT
AXLE LOAD:
12000 lb
9000 lb
6000 lb
LEFT
RIGHT
for 12K
STEER ANGLE (deg) (← RIGHT)
1000 lb
0
LATERAL FORCE PER WHEEL (lb) (← RIGHT)
APPLIED TO BOTH SIMULTANEOUSLY

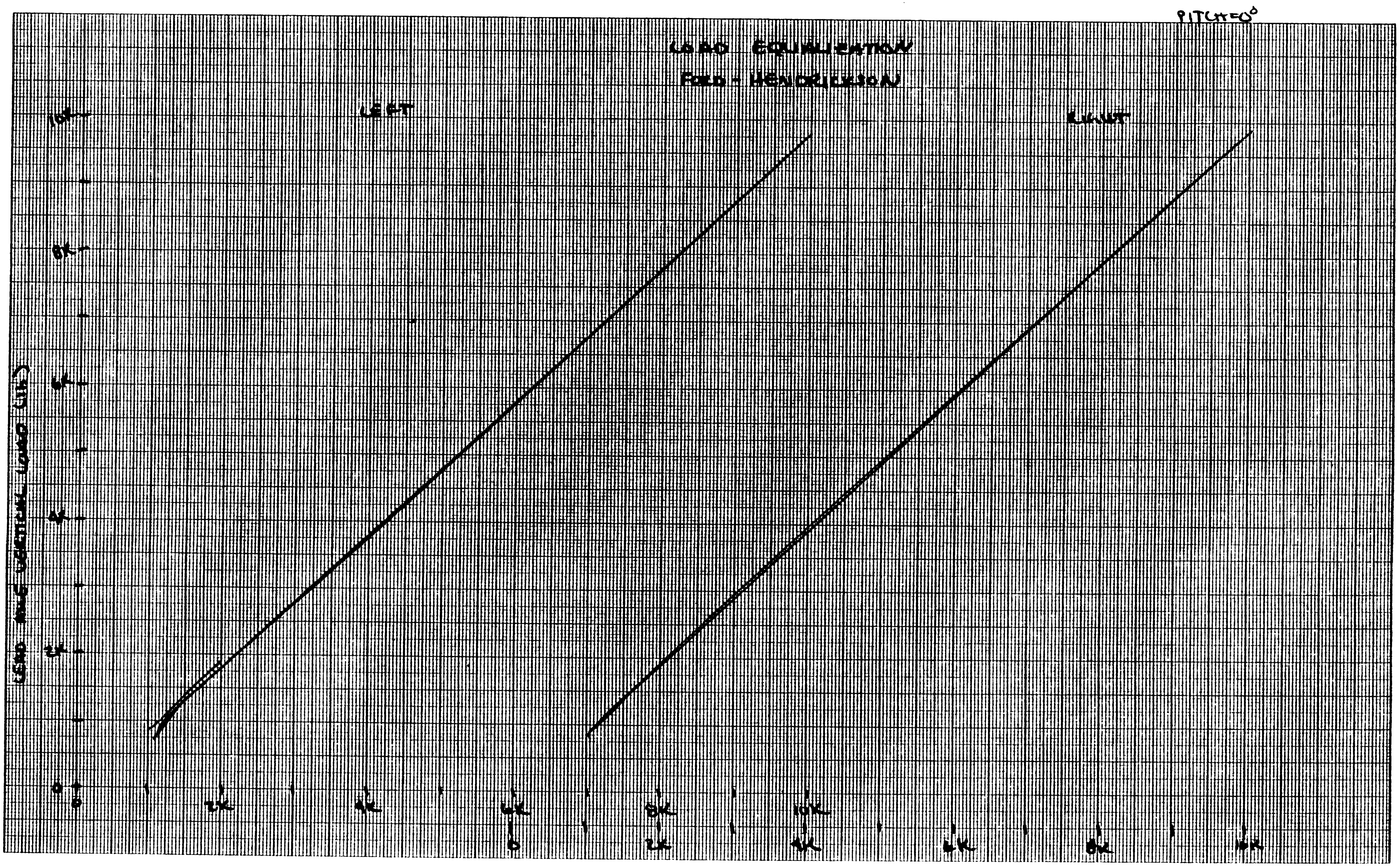
47 1510

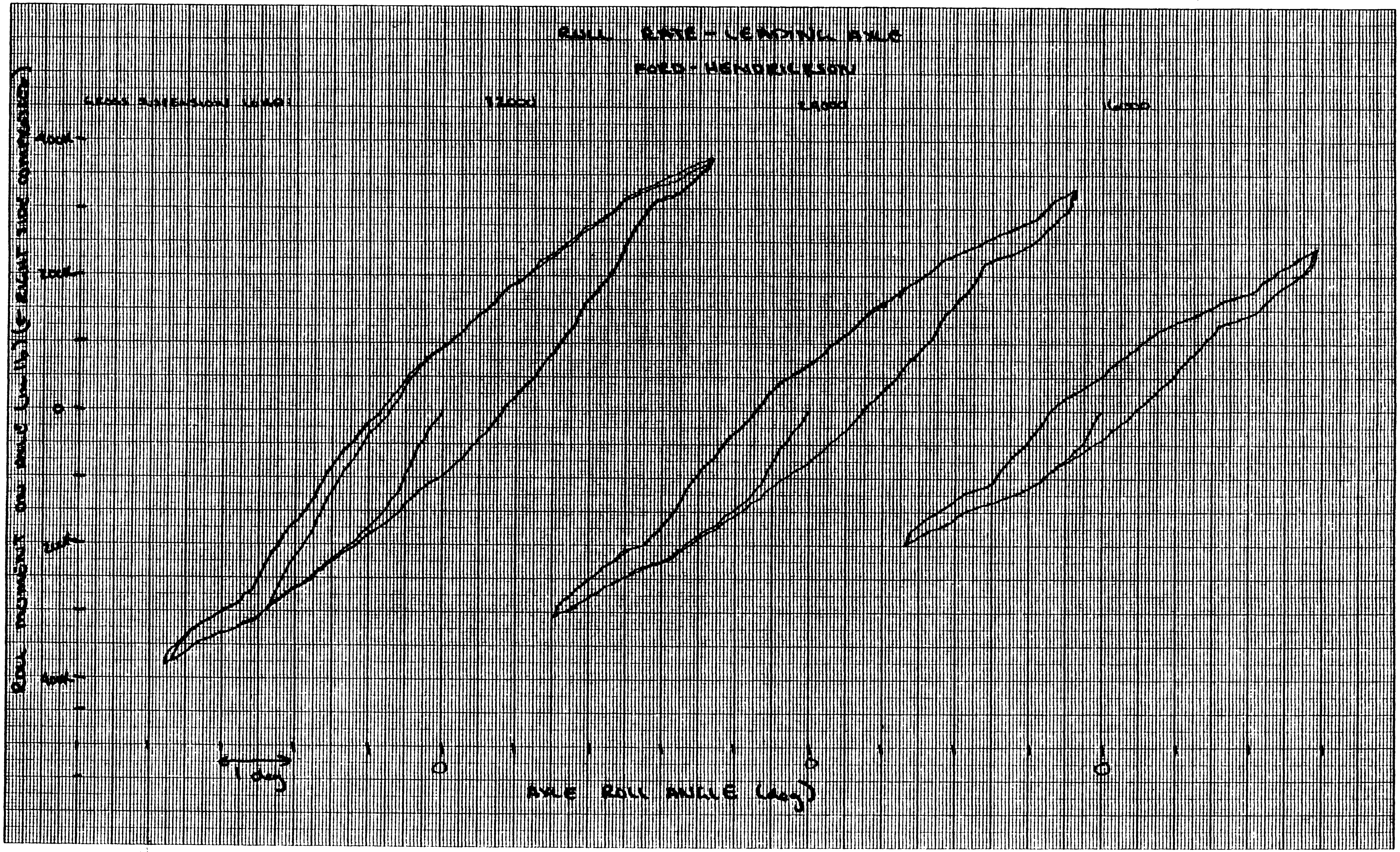


BRAKE FORCE COMPLIANCE STEER
FORD - FRONT
AXLE LOAD
12000 lb
9000 lb
6000 lb
STEER ANGLE (deg) (← RIGHT)
.2 deg
1000 lb
BRAKE FORCE PER WHEEL (lb)
APPLIED TO BOTH SIMULTANEOUSLY

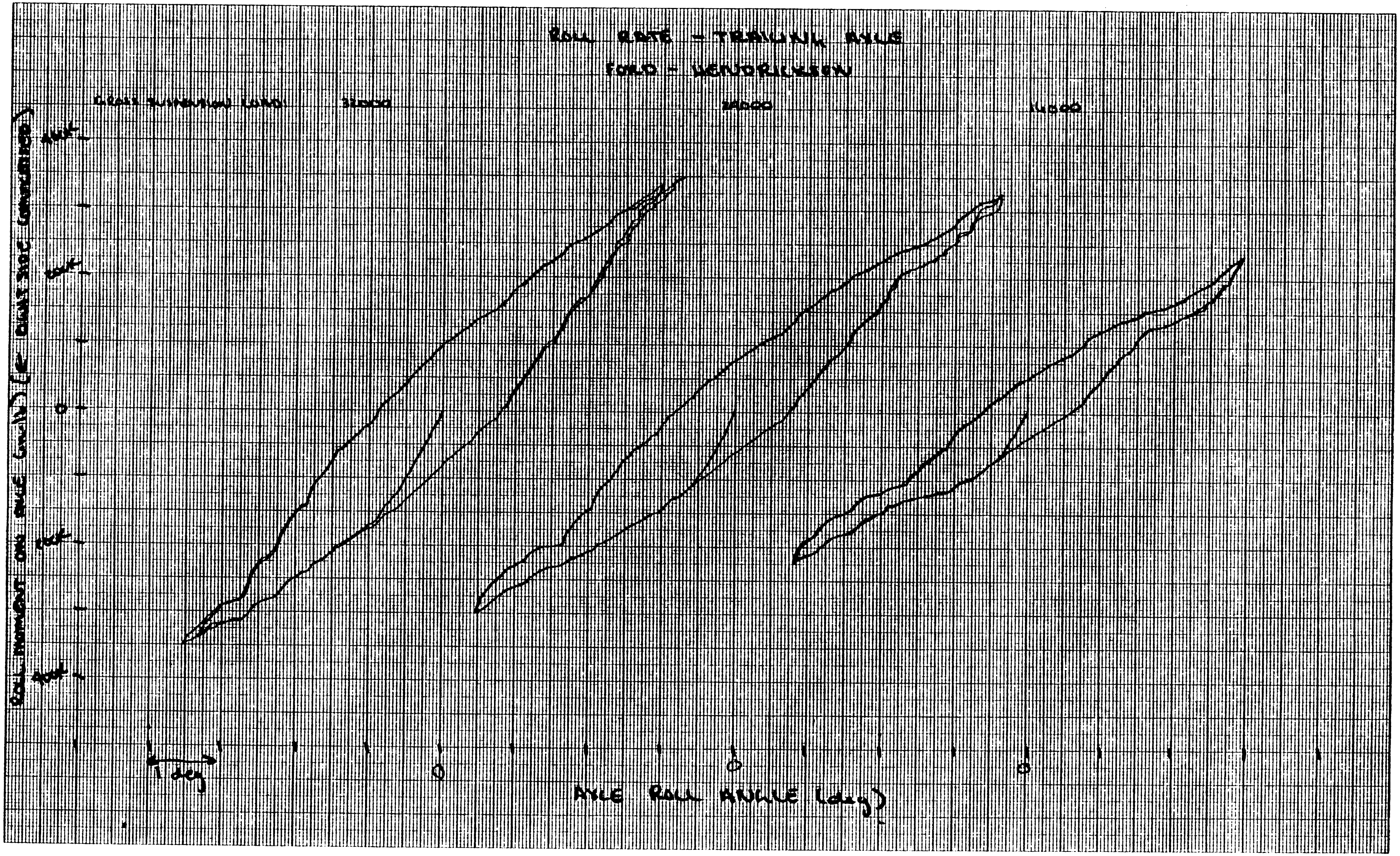
FORD REAR

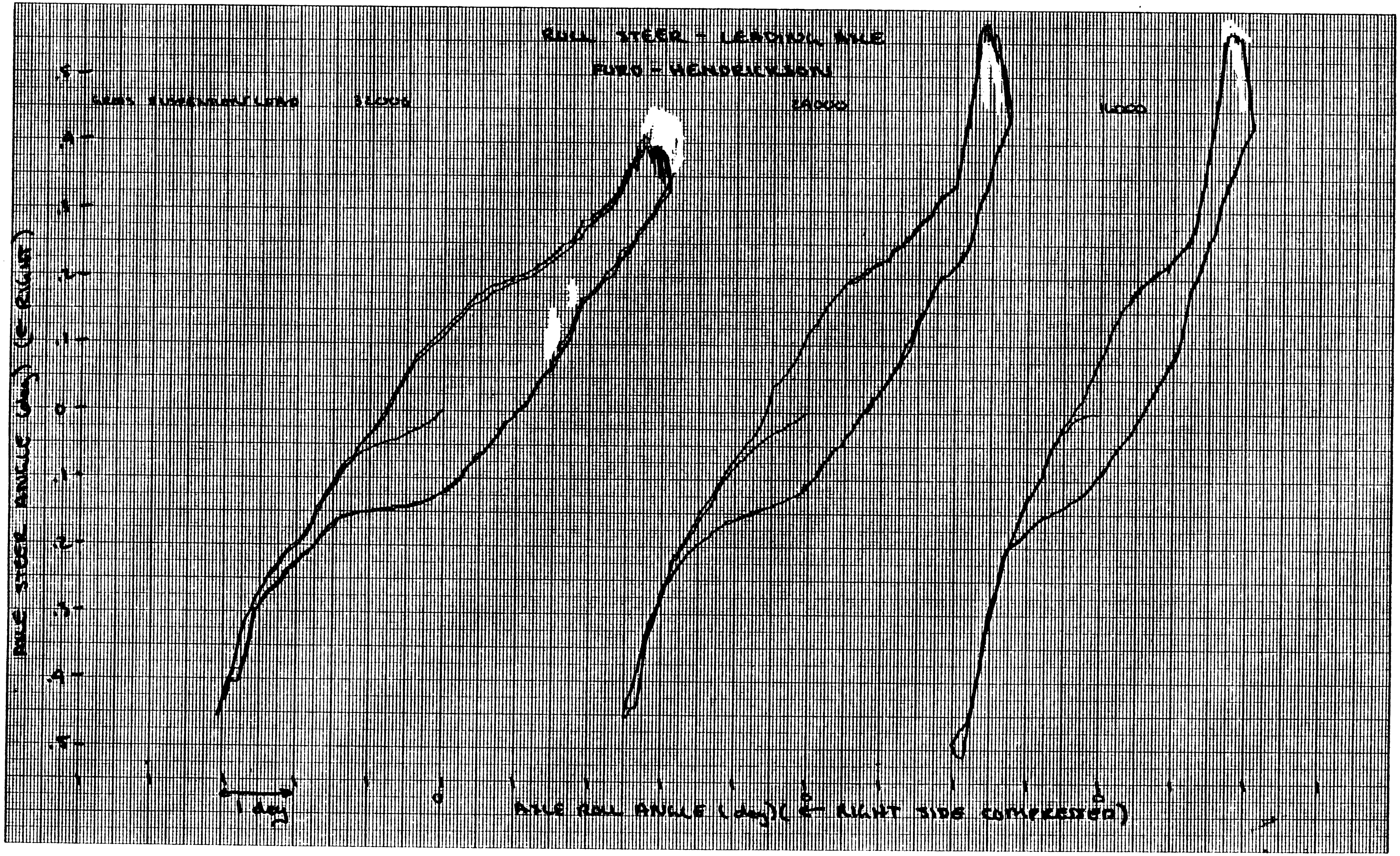

VERTICAL RATE
FORD - HENDRICKSON
AVERAGE VERTICAL LOAD PER WHEELSET (lbs)
10K
8K
6K
4K
2K
0
.25 in
AVERAGE VERTICAL DEFLECTION (in)

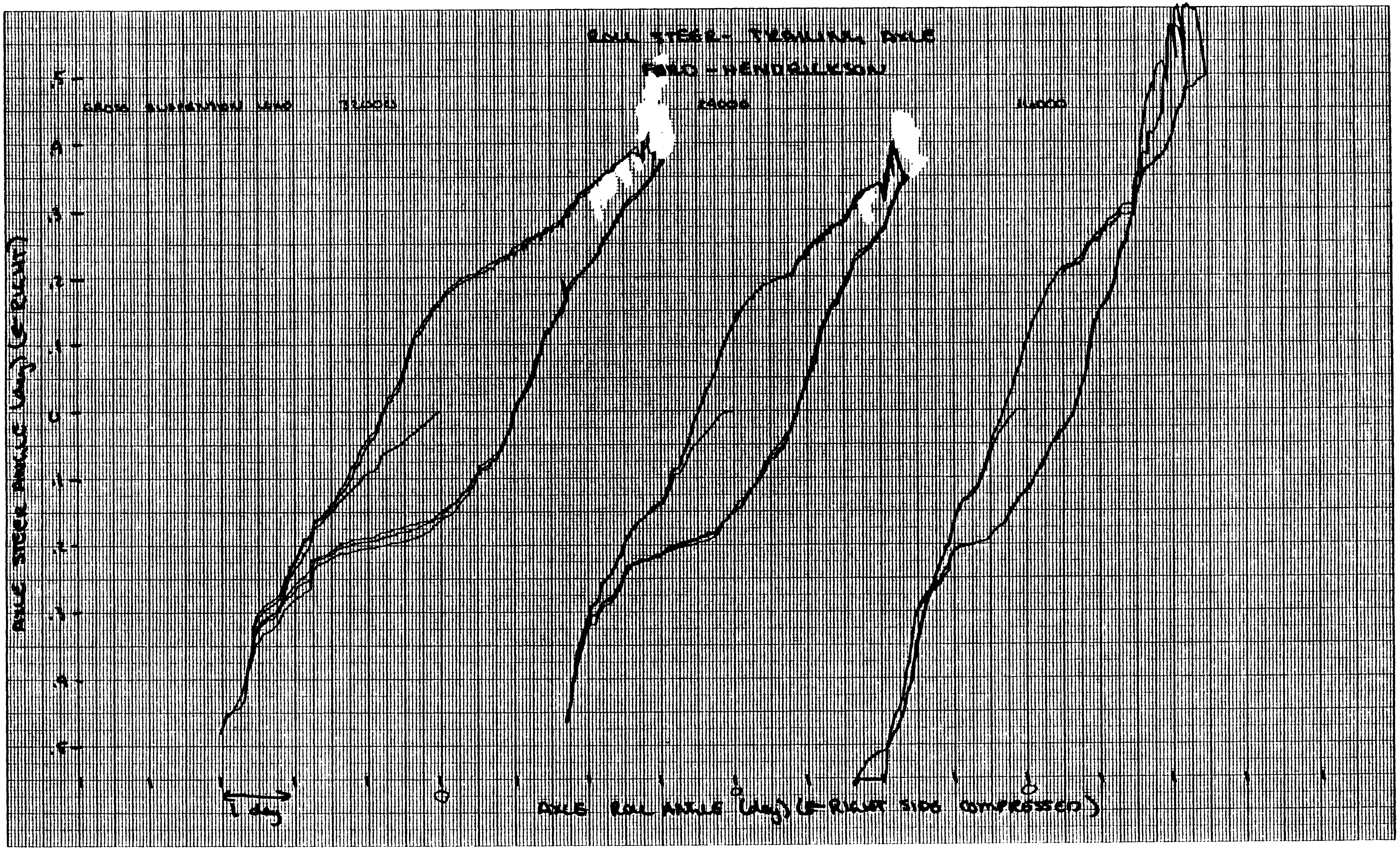

PITCH=0°
LOAD EQUALIZATION
FORD - HENDRICKSON
LEFT
RIGHT
LEAD AXLE VERTICAL LOAD (LBS)
10K
8K
6K
4K
2K
0

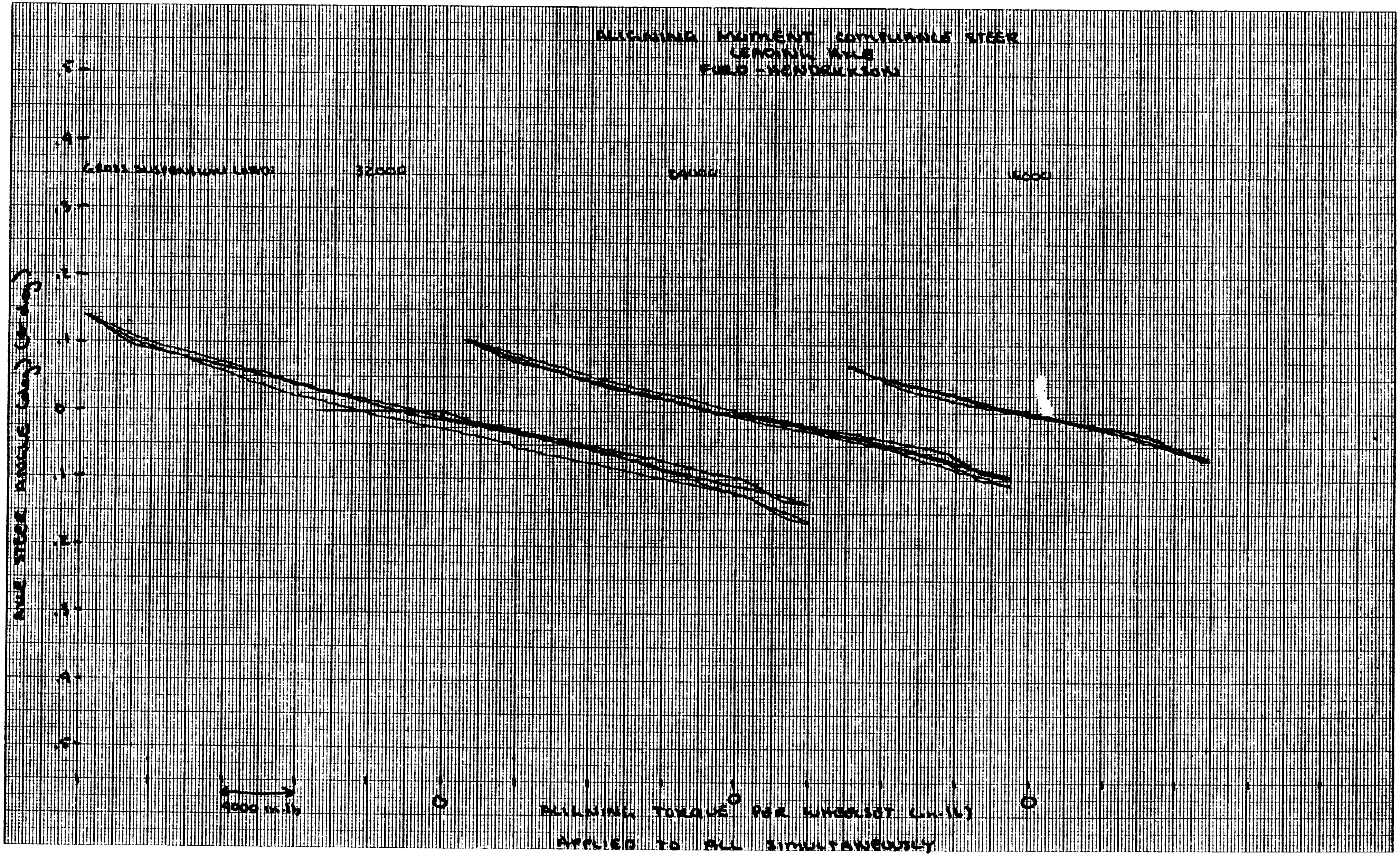


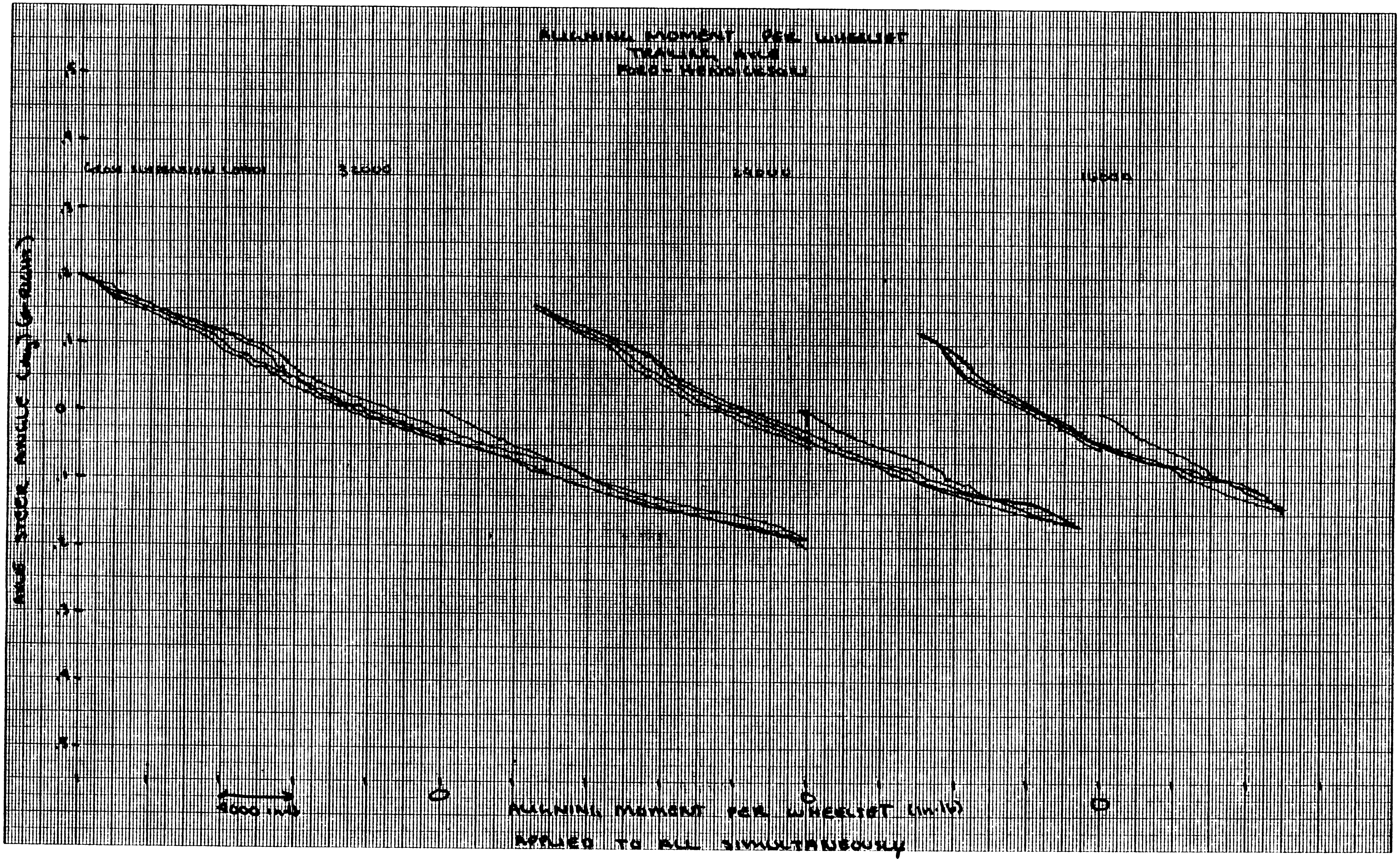
ROLL RATE - LEADING AXLE
FORD - HENDRICKSON
GROSS SUSPENSION LOAD: 12000
8000
4000
ROLL MOMENT ON AXLE (in-lb)(+ RIGHT SIDE COMPRESSION)
400K
200K
0
0
0
0
1 deg
AXLE ROLL ANGLE (deg)

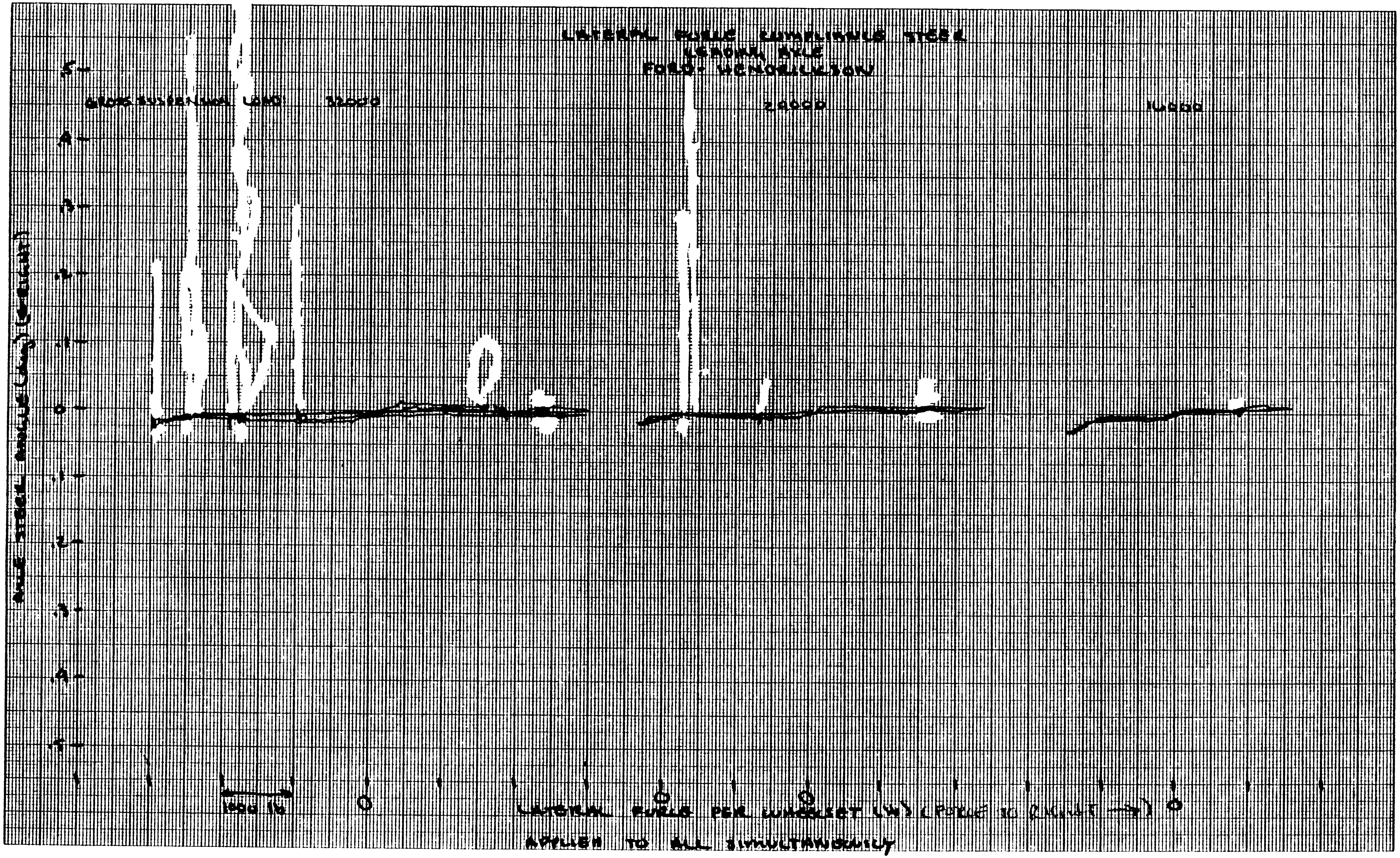

ROLL RATE - TRAILING AXLE
FORD - HENDRICKSON
GROSS SUSPENSION LOAD: 32000
24000
16000
1 deg
0
0
0
AXLE ROLL ANGLE (deg)

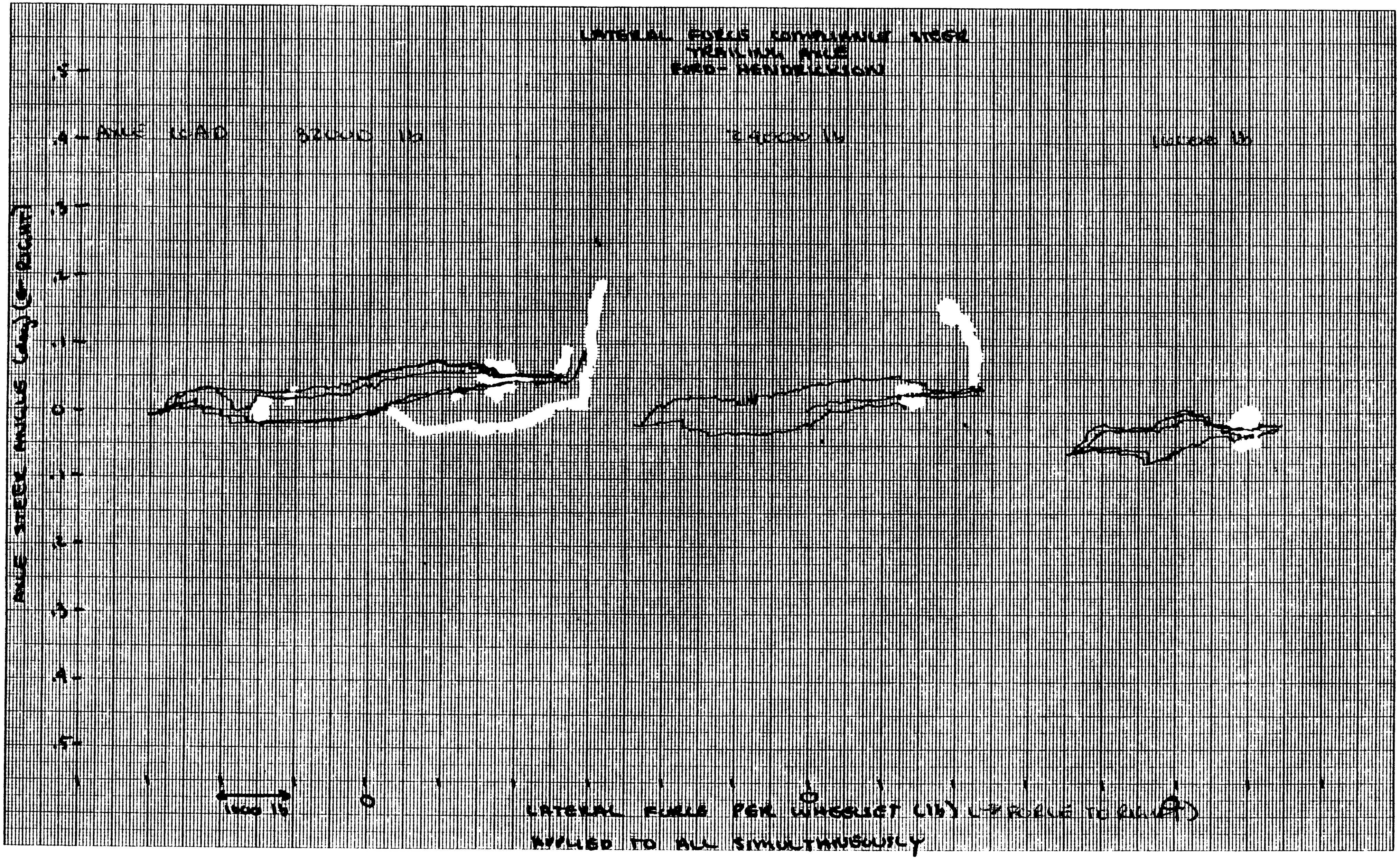

ROLL STEER - LEADING AXLE
FURO - HENDRICKSON
GROSS SUSPENSION LOAD
32000
24000
16000
AXLE STEER ANGLE (deg) (← RIGHT)
AXLE ROLL ANGLE (deg) (← RIGHT SIDE COMPRESSED)
1 deg
0

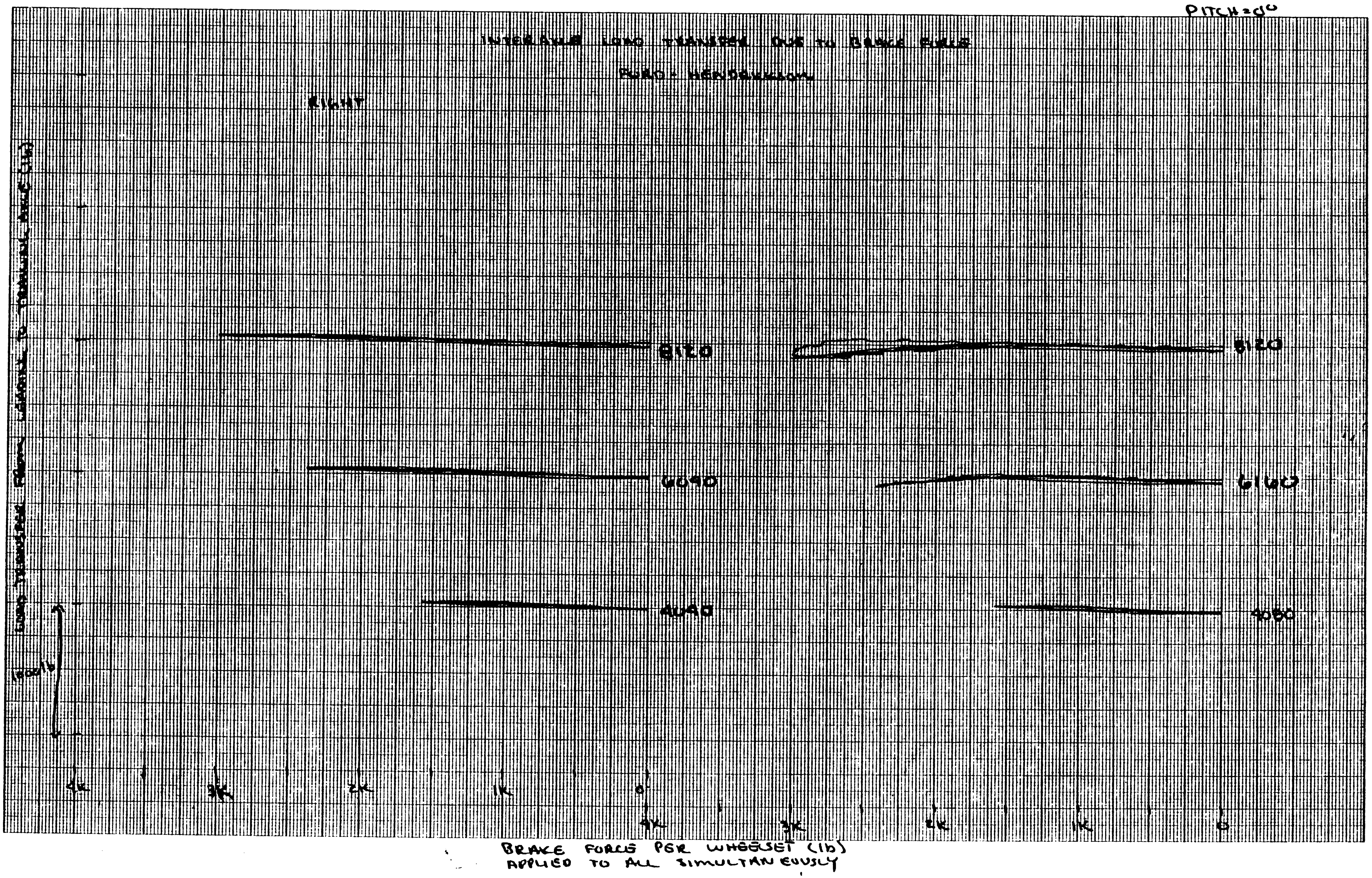

ROLL STEER - TRAILING AXLE
FORD - HENDRICKSON
GROSS SUSPENSION LOAD 32000
24000
16000
AXLE STEER ANGLE (deg) (+ RIGHT)
AXLE ROLL ANGLE (deg) (+ RIGHT SIDE COMPRESSED)
1 deg


ALIGNING MOMENT COMPLIANCE STEER
LEADING AXLE
FORD-HENDRICKSON
GROSS SUSPENSION LOAD:
32000
24000
16000
AXLE STEER ANGLE (deg) (deg)
4000 in-lb
0
0
0
ALIGNING TORQUE PER WHEELSET (in-lb)
APPLIED TO ALL SIMULTANEOUSLY

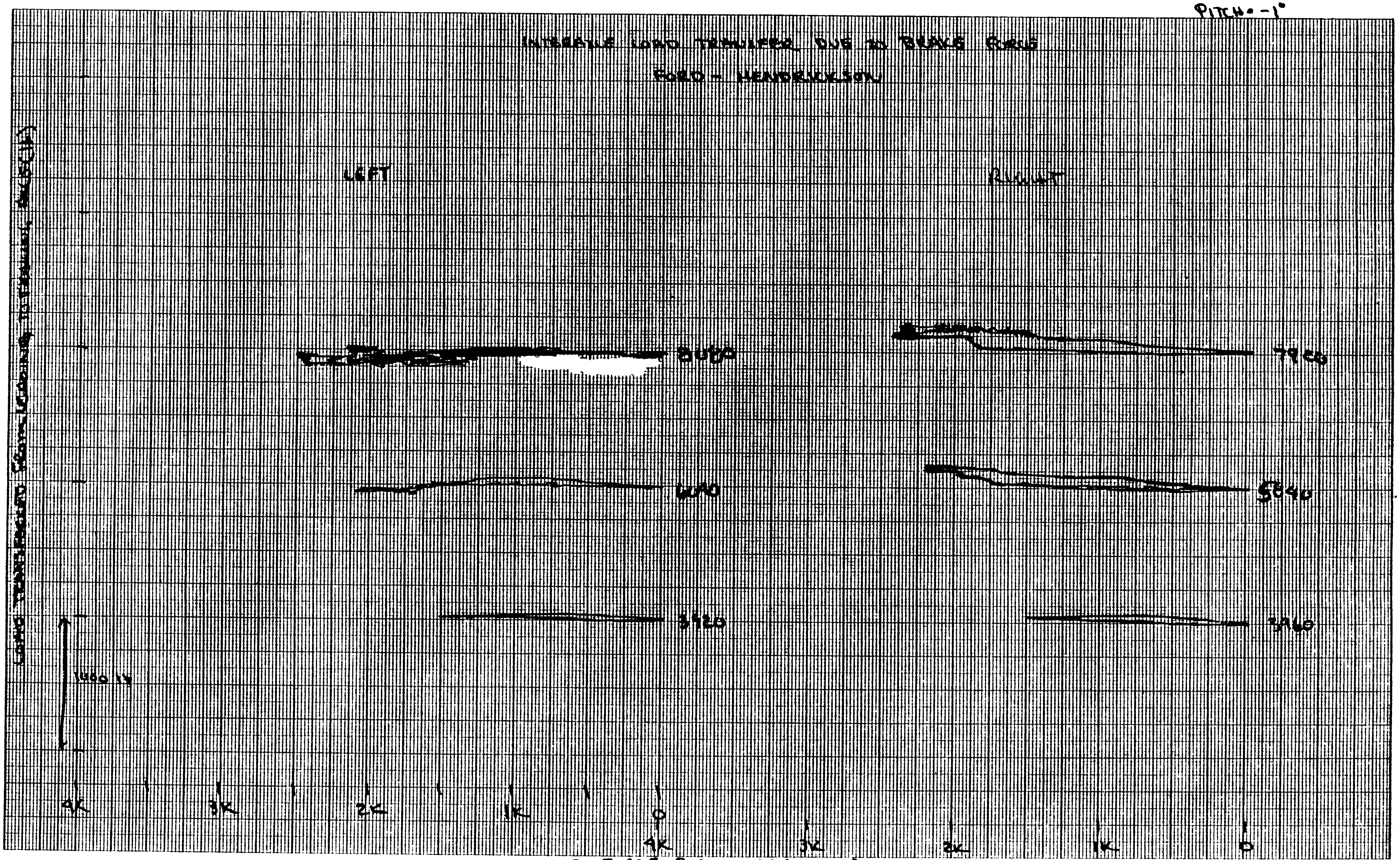

ALIGNING MOMENT PER WHEELSET
TRAILER AXLE
FORD - HENDRICKSON
GROSS SUSPENSION LOAD
32000
24000
16000
AXLE STEER ANGLE
4000 in-lb
ALIGNING MOMENT PER WHEELSET (in-lb)
APPLIED TO ALL SIMULTANEOUSLY


LATERAL FORCE COMPLIANCE STEER
LEADING AXLE
FORD - HENDRICKSON
GROSS SUSPENSION LOAD: 32000
24000
16000
AXLE STEER ANGLE (deg) (+RIGHT)
.5
.4
.3
.2
.1
0
.1
.2
.3
.4
.5
1000 lb
0
0
0
0
LATERAL FORCE PER WHEELSET (W) (FORCE TO RIGHT →)
APPLIED TO ALL SIMULTANEOUSLY


LATERAL FORCE COMPLIANCE STEER
TRAILING AXLE
FORD-HENDRICKSON
AXLE LOAD 8200 lb
AXLE STEER ANGLE (deg)
LATERAL FORCE PER WHEELSET (lb)
APPLIED TO ALL SIMULTANEOUSLY
1000 lb
0

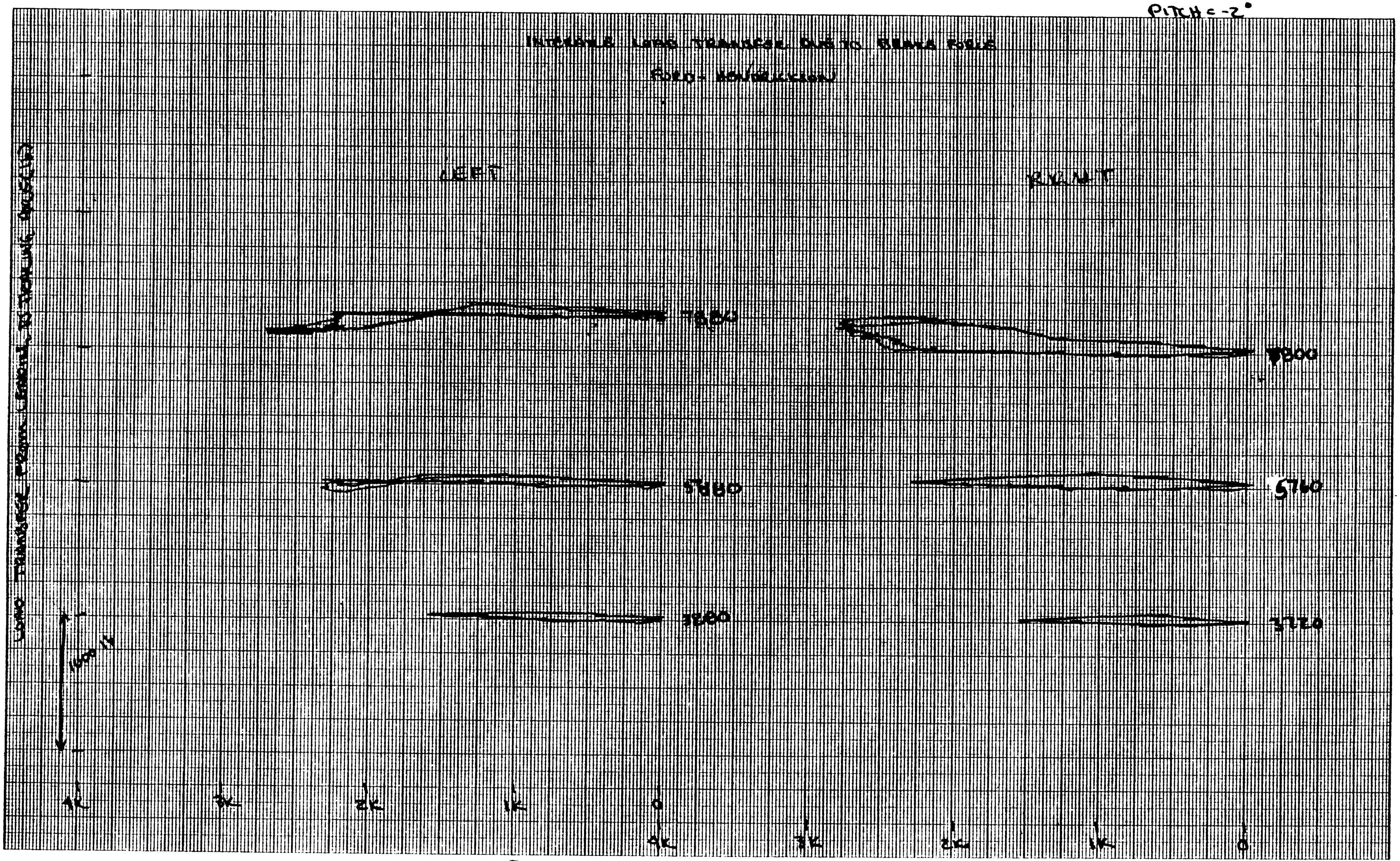

PITCH=0°
INTERAXLE LOAD TRANSFER DUE TO BRAKE FORCES
FORD - HENDRICKSON
RIGHT
LOAD TRANSFER FROM LEADING TO TRAILING AXLE (lb)
1000 lb
8120
6090
4040
8120
6160
4080
4K
3K
2K
1K
0
4K
3K
2K
1K
0
BRAKE FORCES PER WHEELSET (lb)
APPLIED TO ALL SIMULTANEOUSLY

PITCH = -1°



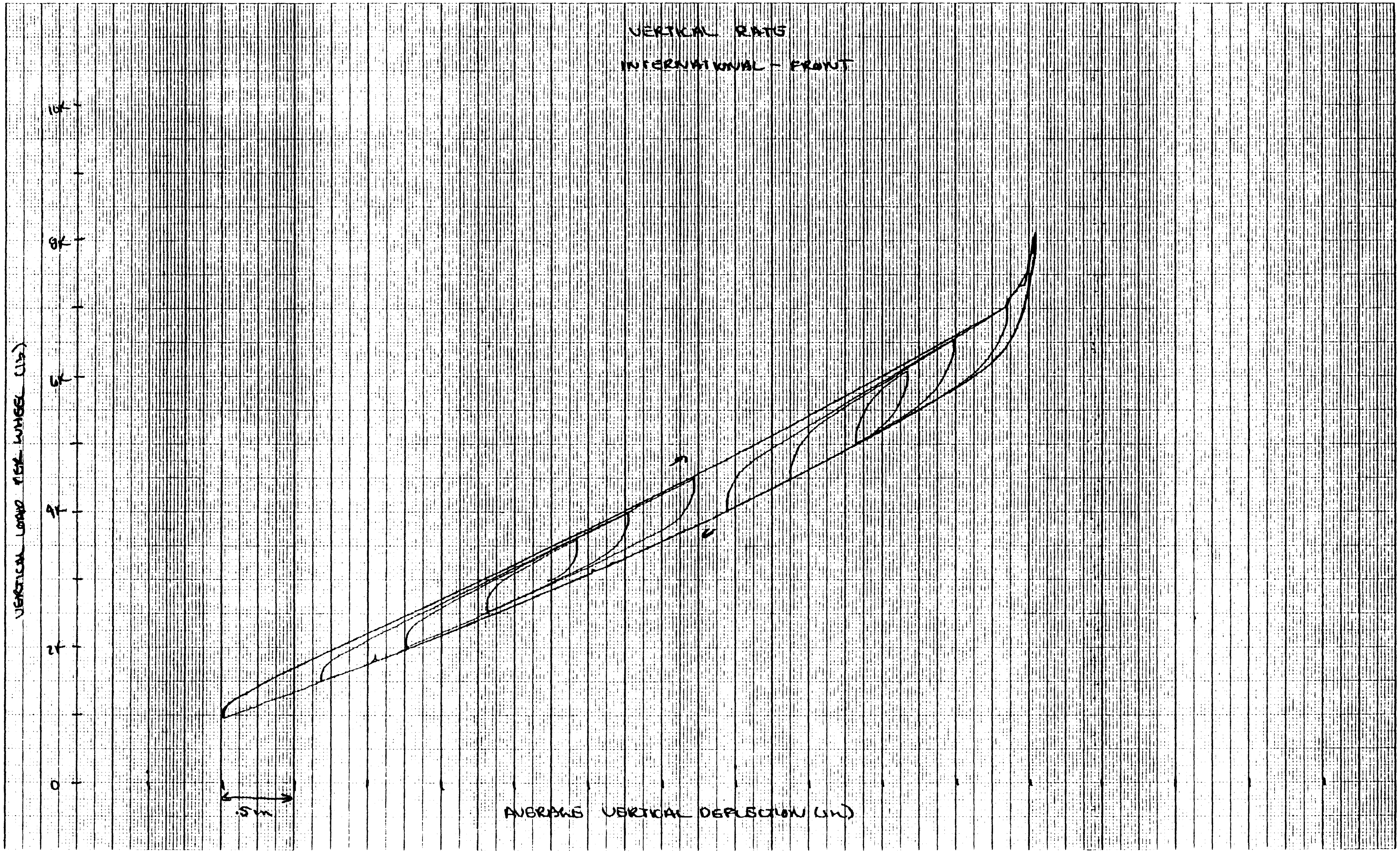
BRAKE FORCE PER WHEELSET (lb)
APPLIED TO ALL SIMULTANEOUSLY

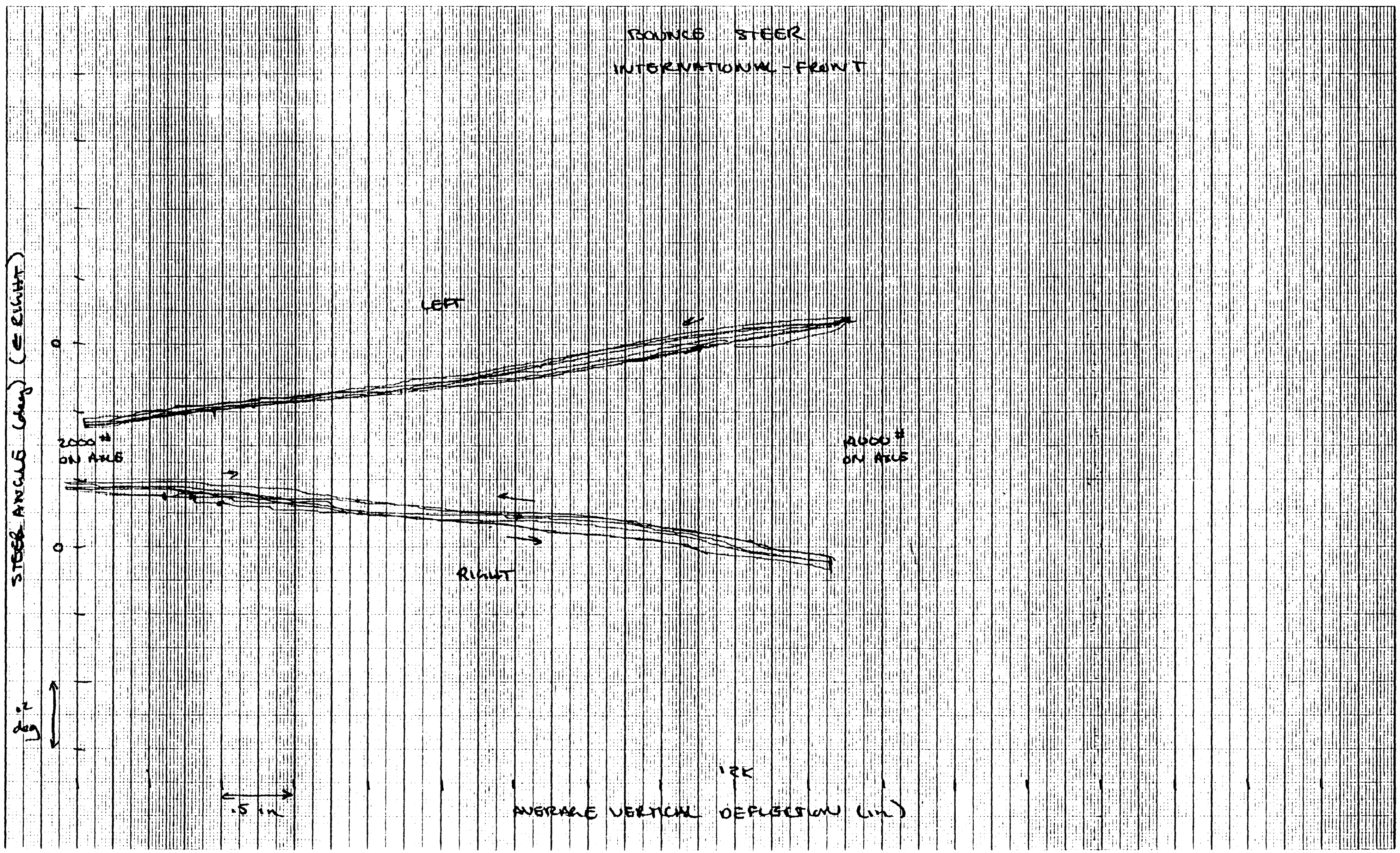
PITCH = -2°



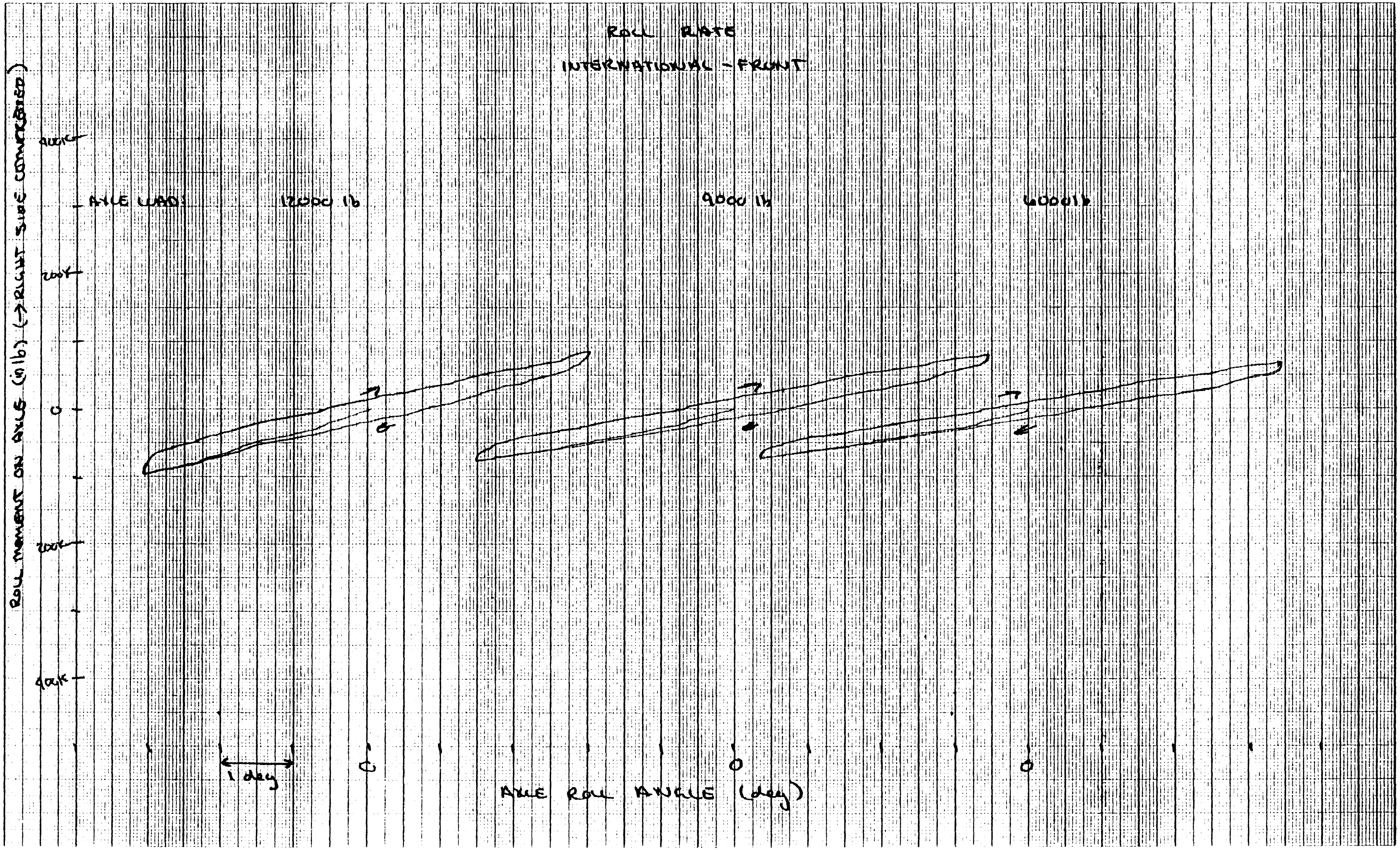
BRAKE FORCE PER WHEELSET (lb)
APPLIED TO ALL SIMULTANEOUSLY

INTERNATIONAL HARVESTER FRONT

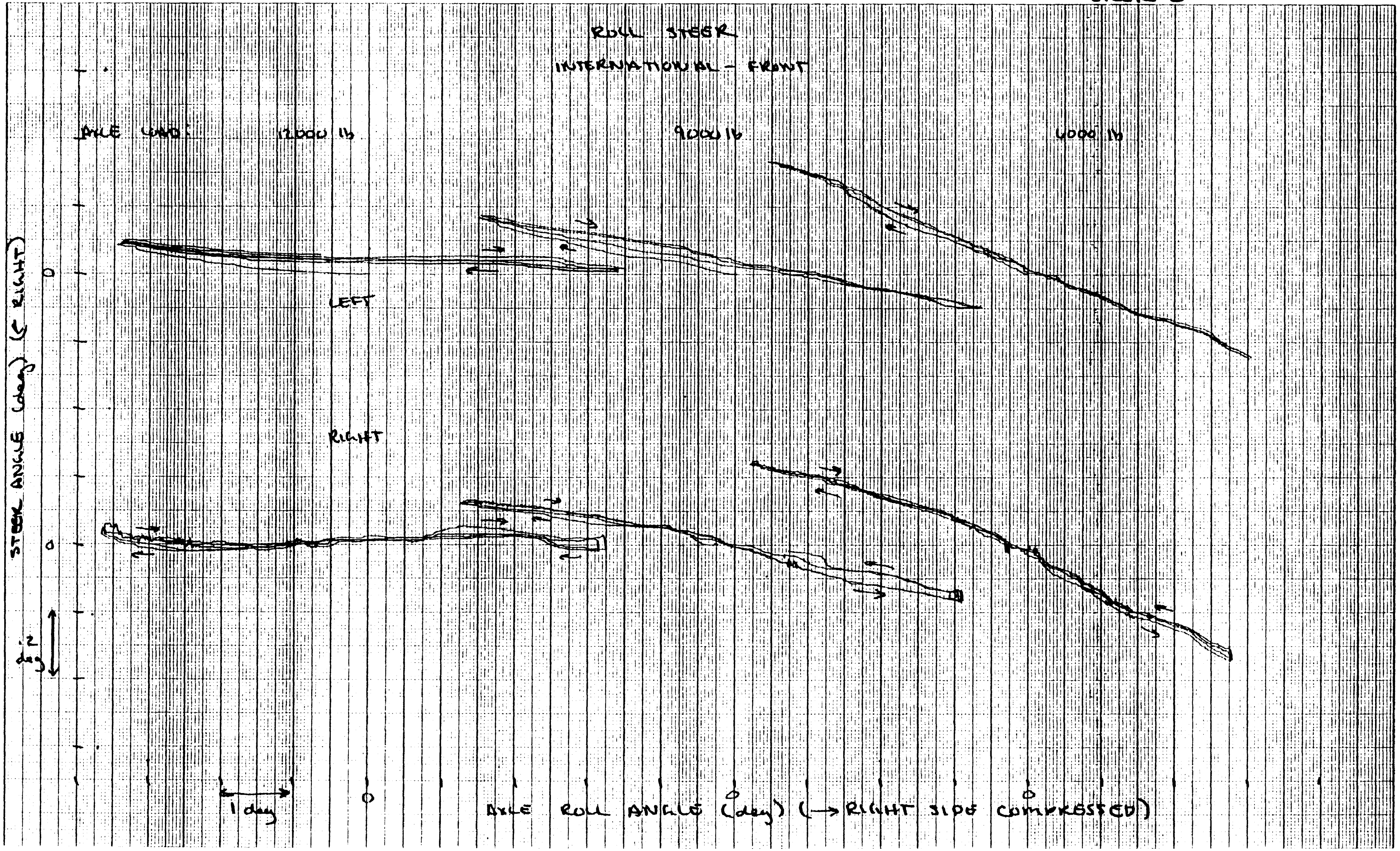

VERTICAL RATE
INTERNATIONAL - FRONT
VERTICAL LOAD PER WHEEL (lb)
10K
8K
6K
4K
2K
0
.5in
AVERAGE VERTICAL DEFLECTION (in)


BOUNCE STEER
INTERNATIONAL - FRONT
LEFT
RIGHT
2000 # ON AXLE
12000 # ON AXLE
STEER ANGLE (deg) (⇐ RIGHT)
0
0
.2 deg
.5 in
12K
AVERAGE VERTICAL DEFLECTION (in)

47 1510

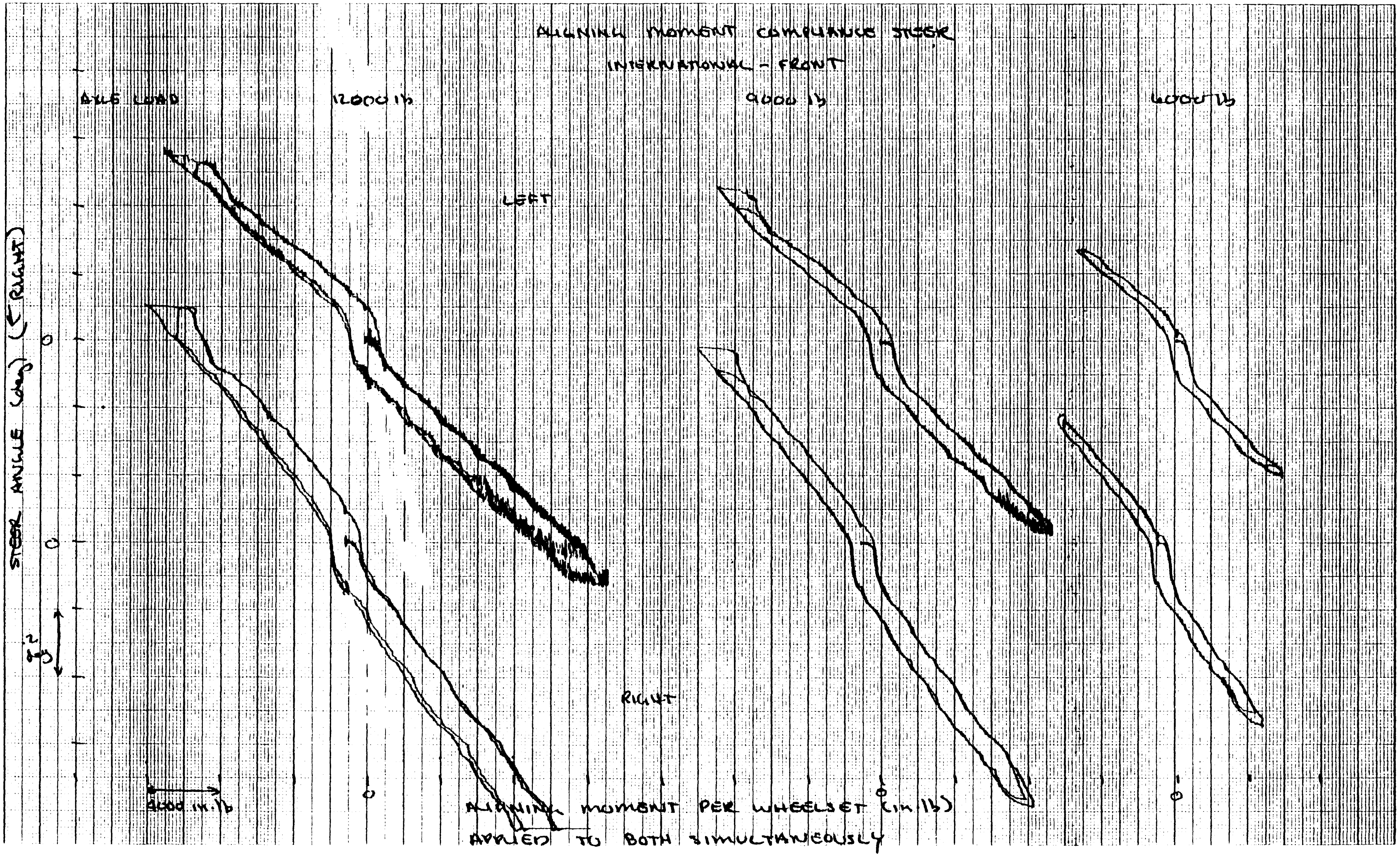

ROLL RATE
INTERNATIONAL - FRONT
AXLE LOAD:
12000 lb
9000 lb
6000 lb
400K
200K
0
200K
400K
ROLL MOMENT ON AXLE (in lb) (→RIGHT SIDE COMPRESSED)
1 deg
0
0
0
AXLE ROLL ANGLE (deg)

STEER = 0°

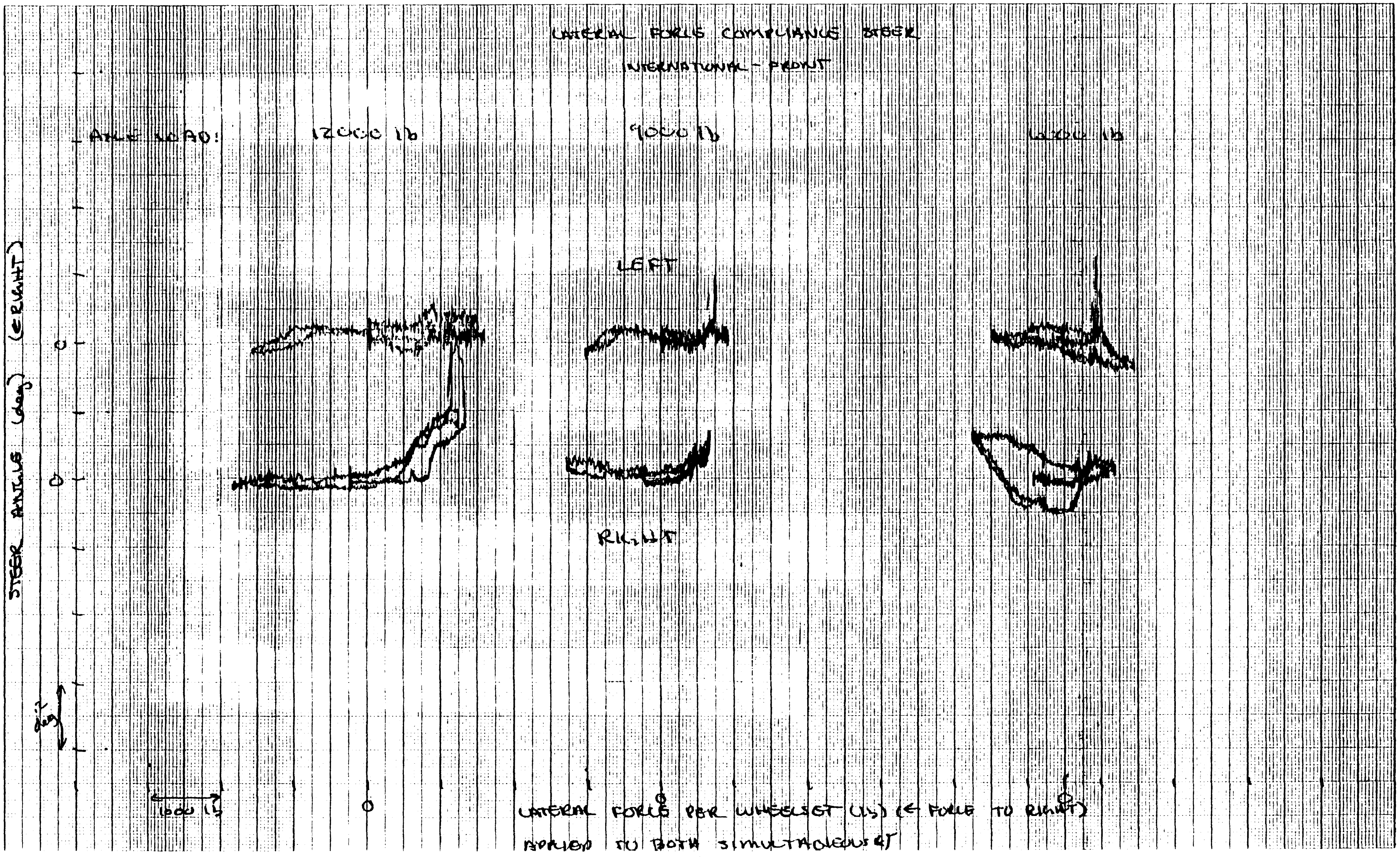


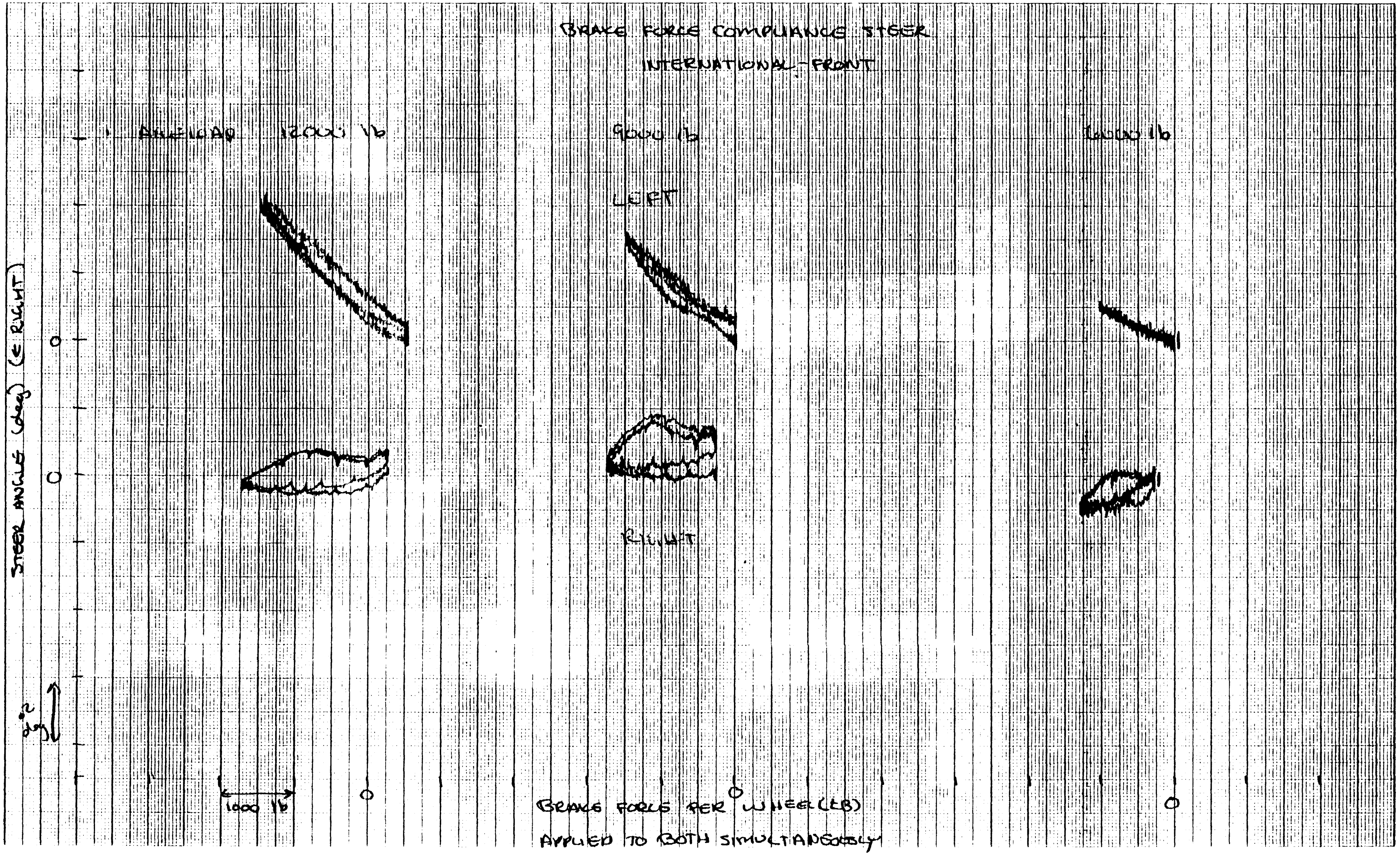
47 1510

K&E 10 X 10 TO THE CENTIMETER KEUFFEL & ESSER CO.

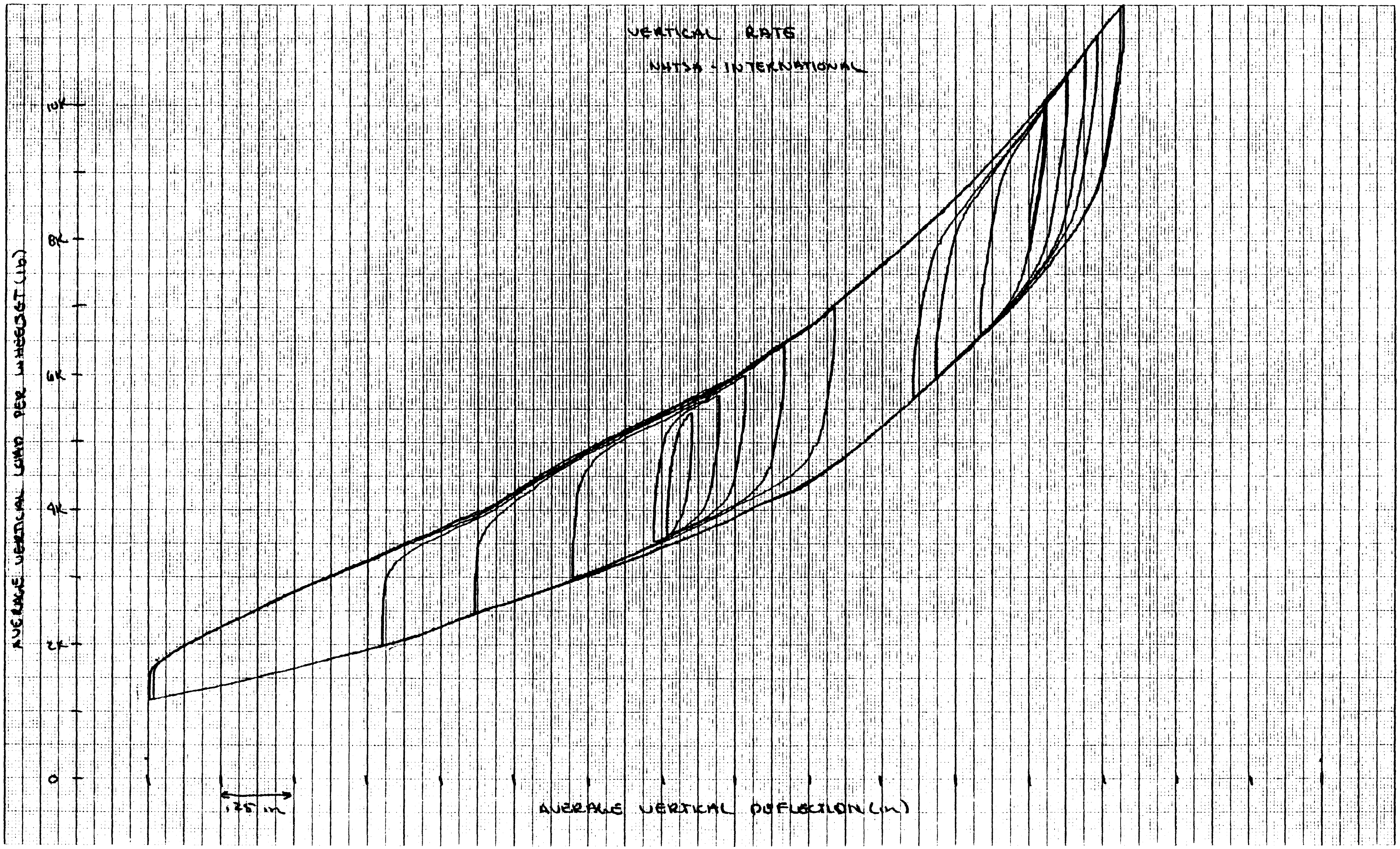

ALIGNING MOMENT COMPLIANCE STEER
INTERNATIONAL - FRONT
AXLE LOAD
12000 lb
9000 lb
6000 lb
LEFT
RIGHT
STEER ANGLE (deg) (← RIGHT)
0
0
2 deg
4000 in.lb
0
0
0
ALIGNING MOMENT PER WHEELSET (in lb)
APPLIED TO BOTH SIMULTANEOUSLY

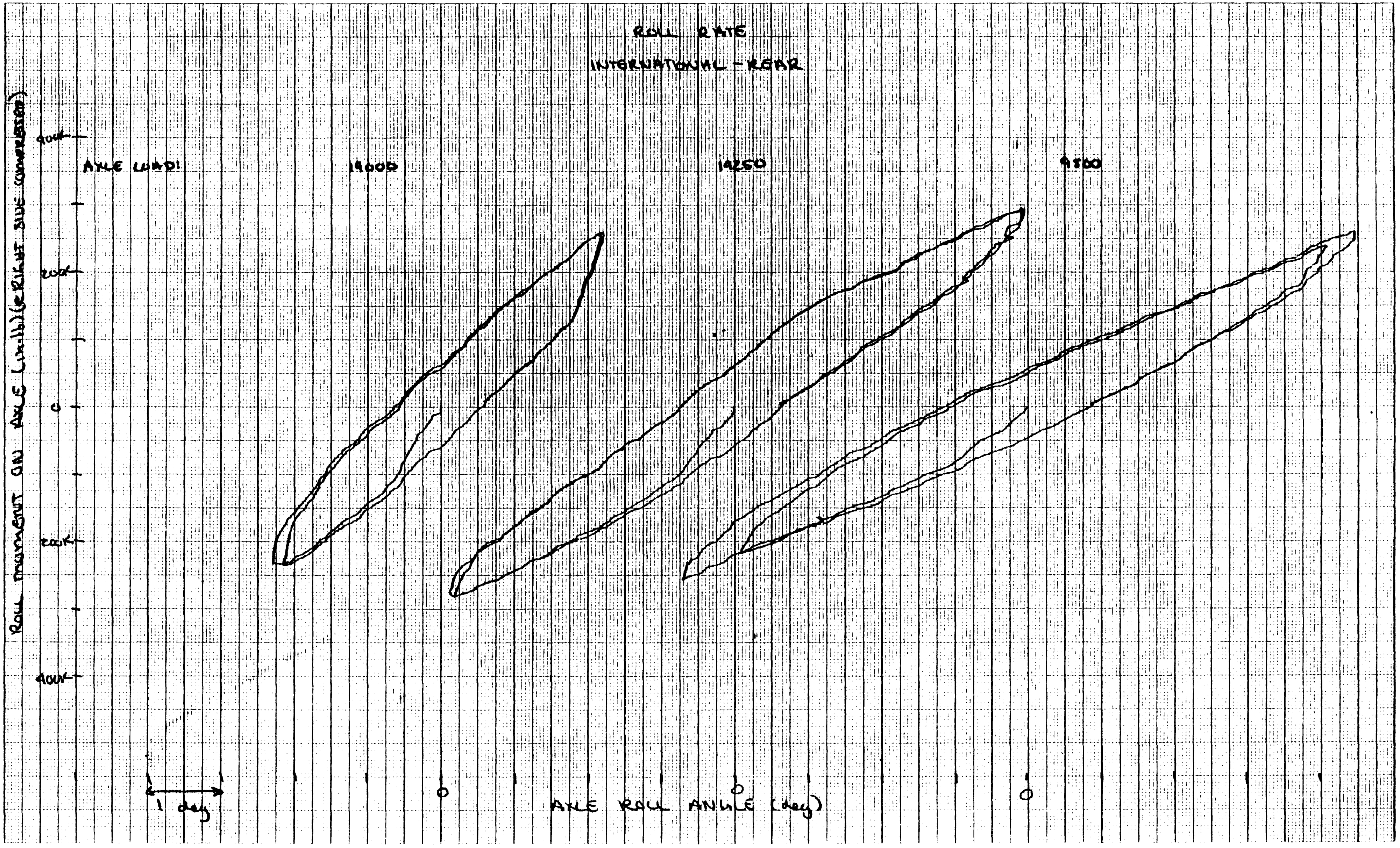
47 1510

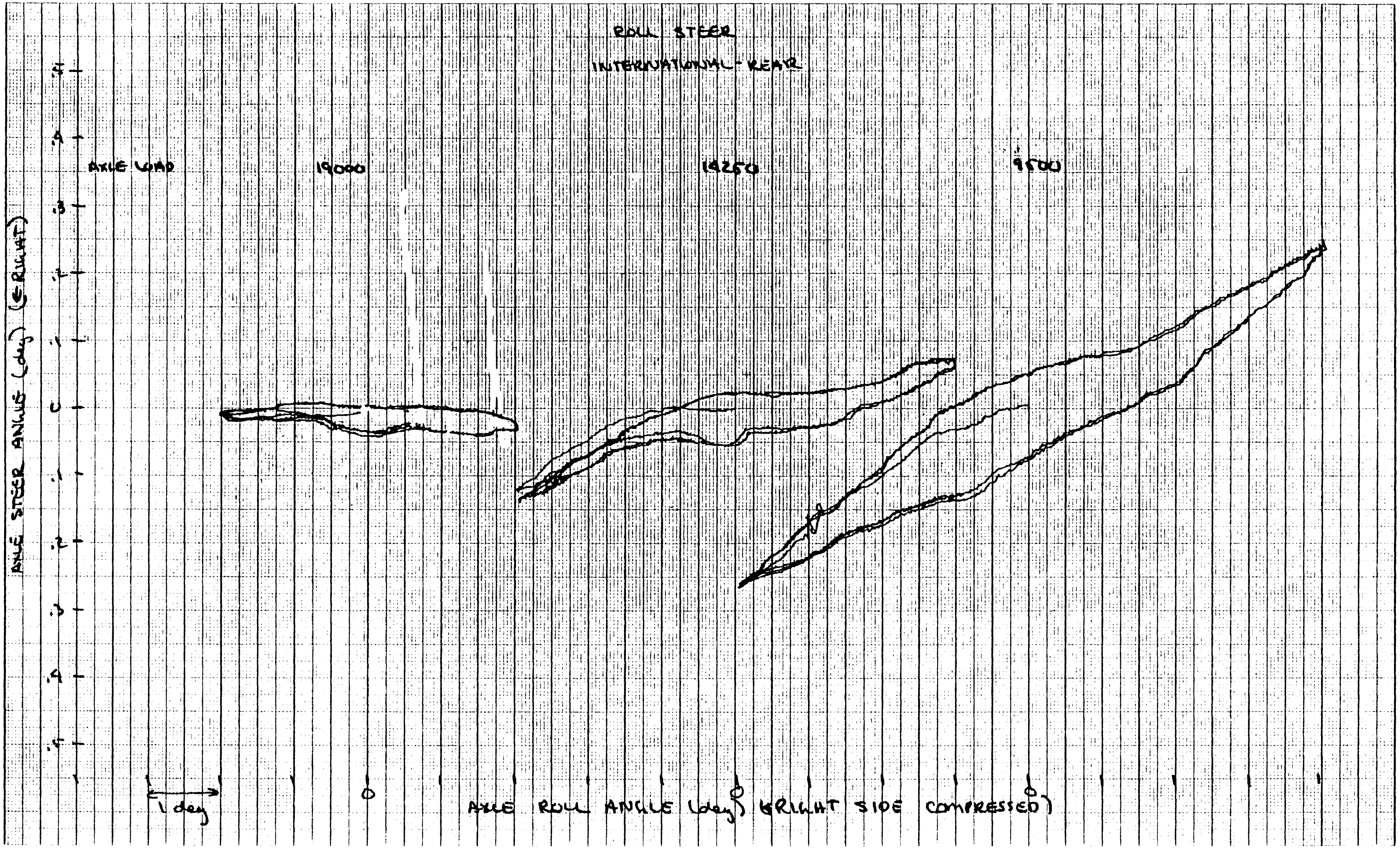

LATERAL FORCE COMPLIANCE STEER
INTERNATIONAL - FRONT
AXLE LOAD:
12000 lb
9000 lb
6000 lb
LEFT
RIGHT
STEER ANGLE (deg) (← RIGHT)
2 deg
1000 lb
LATERAL FORCE PER WHEELSET (lb) (← FORCE TO RIGHT)
APPLIED TO BOTH SIMULTANEOUSLY
0
0
0
0
0

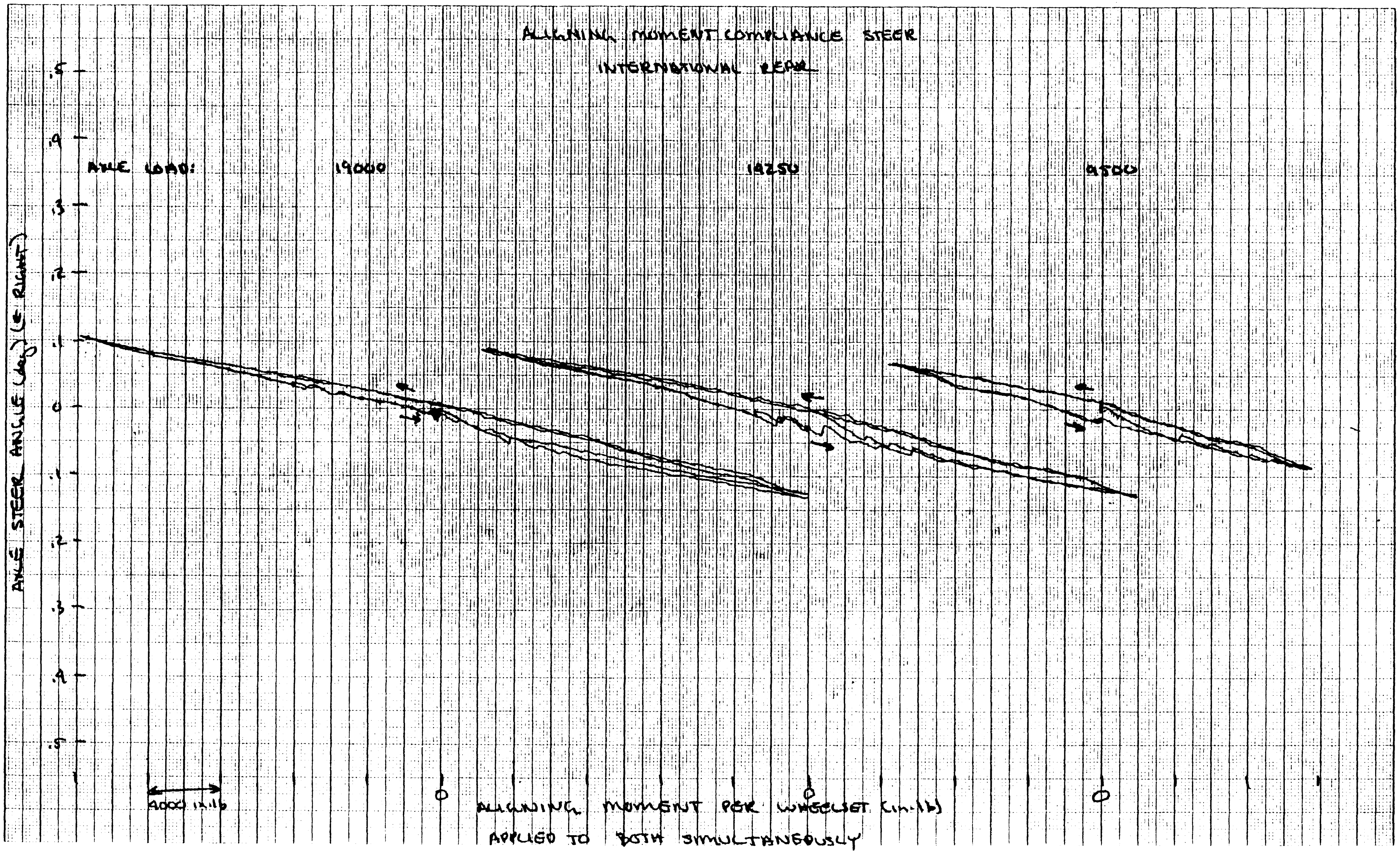

BRAKE FORCE COMPLIANCE STEER
INTERNATIONAL - FRONT
12000 lb
9000 lb
6000 lb
LEFT
RIGHT
0
0
STEER ANGLE (deg) (← RIGHT)
2 deg
1000 lb
BRAKE FORCE PER WHEEL (LB)
APPLIED TO BOTH SIMULTANEOUSLY
47 1510

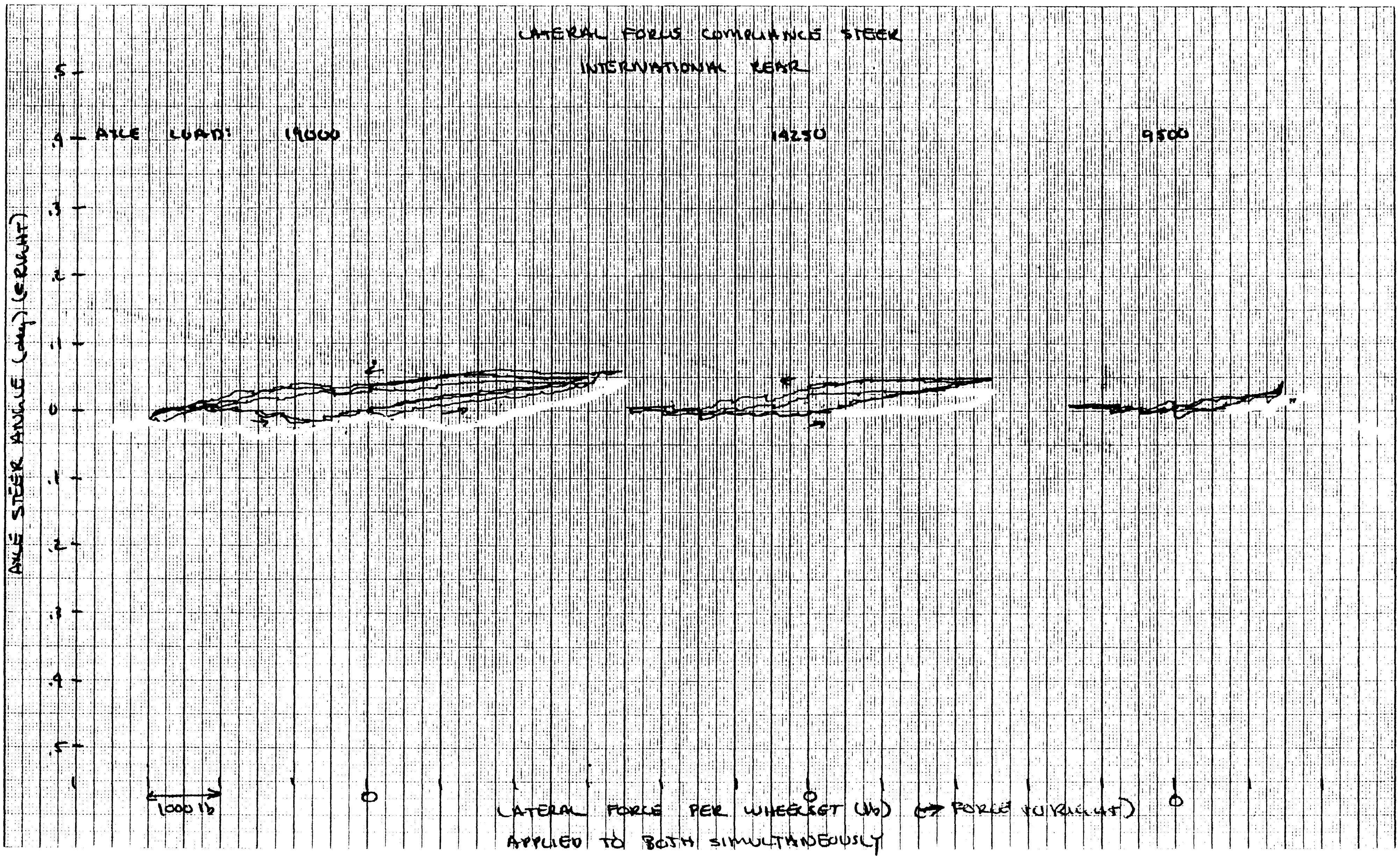
INTERNATIONAL HARVESTER REAR


VERTICAL RATE
NHTSA - INTERNATIONAL
10K
8K
6K
4K
2K
0
AVERAGE VERTICAL LOAD PER WHEELSET (lb)
.125 in
AVERAGE VERTICAL DEFLECTION (in)


ROLL RATE
INTERNATIONAL - REAR
AXLE LOAD:
19000
14250
9500
Roll moment on axle (in-lb) (right side compressed)
400k
200k
0
200k
400k
0
0
0
1 deg
AXLE ROLL ANGLE (deg)


ROLL STEER
INTERNATIONAL - REAR
AXLE LOAD
19000
14250
9500
AXLE STEER ANGLE (deg) (⇐ RIGHT)
AXLE ROLL ANGLE (deg) (RIGHT SIDE COMPRESSED)
1 deg
0


ALIGNING MOMENT COMPLIANCE STEER
INTERNATIONAL REAR
AXLE LOAD:
19000
14250
9500
.5
.4
.3
.2
.1
0
.1
.2
.3
.4
.5
AXLE STEER ANGLE (deg) (← RIGHT)
4000 in.lb
0
0
0
ALIGNING MOMENT PER WHEELSET (in.lb)
APPLIED TO BOTH SIMULTANEOUSLY



LATERAL FORCE COMPLIANCE STEER
INTERNATIONAL REAR
AXLE LOAD: 19000
14250
9500
AXLE STEER ANGLE (deg) (+RIGHT)
.5
.4
.3
.2
.1
0
.1
.2
.3
.4
.5
1000 lb
0
0
0
LATERAL FORCE PER WHEELSET (lb) (→ FORCE TO RIGHT)
APPLIED TO BOTH SIMULTANEOUSLY