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STEERING AND SUSPENSION SYSTEM

Descriptive Parameters Used in Analyzing the Braking and Handling of Heavy Trucks

Volume 4
2nd Edition

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16. Abstract

This volume is one of a set of five volumes which provided a compilation of heavy vehicle parameter data. The original editions of these volumes were prepared under support from the Motor Vehicle Manufacturers Association and were published in 1981. The five volumes address (1) brakes, (2) inertial properties, (3) tires, (4) steering and suspension systems, and (5) antilock systems. This volume is one of two "2nd Editions" providing updated information on (1) inertial properties and (2) steering and suspension systems.

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1.0 INTRODUCTION

The purpose of this volume is to provide a source of data, describing the mechanical properties of heavy vehicle suspensions. Properties of interest herein are the compliance, kinematic, and Coulomb friction properties which are of interest in the study of vehicle ride, handling and/or braking.

This document contains data derived from the measurement of some 23 heavy vehicle suspensions. All measurements were made using the UMTRI Heavy Vehicle Suspension Measurement Facility. The facility is described in [1]. Data describing the properties of truck and tractor front and rear suspensions, trailer suspensions, and dolly suspensions are included. Tandem and single axle suspensions are included as are suspensions using a variety of springing elements and linkage arrangements.

All of the data provided herein represent measurements of suspension characteristics alone and do not include tire characteristics. That is, referenced linear (e.g., vertical displacement) and angular (e.g., roll angle) displacements are motions of the suspension, wheel, or axle (all measured suspensions are of solid axle configuration) motion relative to the vehicle frame. They are not measurements of body or frame motions relative to the ground plane.

All data presented herein were gathered with the vehicle frame parallel to the ground plane (in pitch and roll) unless otherwise noted. Steering axle data was gathered at a nominally zero steer angle unless otherwise noted.

Section 2.0 of this document contains a discussion of measurement and data reduction techniques. The reader is encouraged to read and understand this material prior to making use of the data presented.

In Section 3.0 of this document, the available suspension data is presented in a suspension-by-suspension format. For each suspension, a "summary sheet" is provided wherein simplified numerics describing the suspension performance are given. This presentation is made in order to provide the reader with data in a convenient, readily useable form. The reader must be aware, however, that a great deal of information regarding the behavior of the suspension is lost, when raw measurement data is reduced

to the simple (usually linear approximation) numerics provided in Section 3.0. Accordingly, for each suspension, the summary sheet is followed by data in unreduced, graphical form as obtained directly from the measurement facility. This presentation retains all of the complex, nonlinear behavioral characteristics of the measured suspensions.

2.0 MEASUREMENT AND DATA REDUCTION PROCEDURES

All of the data provided herein represent measurement of suspension characteristics alone and do not include tire characteristics. That is, referenced linear (e.g. vertical displacement) and angular (e.g. roll angle) displacements are motions of the suspension, wheel, or axle (all measured suspensions are of solid axle configuration) motion relative to the vehicle frame. They are not measurements of body or frame motions relative to the plane of the road.

All data presented herein were gathered with the vehicle frame parallel to the ground plane (in pitch and roll) unless otherwise noted. Steering axle suspension data were gathered at a nominal zero steer condition unless otherwise noted.

2.1 Loads

Where applicable, referenced suspension loads are defined in accordance with the definitions of "TIRE FORCES AND MOMENTS" given by the SAE in [2]. That is, the terms vertical load, lateral force, brake force, and aligning moment all refer to tire forces and moments. In particular, with respect to compliance steer properties, the measurements presented derive from forces and moments applied relative to SAE tire axis system (and not necessarily relative to the kingpin axis for steering suspensions). Finally, where dual tires are involved, each dual tire pair is considered as one tire, for purposes of applying the SAE definitions. The exception to this general rule is "Roll Moment." Roll moment applied to a given axle is the sum of (1) the couple derived from the difference in vertical loads, side-to-side, plus, (2) the overtuning moments present at each tire of the axle.

2.2 Vertical Rate and Coulomb Friction

Figure 2.1 presents a qualitative facsimile of the data derived from a vertical rate test. The ordinate is the average (i.e., per wheel) vertical load applied to the suspension. The abscissa is the average vertical deflection of the wheel spindles of the suspension. The test is conducted under conditions of equal side-to-side loading and zero tire shear forces and moment. As implied by the figure, the suspension is exercised cyclically

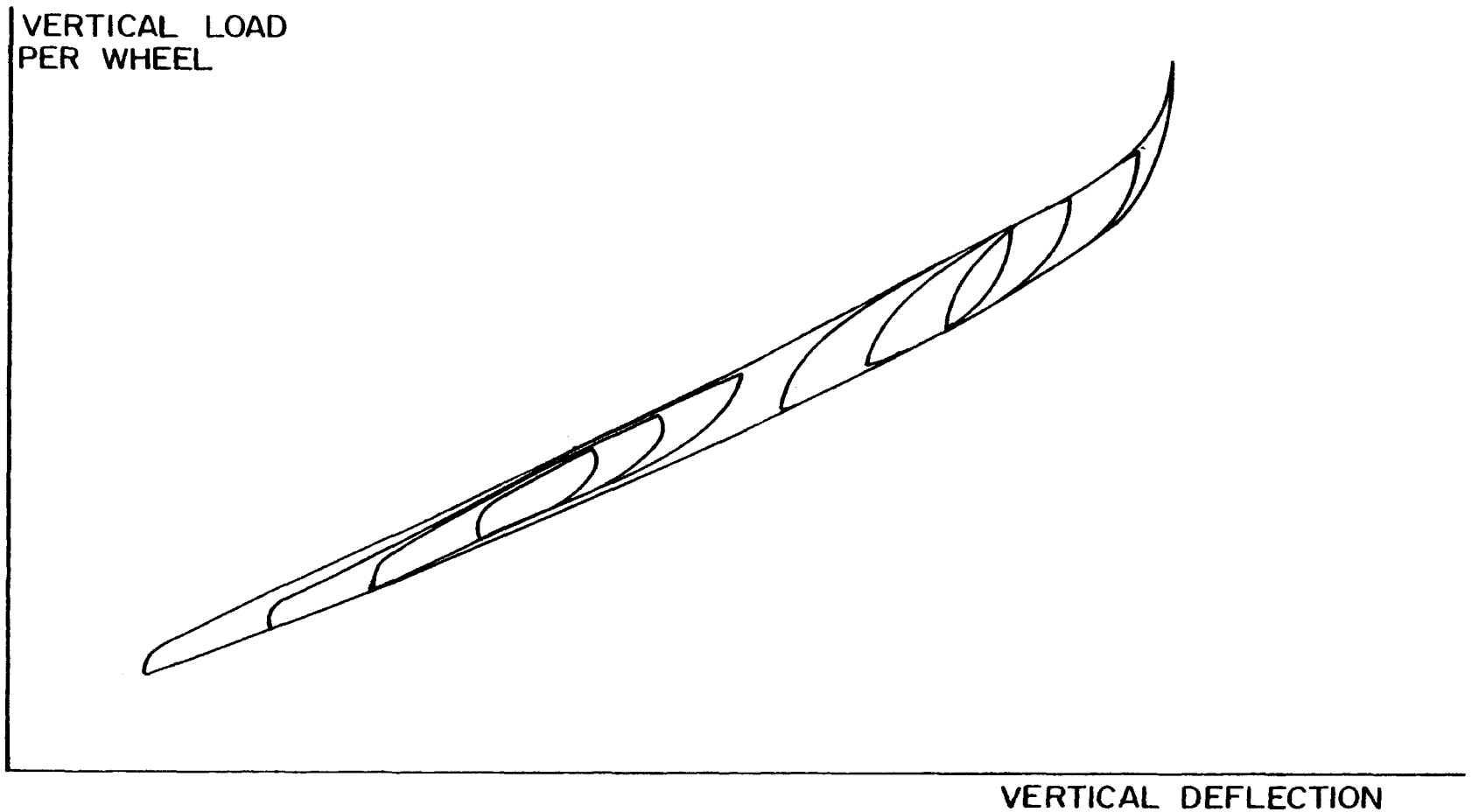


Figure 2.1 Typical leaf spring vertical rate performance.

over various levels of vertical stroke at various nominal vertical loads. Exercising the suspension cyclically over its full range of stroke in a single cycle generates the "outer envelope" curve. (The "tail" at the right end of the curve indicates contact with the axle bump stops.) Exercising the suspension over shorter strokes produces the smaller hysteretic loops.

The numerics reported as "vertical rate" and "Coulomb friction" on the summary sheets are derived from the full stroke, "outer envelope" data. The vertical rate numeric is the average slope of the upper and lower curves (in pounds per inch). Coulomb friction is one half of the ordinate distance between the upper and lower curves (in pounds). These summary numerics are, then, appropriate only for describing the large stroke performance of the suspension. They are not appropriate for short stroke behavior (e.g., as may be involved in ride vibrations). Reference [3] describes two useful methods for deriving representative numerics from the graphical data.

2.3 Roll Rate

Figure 2.2 is an example of data describing suspension roll rate. The ordinate represents axle roll moment (in inch-pounds). The abscissa gives axle roll displacement (in degrees). Roll moment data is presented on a per axle basis whether the suspension is single or tandem axle.

Test conditions under which such data are gathered include (1) a constant value of applied vertical load on the suspension, and (2) zero values of tire shear forces and moment.

The example graph shows that suspension roll performance contains much of the hysteretic quality shown in suspension vertical performance. Although not apparent from this example, it should be noted that truck suspensions often exhibit significantly greater roll stiffness than would be implied by a simple model using the vertical spring stiffness and the lateral spring spacing [1]. The example data does show the influence of spring lash. That is, the portions of the curve showing very low roll rate are the result of the lightly loaded suspension spring passing through lash as it goes from compression to tension [4].

The roll rate numeric represents the average slope of the upper and lower, large deflection curves, taken at the zero roll condition.

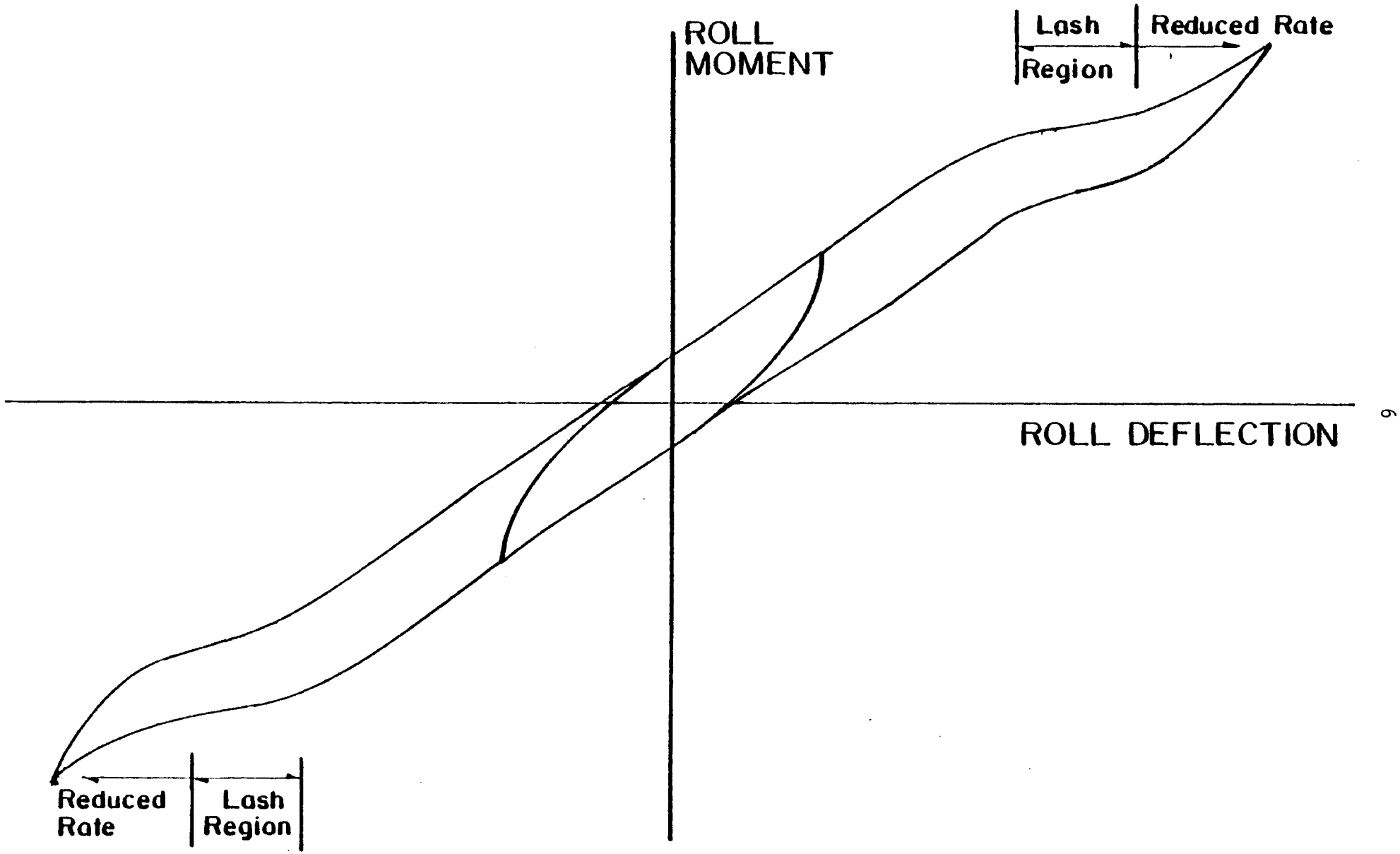


Figure 2.2 Typical leaf spring roll rate performance.

2.4 Roll Center Height

Roll center height is measured under the same test conditions described for roll rate. It is presented only as a numeric on the summary sheets. The numeric presented locates the instant center of the axle and frame at the zero roll angle condition. In most cases, the roll center height is given relative to the top surface of the vehicle frame rather than relative to the ground in order to avoid the need to track roll center height as a function of tire rolling radius. In the absence of specific data, the reader might assume frame height to be approximately 42 inches above the ground.

2.5 Roll Steer

Roll steer data is collected under the same test conditions as noted for roll rate. The graphical presentations plot road wheel steer angle vs. axle roll angle. For steering axles, separate presentations are made for left and right wheels. For non-steering axles, only one presentation is made, assuming that both wheels of an axle steer equally. For tandem suspensions, separate presentations are made for each axle. In the summary data, the numeric given represents the average slope of the graphical data at the zero roll angle condition.

2.6 Compliance Steers

Data describing steer response to three tire shear loads, viz (1) aligning moment, (2) lateral force, and (3) brake force are given in Section 3.0. The following conditions prevail for tests of each of these steer responses. The specified total suspension vertical load is established with equal vertical load side-to-side. Henceforth, the vertical and roll positions of the suspension are held fixed (average vertical and roll positions of the two axles, for tandem suspensions) to avoid contamination of the data by kinematic steer effects. The shear plane load of interest is applied equally at all wheels of the suspension while all other shear plane loads are maintained at zero.

2.6.1 Aligning Moment Steer. Aligning moment steer data is presented graphically in plots of road wheel steer angle (in degrees) vs. applied aligning moment (in inch-pounds per wheel). For steering axles, data is presented

for left and right sides. For nonsteering axles, it is assumed that right and left wheels steer equally; however, data is presented separately by axle for tandem suspensions.

The data is generally well-behaved for nonsteering axles, in that it is quite linear and shows little influence of vertical load. Steering axle response to aligning moment tends to be nonlinear due to hysteresis and the influence of steering system lash around zero applied moment. The summary sheet numeric for aligning moment steer is the approximate slope of the graphical data, ignoring the influence of lash.

2.6.2 Lateral and Brake Force Compliance Steers. It must be candidly noted that the measurement of shear force compliance steers is extremely difficult to accomplish with a high degree of accuracy. *Shear force compliance steer data presented herein* (and elsewhere) *should be received and employed with caution.*

The experimental difficulty derives from the following: (1) aligning moment compliance steer mechanisms (particularly for steering axles) is generally quite "soft" relative to shear force steer mechanisms, and (2) the accurate maintenance of the orientation of the applied shear force vector along the reference axis of interest (in this case, the SAE tire x- or y-axis) throughout the experiment is extremely difficult. That is, since aligning moment effects tend to generate larger steer responses than do shear force effects, the experiment must take extra care to applying shear forces in the complete absence of aligning moment (i.e., the applied shear force must be oriented on the reference axis of interest), to avoid contamination of the response data. However, since the application of the shear force itself generates steer and translational motions of the road wheel, the necessary shear force orientation is difficult to maintain, let alone establish initially.

Shear force compliance steer data is presented graphically in plots of steer angle (in degrees) vs. applied shear force (in pounds per wheel). Left and right side data are presented for steering axles and the data is presented on a per axle basis for tandem suspensions. Brake force steer is not measured for nonsteering axles. The summary sheet numeric is the linear approximation of the slope of the graphical data.

2.7 Tandem Suspension Properties

The following two suspension properties apply to tandem axle suspensions only.

2.7.1 Interaxle Load Leveling. The majority of tandem axle suspensions include a mechanism intended to maintain equal vertical loading on the two axles of the suspension. Data describing this interaxle load leveling function is gathered under the same conditions described for vertical rate, and is presented in the form of plots of leading axle vertical load (in pounds) vs. trailing axle vertical load (in pounds) for both right and left sides. "Perfect" load leveling would then be represented by a slope of unity. No summary numeric is presented.

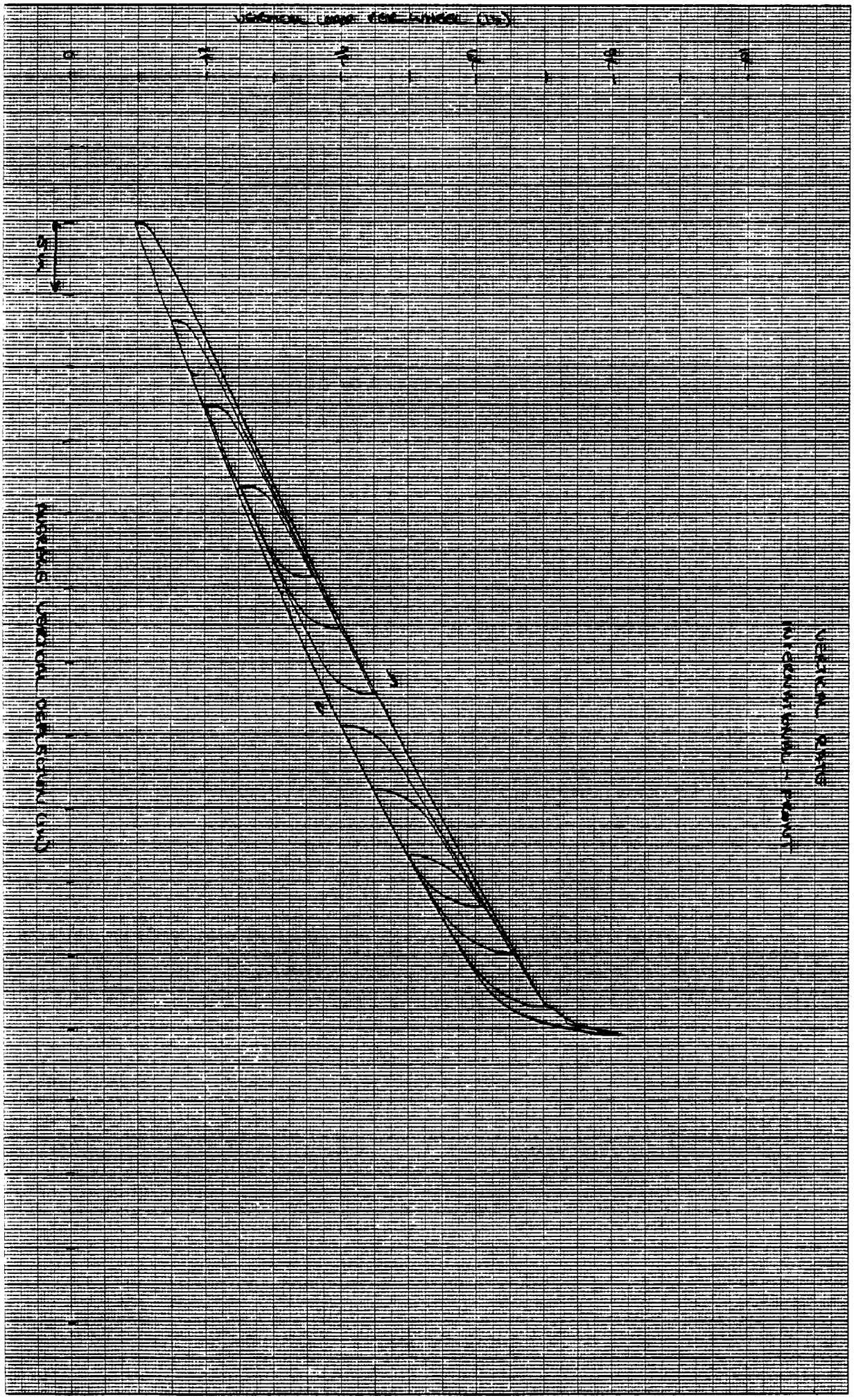
2.7.2 Interaxle Load Transfer. The same tandem axle mechanisms which provide load leveling under free running generally induce the transfer of load from one axle of the tandem set to the other during the application of longitudinal tire shear force (braking or driving). Data describing interaxle load transfer due to braking is gathered in the following manner. The specified total suspension load is applied with equal (average) load distribution side-to-side and these conditions are maintained throughout the test. Brake forces are then applied, equally at all four wheels of the suspension. Graphical data is gathered in which trailing axle vertical wheel load (in pounds) is plotted on the ordinate, and applied brake force per wheel (in pounds) is plotted on the abscissa. Since total and side-to-side vertical loading are held constant, vertical load changes at the trailing axle are known to be mirrored at the leading axle. Data is gathered for right and left sides separately. The summary sheet numeric is the representative slope of the graphical data in vertical load transferred per side (pounds), per brake force applied per wheel (pounds).

3.0 SUSPENSION DATA

This section presents measured suspension properties in reduced and graphical forms. The numerics presented are, in most cases, linear approximations of system performance, at specific operating points as defined by total suspension load. More complete descriptions of measurement and data reduction techniques are given in Section 2.0. The reader is encouraged to read and understand these discussions prior to making use of the data presented in this section.

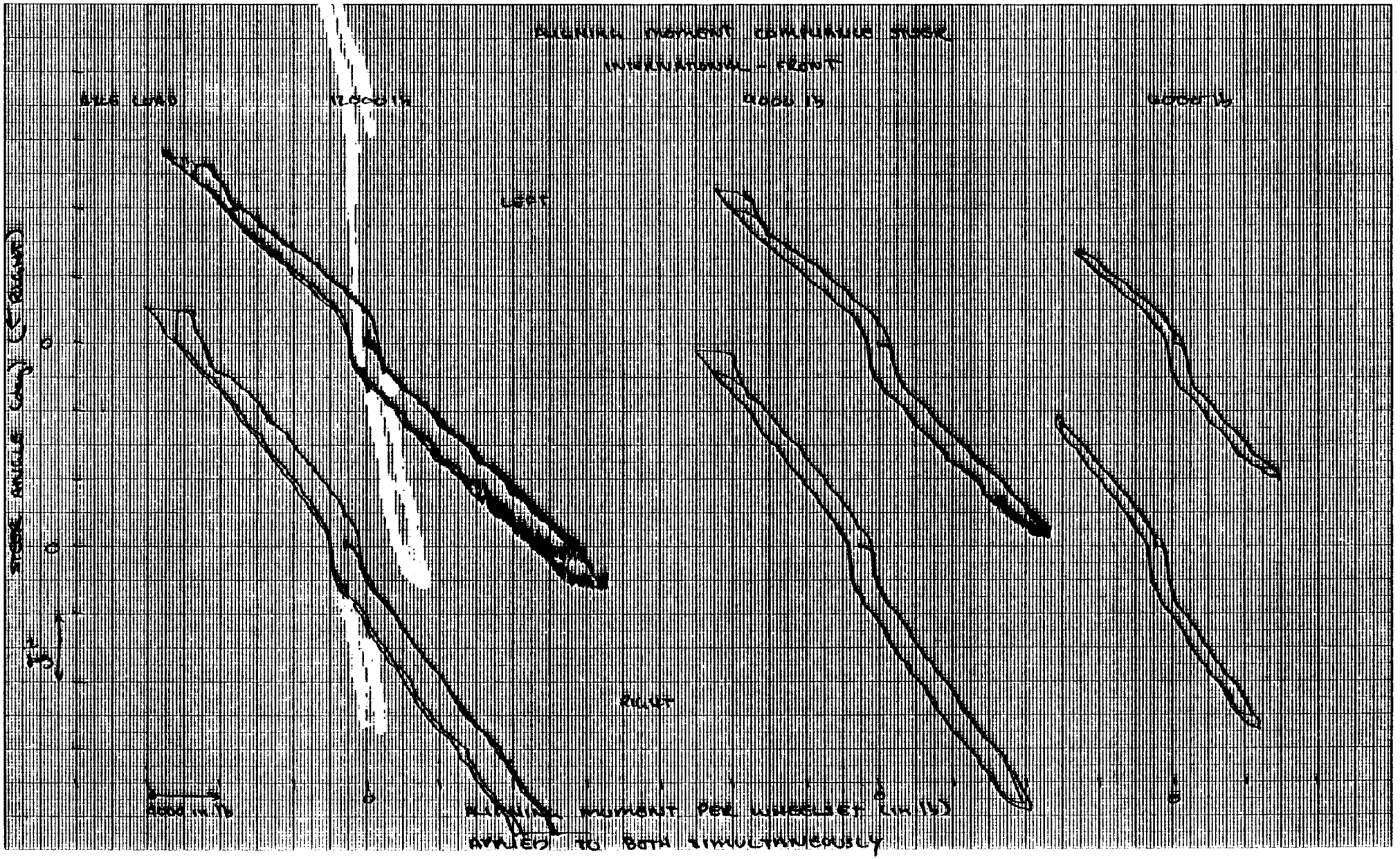
Suspension: International - Front

		Susp Load 12000	9000	6000
Vertical Rate (lb/in)		1200	1100	1100
Coulomb Friction (lb)		400	375	325
ROLL RATE (in-lb/deg)	F	25K	20K	18K
	R			
ROLL CENTER HT (in below top of horn)	F	———	NA	———
	R			
ROLL STEER (DEG / DEG) @ 0° SW	L	nil	-.04	-.08
	R	nil	-.06	-.10
ALIGNING MOMENT COMPLIANCE STEER (deg/in lb)	L	5×10^{-5}	5.5×10^{-5}	5.5×10^{-5}
	R	5×10^{-5}	6.5×10^{-5}	7×10^{-5}
LATERAL FORCE COMPLIANCE (deg/lb)	R	———	nil	———
	L	———	nil	———
Brake Force Compliance Steer (deg/lb)	L	2.2×10^{-4} out	2×10^{-4} out	2×10^{-4} out
	R	nil	nil	1.2×10^{-4} out


Vertical Load, kips
0
1/4
1/2
3/4
1
1 1/4
Deflection, inches
Vertical Deflection Gage
Horizontal Deflection Gage

Axial Displacement (Inches)
Axial Load (Kips)
Axial Load Versus Displacement
Load Point
Load Point
Load Point

STEER 2.0°
ROLL STEER
INTERMEDIATE FLAP
LOAD 1
LOAD 2
LOAD 3
LOAD 4
LOAD 5
LOAD 6
LOAD 7
LOAD 8
LOAD 9
LOAD 10
LOAD 11
LOAD 12
LOAD 13
LOAD 14
LOAD 15
LOAD 16
LOAD 17
LOAD 18
LOAD 19
LOAD 20
LOAD



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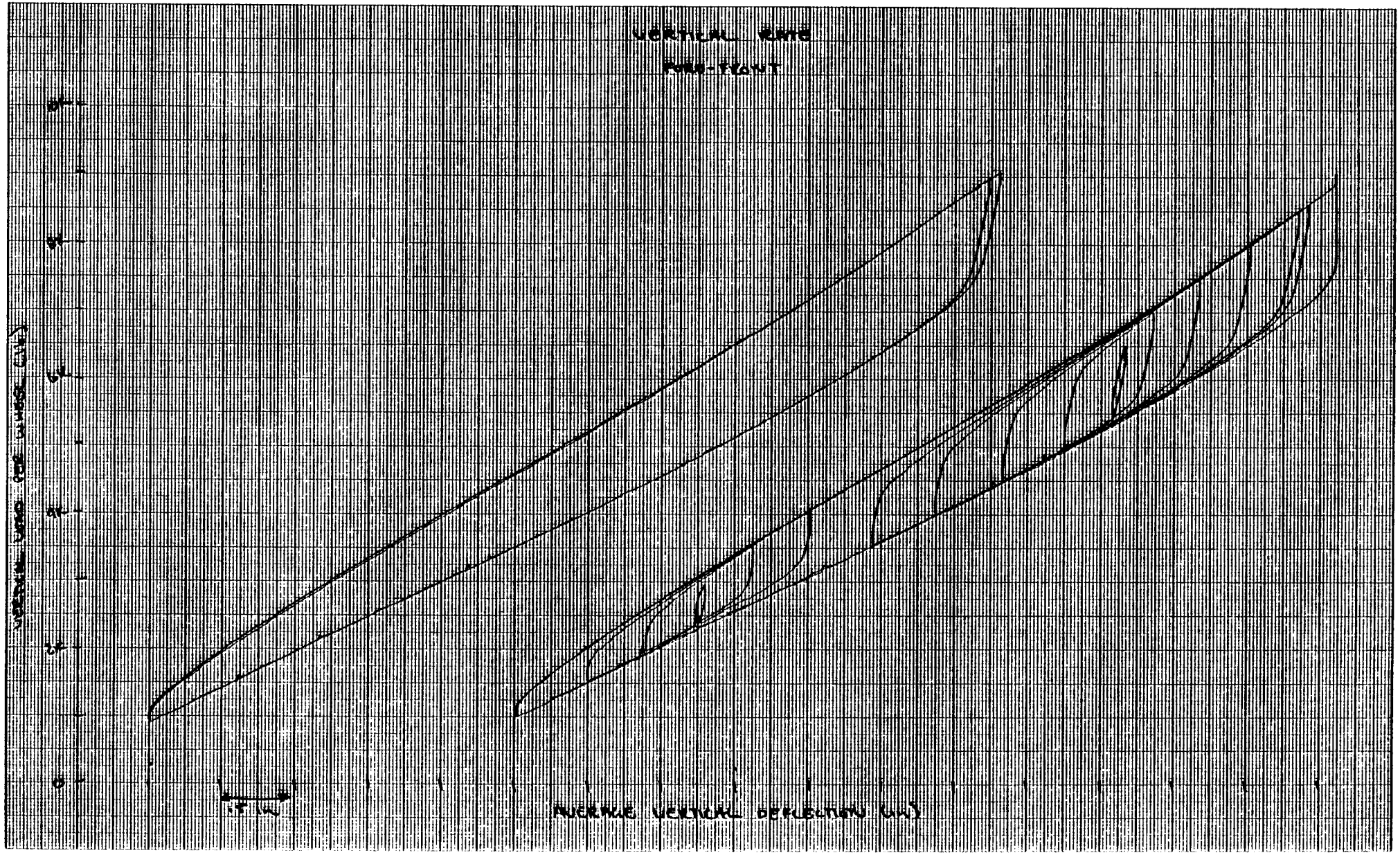
ANKLE LOAD
12 LOAD 1/2
4 LOAD 1/2
UNILATERAL BALANCE COMPENSATIONS
UNILATERAL PLANK
Quiet
Right Lat
Right Lat
Left Lat
Left Lat
Quiet
Quiet
Quiet

Blade Root Downwards Front
Intermediate Front
Blade Tip
Blade Tip
Blade Root Upwards Front
Blade Tip
Blade Root Upwards Rear
Blade Tip
Blade Root Downwards Rear
Blade Tip

Suspension: Ford - Front

		Susp Load 12000	9000	6000
Vertical Rate (lb/in)		1250	1250	1250
Coulomb Friction (lb)		650	550	400
ROLL RATE (in-lb/deg)	F	30K	25K	25K
	R			
ROLL CENTER HT (in below top of frame)	F		NA	
	R			
ROLL STEER (DEG / DEG) @ 0° SW	L	.11	.12	.17
	R	.10	.12	.17
ALIGNING MOMENT COMPLIANCE STEER (deg/in lb)	L	1.5×10^{-4}	3×10^{-4}	3.5×10^{-4}
	R	4.5×10^{-4}	3.8×10^{-4}	4×10^{-4}
LATERAL FORCE COMPLIANCE (deg/lb)	L			
	R			
INTERAXLE LOAD TRANSFER (BRAKING) (lb/lb)				
Brake Force Compliance Steer	L		Nil	
	R			



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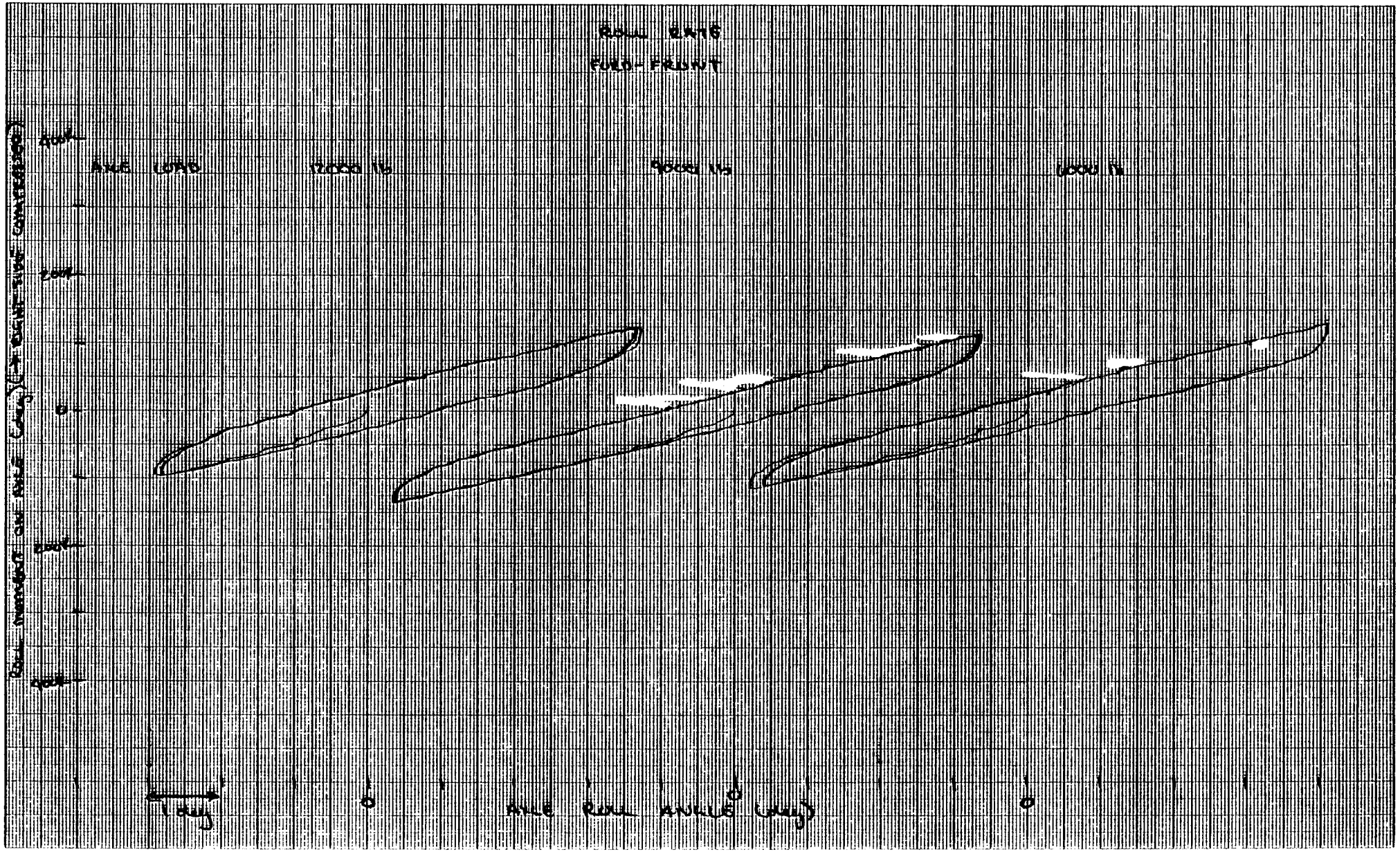
47 1510



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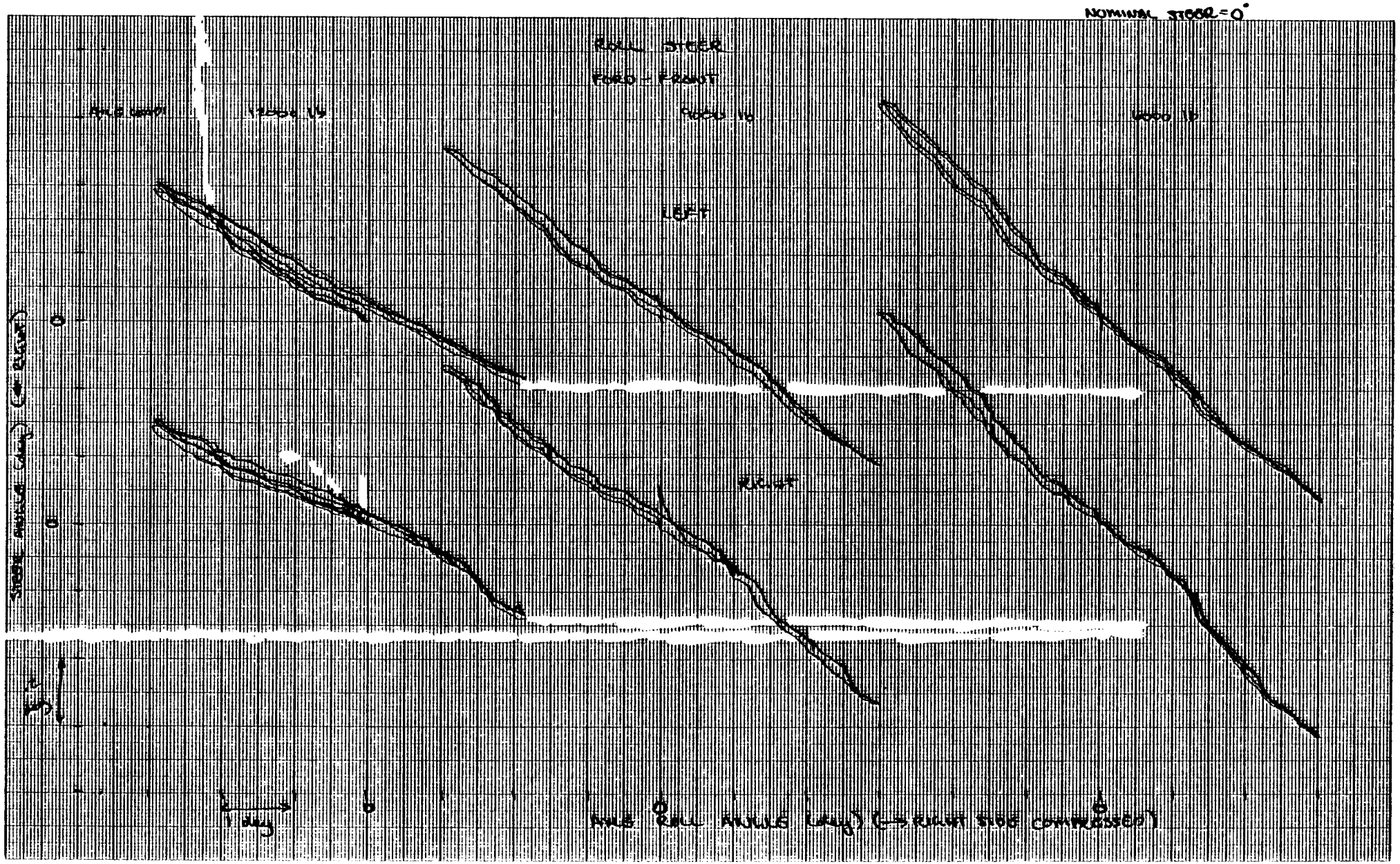

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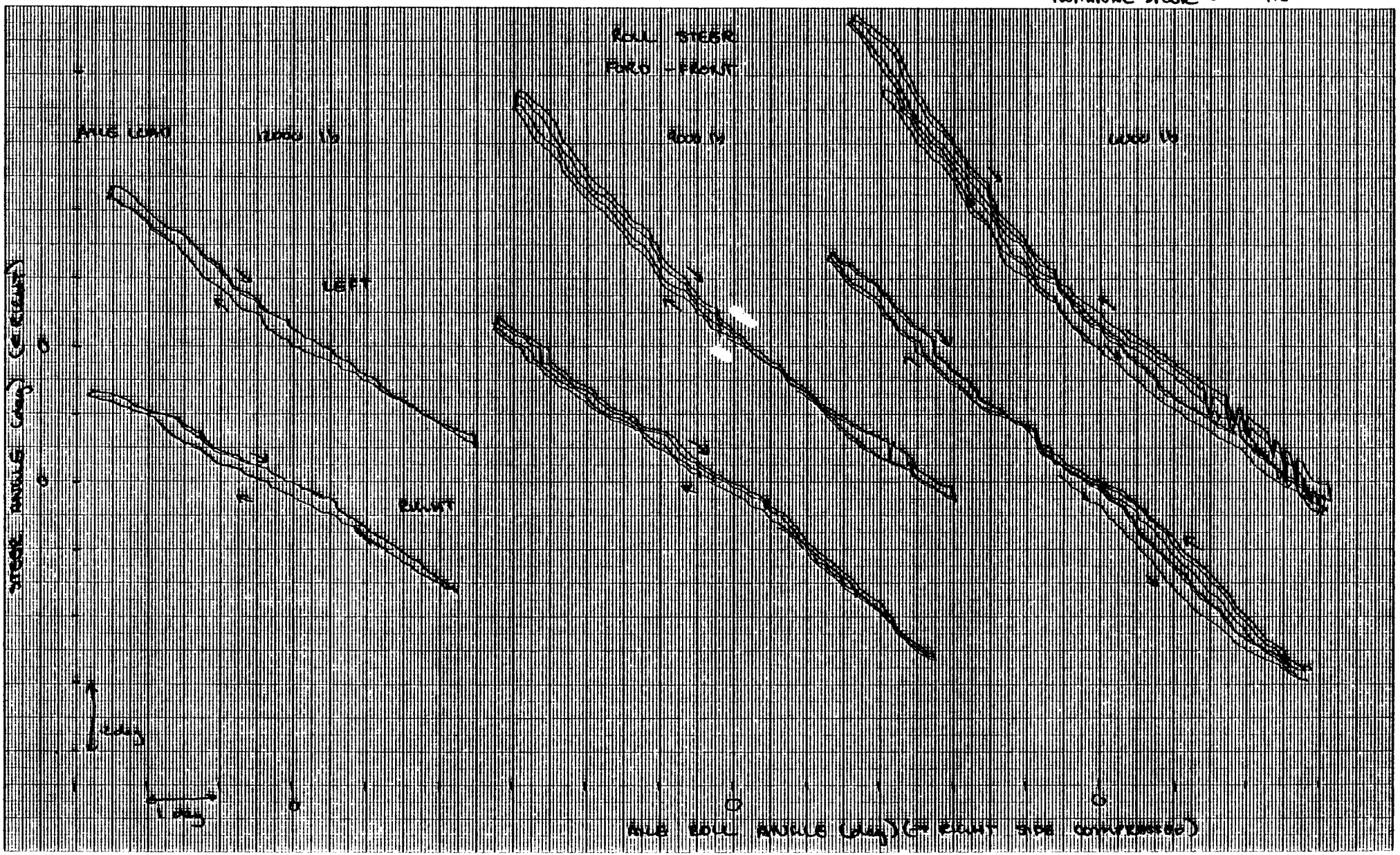
Roll Angle (deg)
Time
Roll Angle (deg)
Time
Roll Angle (deg)
Time

NOMINAL STEER = -1.5°



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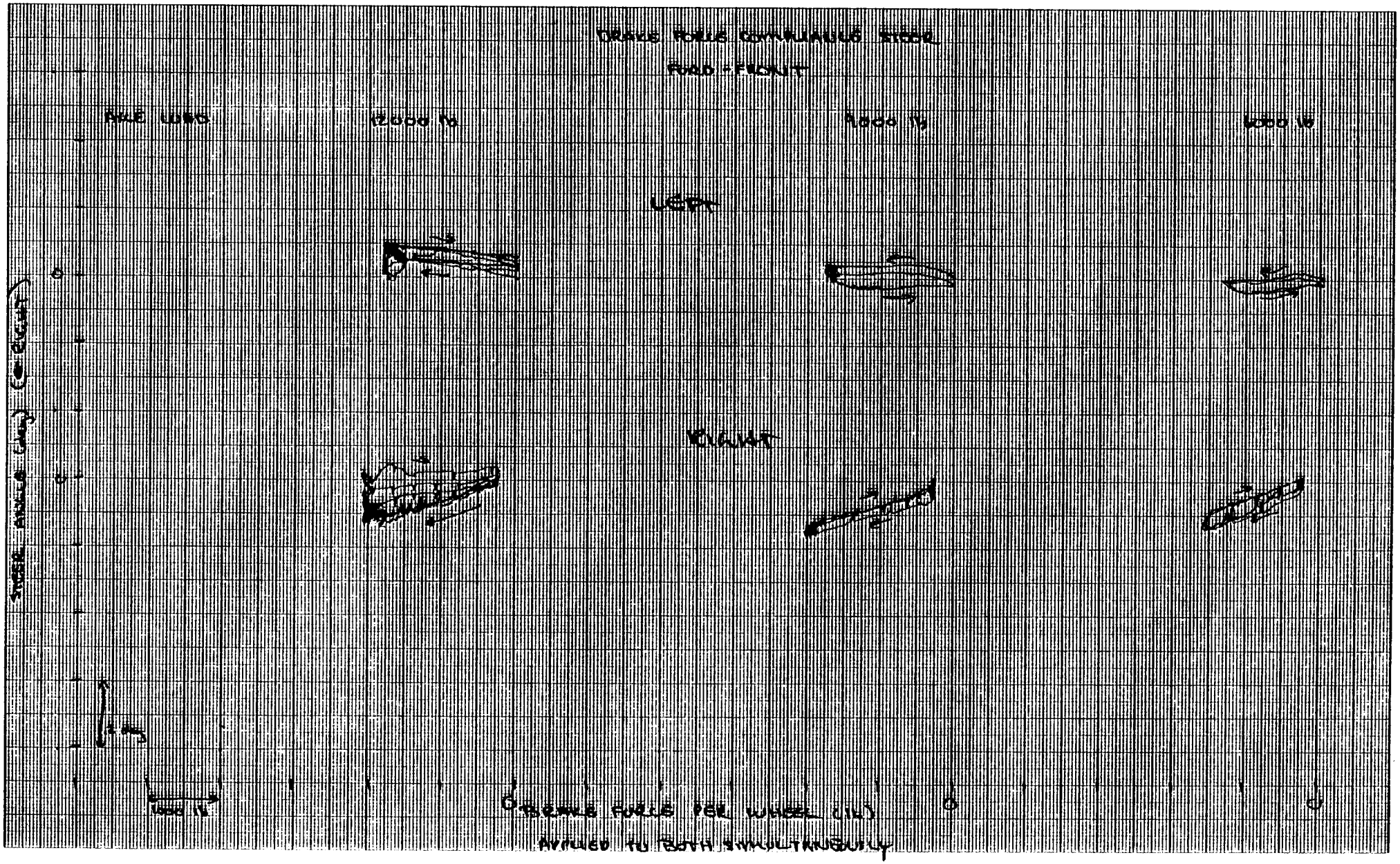
ALUMINUM MANGANESE ALLOY WIRE, 0.040 IN. DIA.
CAPACITOR DISCHARGE THROUGH WIRE
STRESS, KILOPOUNDS PER SQUARE INCH
STRAIN, PERCENT
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390

Lateral Force per wheel (lb) (← right)
Applied to both sides simultaneously
Lateral Force per wheel (lb)
Applied to front wheels only
Rubber
Steel
Lateral Force per wheel (lb)
Applied to front wheels only
Rubber
Steel
Lateral Force per wheel (lb)
Applied to both sides simultaneously



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Suspension: Reyco Taper Leaf Front

Ford CL9000

		Susp Load 12000	10000	8000
Vertical Rate (lb/in)		1000	1100	1100
Coulomb Friction (lb)		300	300	250
ROLL RATE (in-lb/deg)	F	36K	28K	28K
	R			
ROLL CENTER HT (in below top of frame)	F		NA	
	R			
ROLL STEER (DEG / DEG)	F		NA	
	R			
ALIGNING MOMENT COMPLIANCE STEER (deg/in lb)	F	NA	7.0×10^{-4}	NA
	R	NA	7.0×10^{-4}	NA
LATERAL FORCE COMPLIANCE (deg/lb)	F		NA	
	R			
INTERAXLE LOAD TRANSFER (BRAKING) (lb/lb)				

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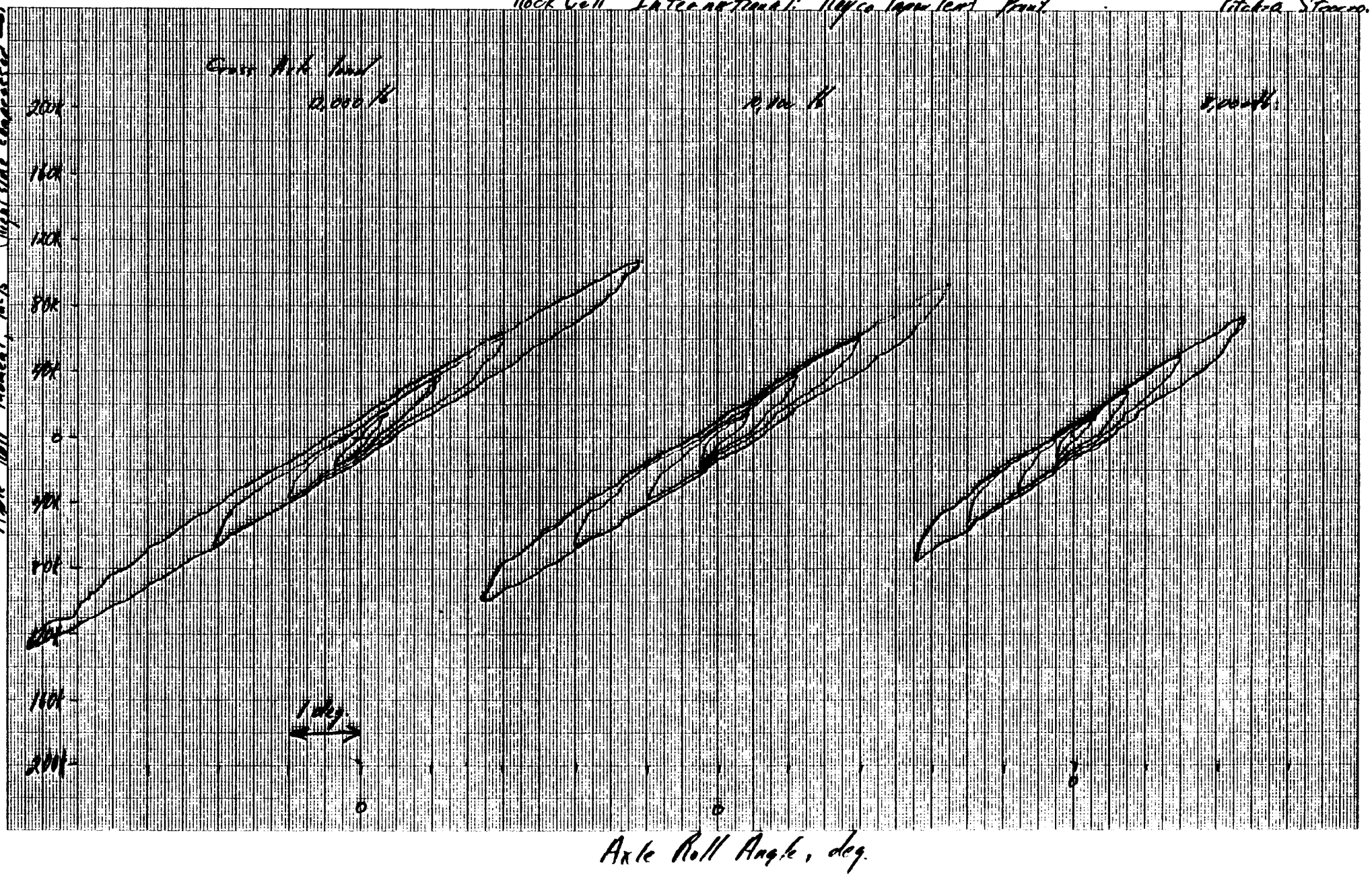

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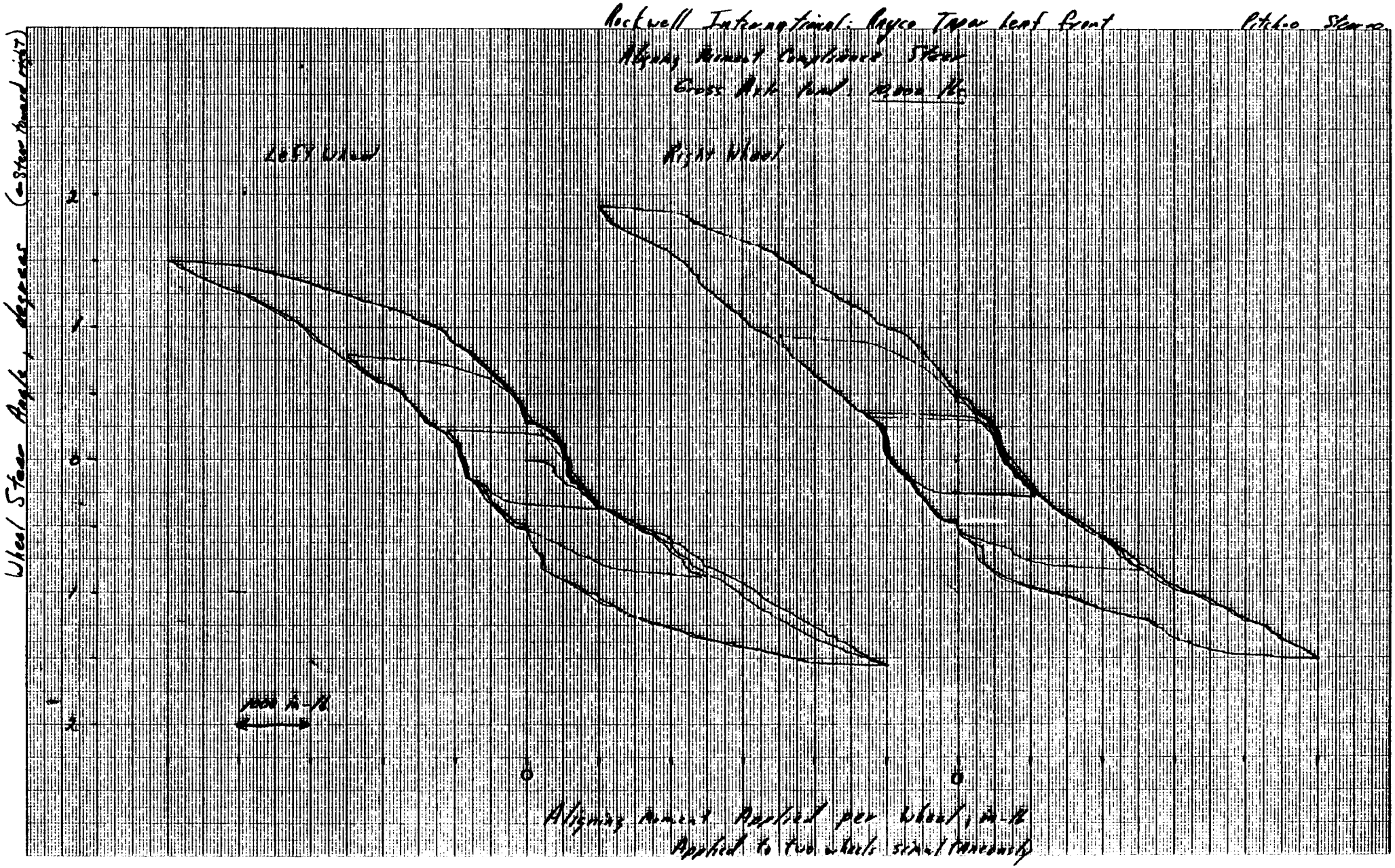

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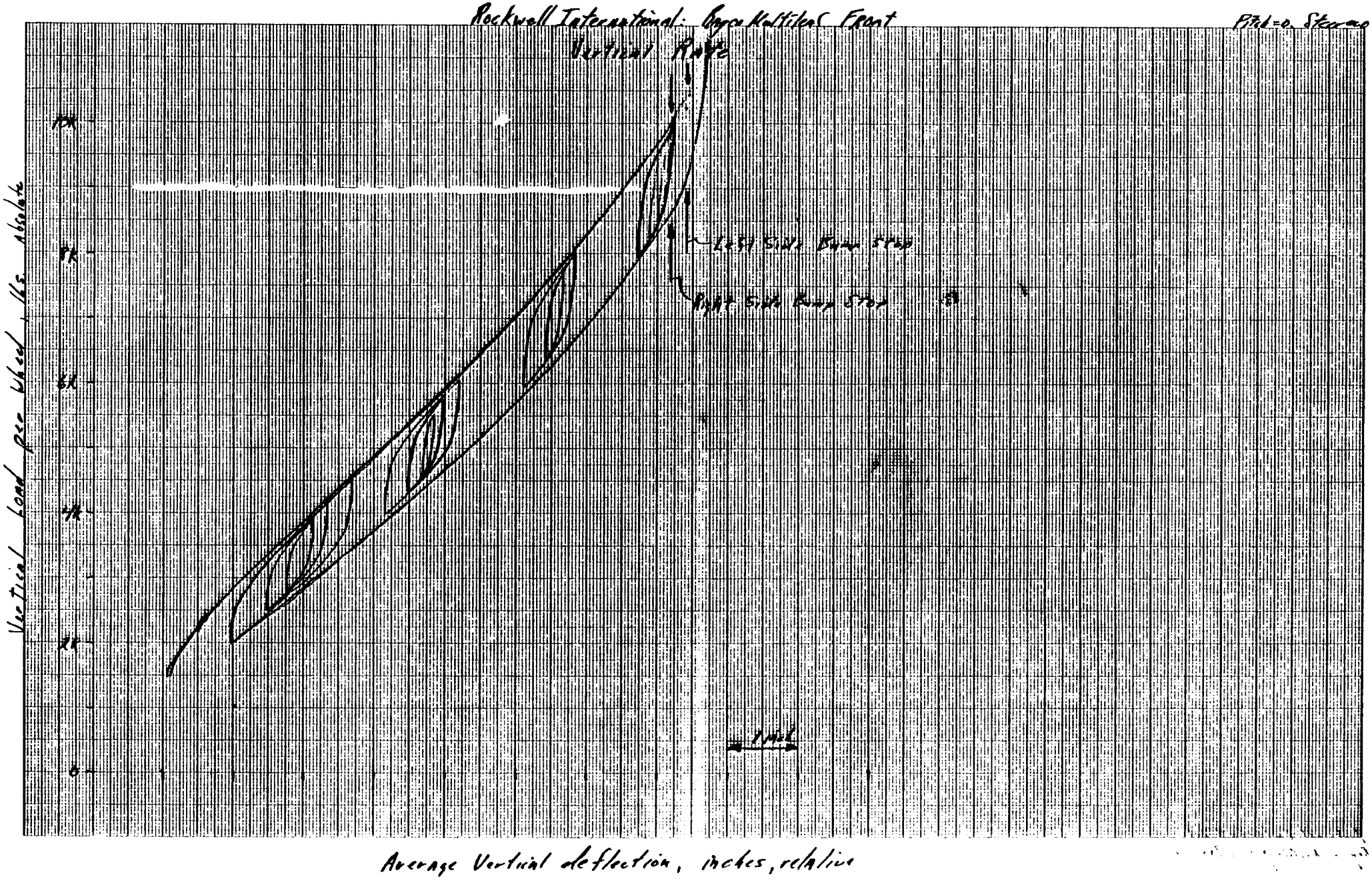
Suspension: Reyco Multileaf Front
Ford CL9000

		Susp Load 12000	10000	8000
Vertical Rate (lb/in)		1100	1000	1000
Coulomb Friction (lb)		625	600	550
ROLL RATE (in-lb/deg)	F	35K	24K	24K
	R			
ROLL CENTER HT (in below top of frame)	F		NA	
	R			
ROLL STEER (DEG / DEG)	L	.1	.11	.13
	R	.17	.16	.16
ALIGNING MOMENT COMPLIANCE STEER (deg/in lb)	F		NA	
	R			
LATERAL FORCE COMPLIANCE (deg/lb)	F		NA	
	R			
INTERAXLE LOAD TRANSFER (BRAKING) (lb/lb)				


Rockwell International: Cargo Military Front
Vertical Rate
Left Side Bump Stop
Right Side Bump Stop
Vertical Load per Wheel, lbs. Absolute
Average Vertical deflection, inches, relative

Rockwell International: Rocky Mountain Metallurgy Group

Over the Hill Mine

Rte. 40 West of Rte. 191

Vernal, Utah

Rte. 40 East of Rte. 191

Utah

Rte. 40

Vernal

Rte. 191

Duchesne

Rte. 40

Roosevelt

Rte. 40

Myton

Rte. 40

Duchesne

Rte. 40

Price

Rte. 40

Helper

Rte. 40

Wellington

Rockwell International Aerospace Multilateral Grant
Full Stop
Pitch-Up Steering
Steer Angle, degrees
Roll Angle, degrees
Left
Right
Left
Right
Left
Right

Suspension: IH Single

		Susp Load (lb) 19000	14250	9500
Vertical Rate (lb/in)		4400	3400	2000
Coulomb Friction (lb)		1250	1175	900
ROLL RATE (in-lb/deg)	F	92K	80K	50K
	R			
ROLL CENTER HT (in below top of hub)	F		NA	
	R			
ROLL STEER (DEG / DEG)	F	nil	nil	.05
	R			
ALIGNING MOMENT COMPLIANCE STEER (deg/in lb)	F	5.4×10^{-5}	6.3×10^{-5}	7.1×10^{-5}
	R			
LATERAL FORCE COMPLIANCE (deg/lb)	F	3.1×10^{-4}	4.3×10^{-4}	nil
	R			
INTERAXLE LOAD TRANSFER (BRAKE) (lb/lb)			NA	

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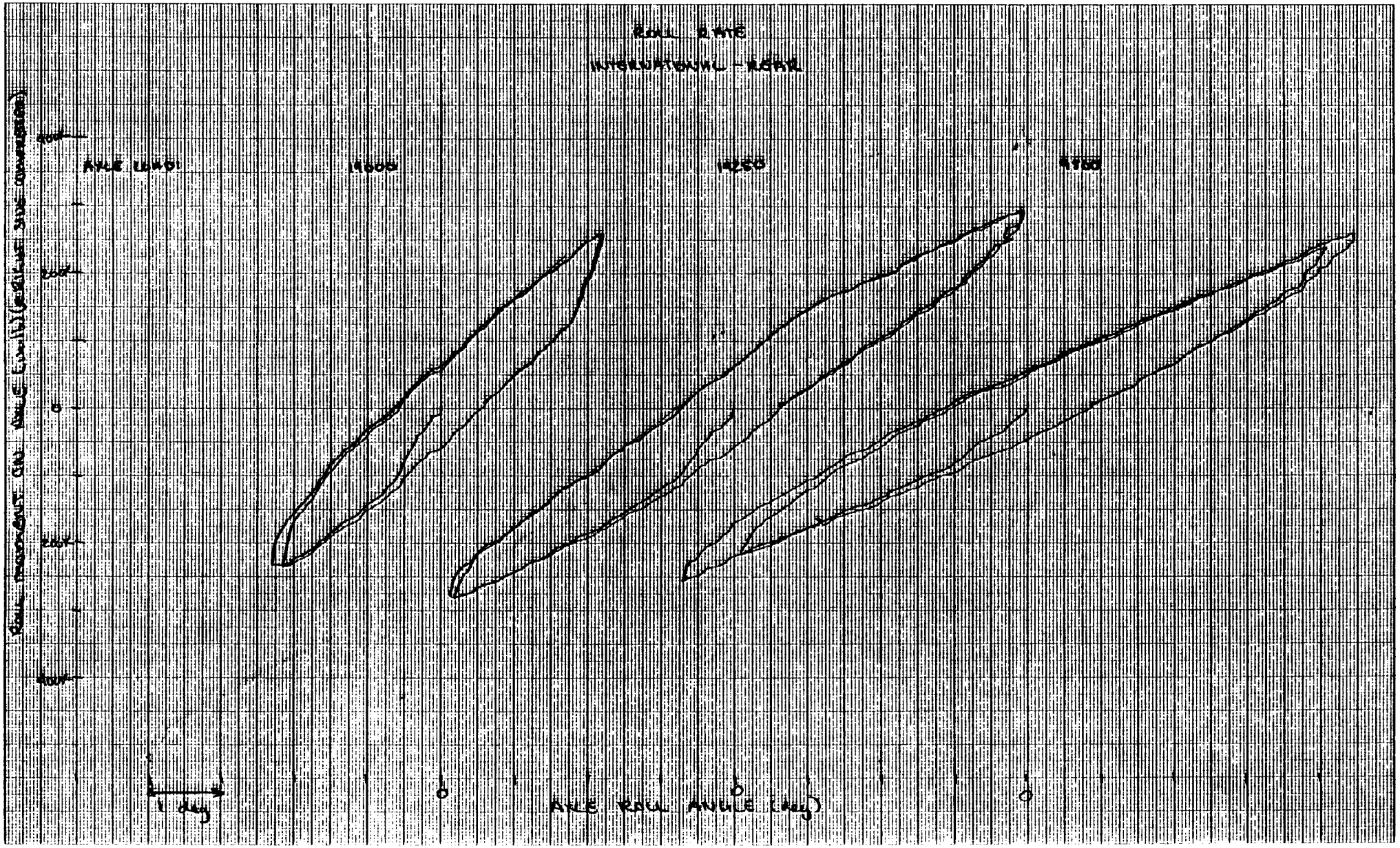

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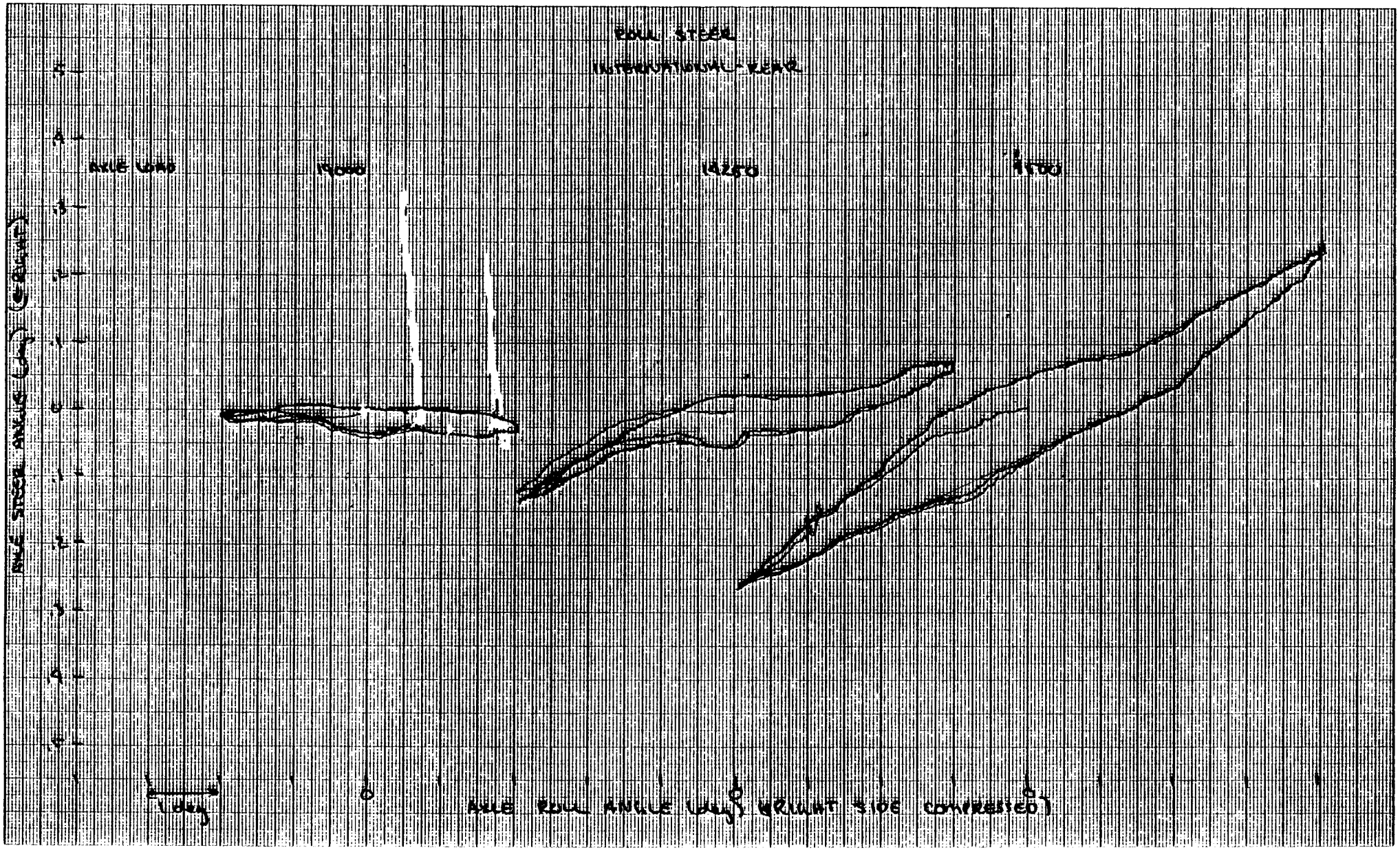

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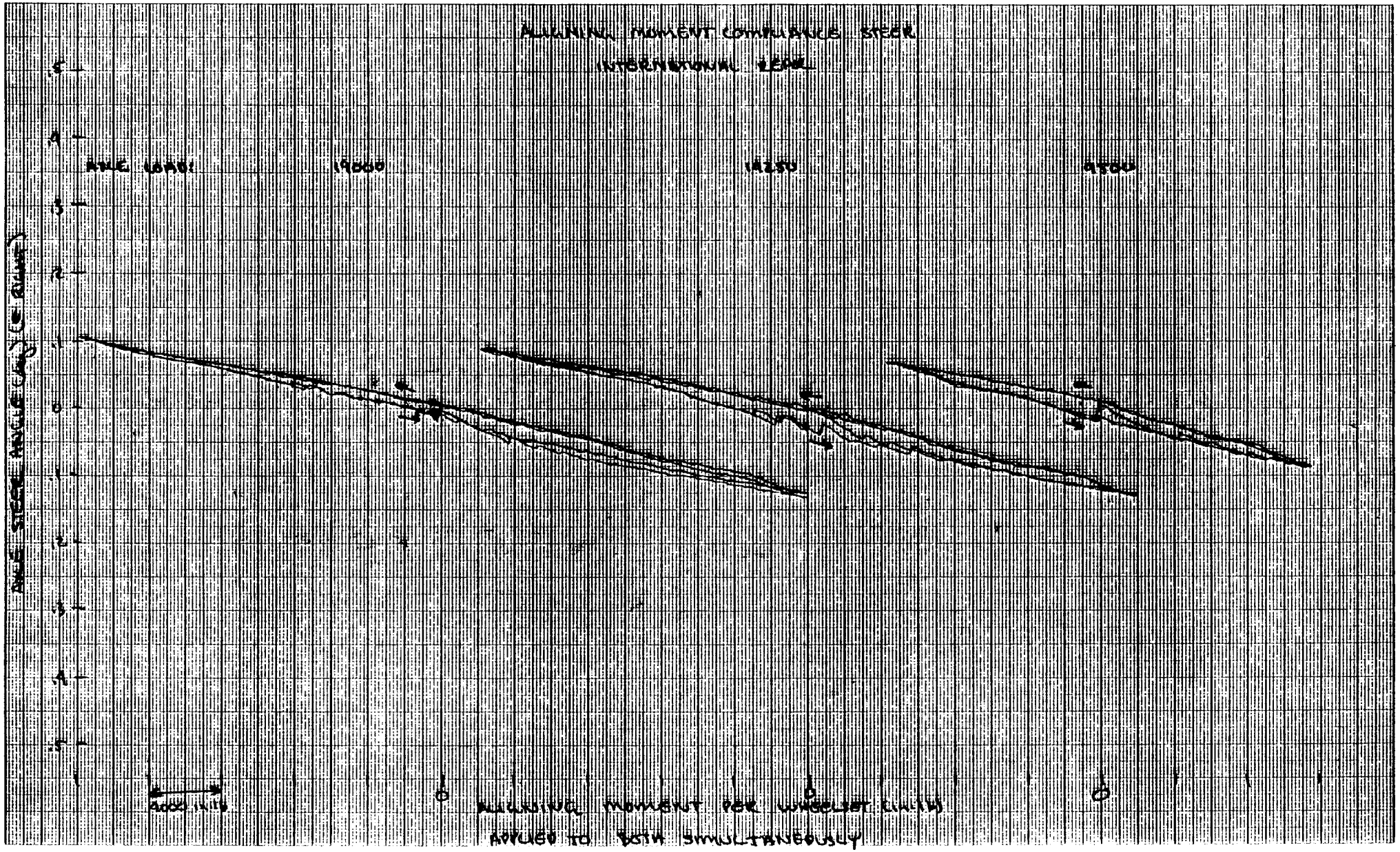

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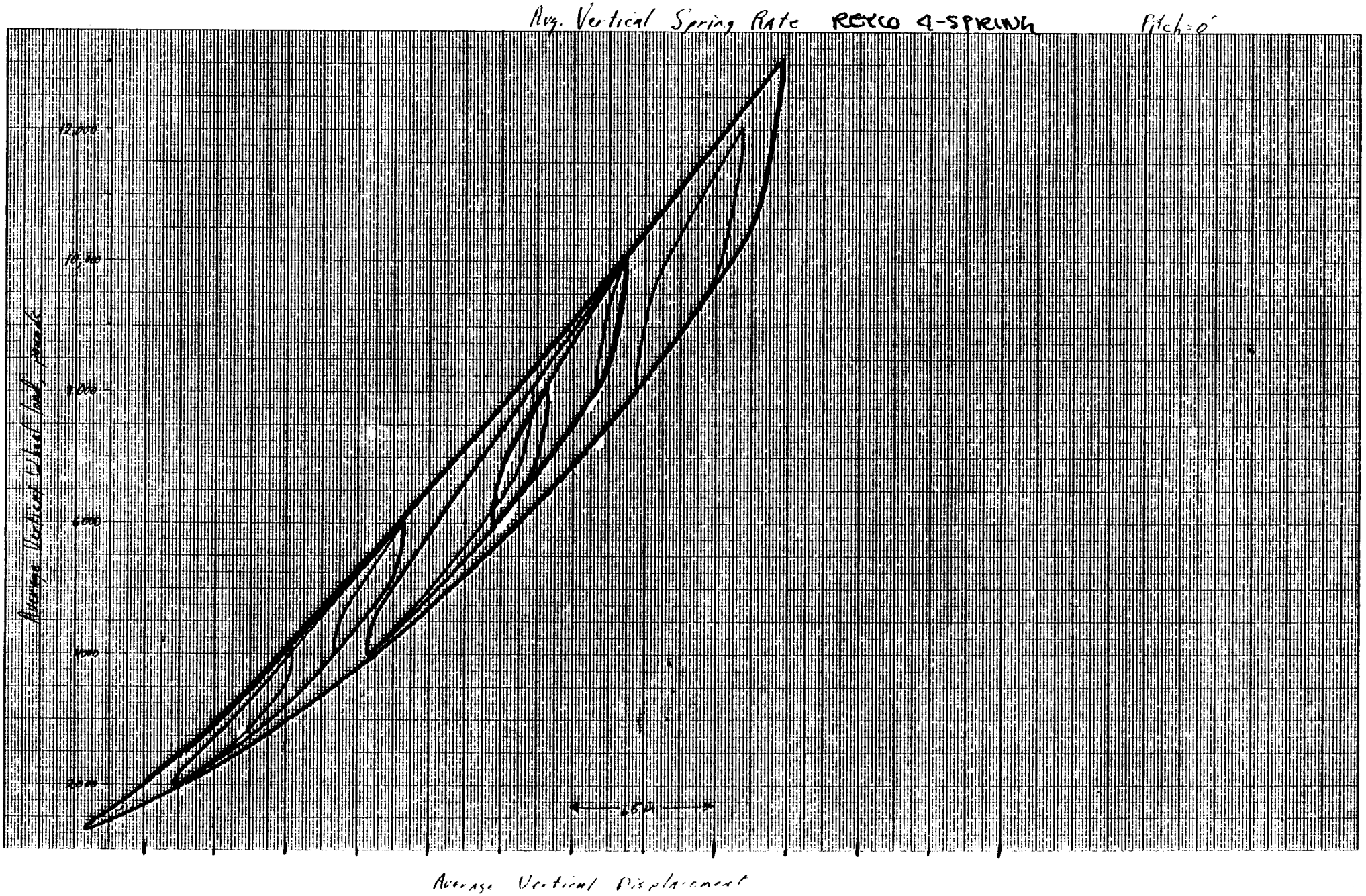
Angle of Attack, α, (degrees)
Lift Coefficient, C_L
Drag Coefficient, C_D
Pitching Moment Coefficient, C_m
Lateral Force Coefficient, C_Y
Yawing Moment Coefficient, C_n
Rolling Moment Coefficient, C_l
Lateral Force per Unit Dynamic Pressure, C_Y/q (ft²/deg)
Rolling Moment per Unit Dynamic Pressure, C_l/q (ft²/deg)
Yawing Moment per Unit Dynamic Pressure, C_n/q (ft²/deg)
Longitudinal Stability Derivative, C_{m_α} (per deg)
Directional Stability Derivative, C_{n_β} (per deg)
Lateral Stability Derivative, C_{l_β} (per deg)
Lateral Control Derivative, $C_{l_{\delta_a}}$ (per deg)
Directional Control Derivative, $C_{n_{\delta_a}}$ (per deg)
Lateral Control Derivative, $C_{l_{\delta_r}}$ (per deg)
Directional Control Derivative, $C_{n_{\delta_r}}$ (per deg)
Lateral Control Derivative, $C_{Y_{\delta_r}}$ (per deg)
Lateral Control Derivative, $C_{Y_{\delta_a}}$ (per deg)
Longitudinal Control Derivative, $C_{m_{\delta_e}}$ (per deg)
Longitudinal Control Derivative, $C_{m_{\delta_f}}$ (per deg)
Longitudinal Control Derivative, $C_{m_{\delta_s}}$ (per deg)
Longitudinal Control Derivative, $C_{m_{\delta_t}}$ (per deg)
Longitudinal Control Derivative, $C_{m_{\delta_{tab}}}$ (per deg)
Longitudinal Control Derivative, $C_{m_{\delta_{trim}}}$ (per deg)
Longitudinal Control Derivative, $C_{m_{\delta_{elev}}}$ (per deg)
Longitudinal Control Derivative, $C_{m_{\delta_{stab}}}$ (per deg)
Longitudinal Control Derivative, $C_{m_{\delta_{canard}}}$ (per deg)
Longitudinal Control Derivative, $C_{m_{\delta_{flap}}}$ (per deg)
Longitudinal Control Derivative, $C_{m_{\delta_{slat}}}$ (per deg)
Longitudinal Control Derivative, $C_{m_{\delta_{spoiler}}}$ (per deg)
Longitudinal Control Derivative, $C_{m_{\delta_{aileron}}}$ (per deg)
Longitudinal Control Derivative, $C_{m_{\delta_{rudder}}}$ (per deg)
Longitudinal Control Derivative, $C_{m_{\delta_{elevator}

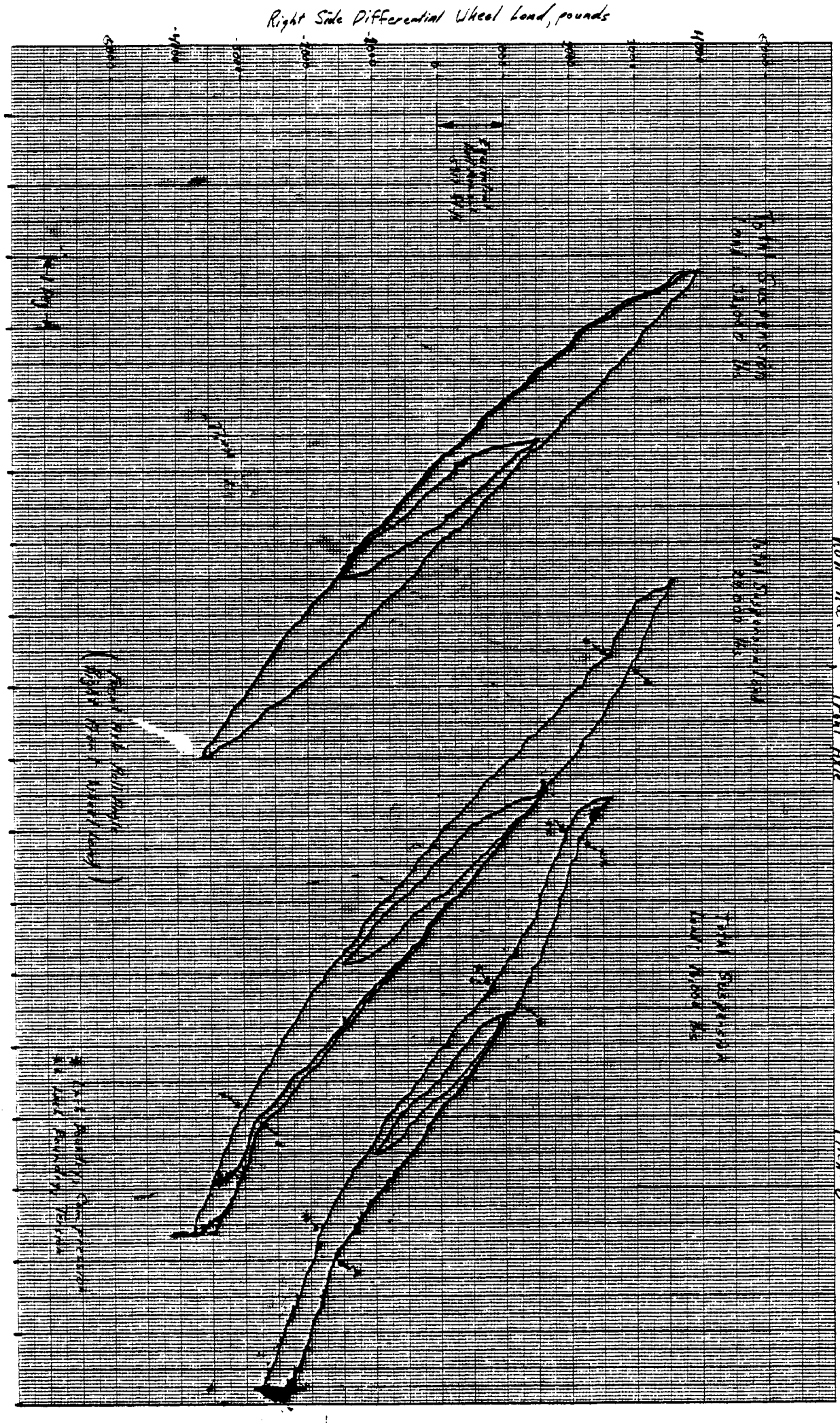
Suspension: Reyco 4-Spring #1
(From Ford)

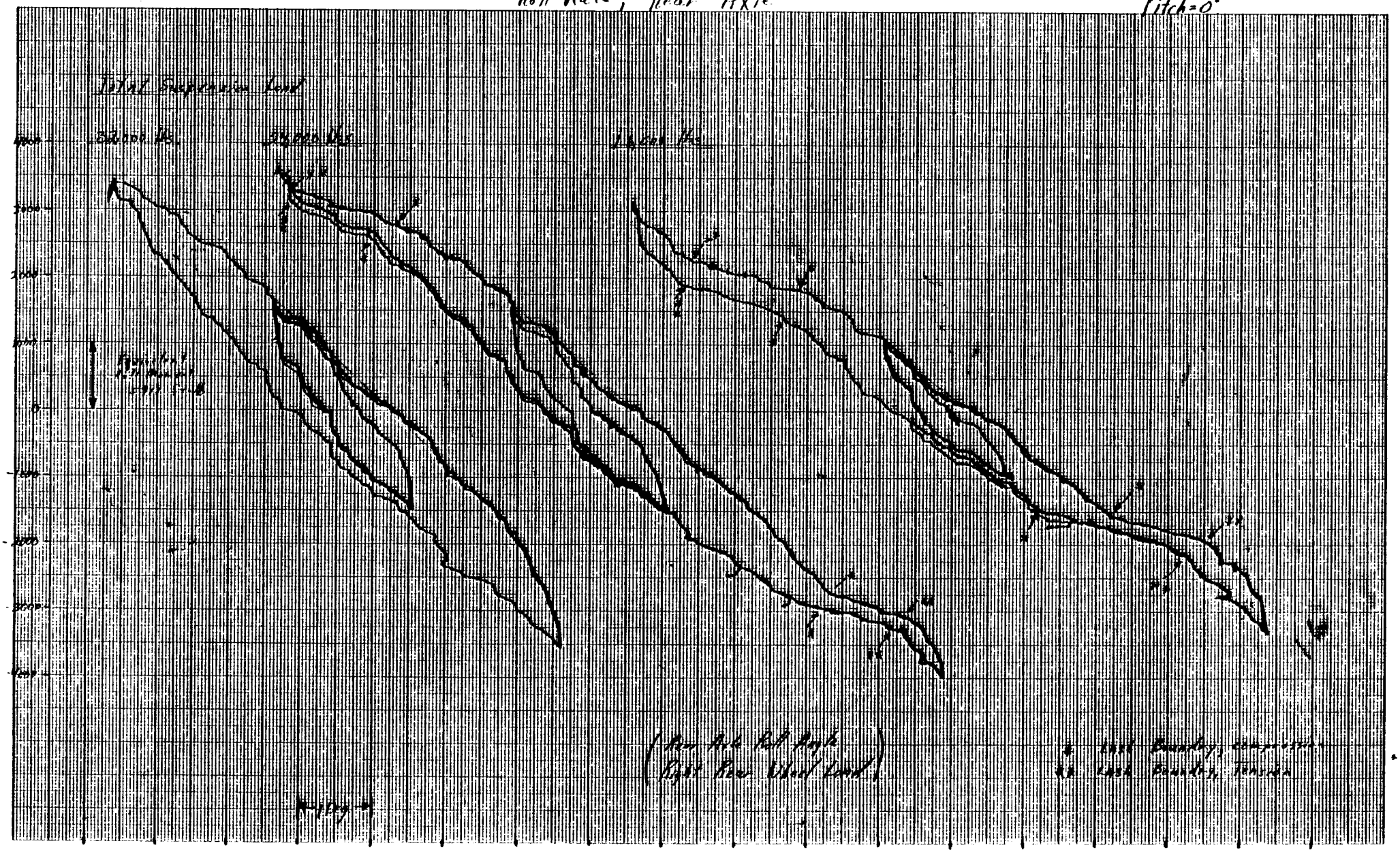
		Susp Load		
		32000	24000	16000
Vertical Rate (lb/in)		5200	4900	4500
Coulomb Friction (lb)		1050	875	550
ROLL RATE	F	78K	67.5K	57K
(in lb/deg)	R	74.5K	64K	50K
ROLL CENTER HT	F	11.6	12.2	12.5
(in below top of frame)	R	11.1	10.9	10.7
ROLL STEER	F	-.12	-.15	-.18
(DEG / DEG)	R	.09	0	-.0
ALIGNING MOMENT COMPLIANCE STEER	F	10^{-5}	1.1×10^{-5}	1.3×10^{-5}
(deg/in lb)	R	8×10^{-6}	8×10^{-6}	8×10^{-6}
LATERAL FORCE COMPLIANCE	F	4.5×10^{-5}	4.6×10^{-5}	5×10^{-5}
(deg/lb)	R		nil	
INTERAXLE LOAD TRANSFER (BRAKING)	L	.25	.33	.24
(lb/lb) + to rear	R	.3	.31	.28

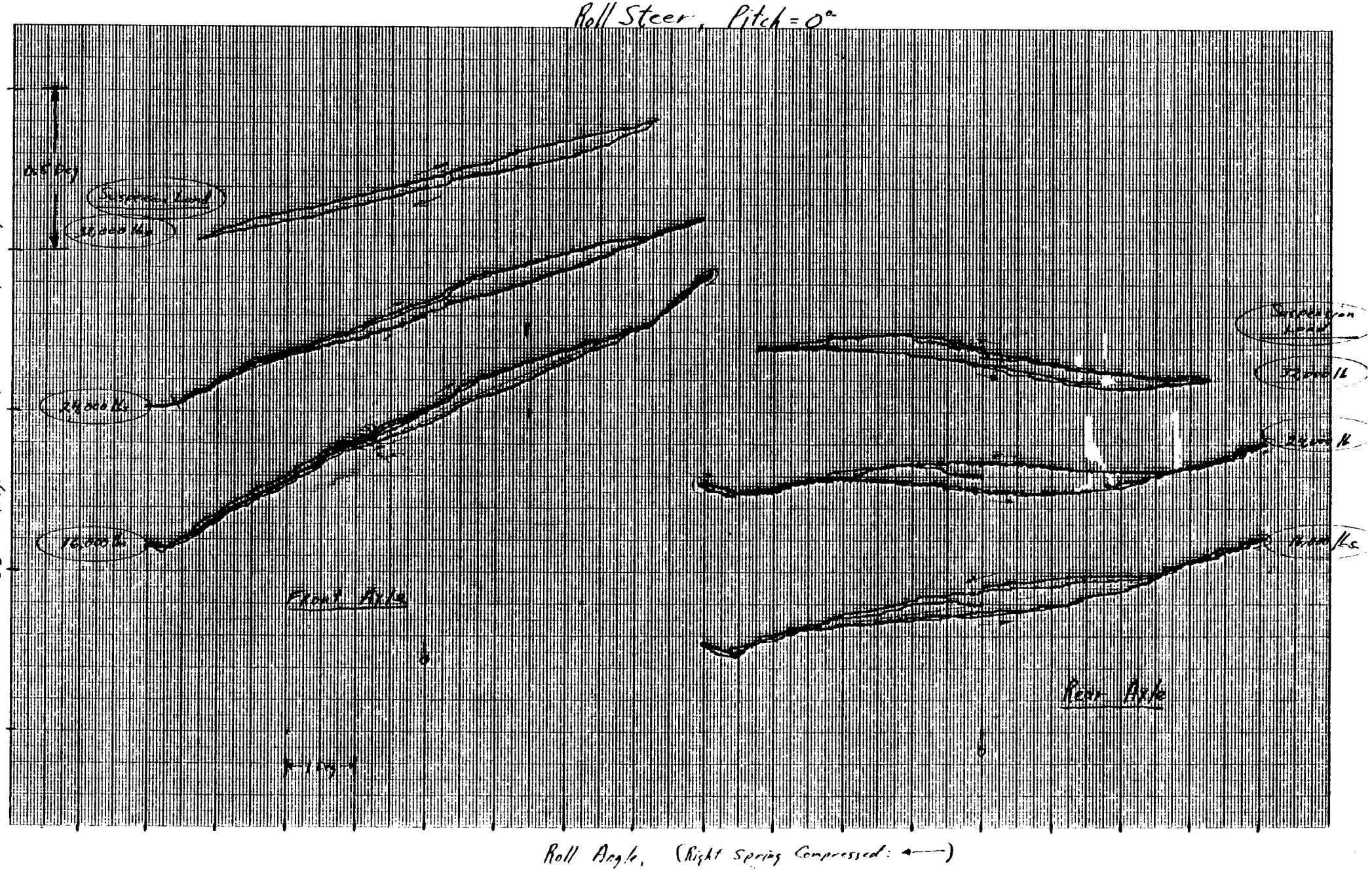
Pitch = 0°

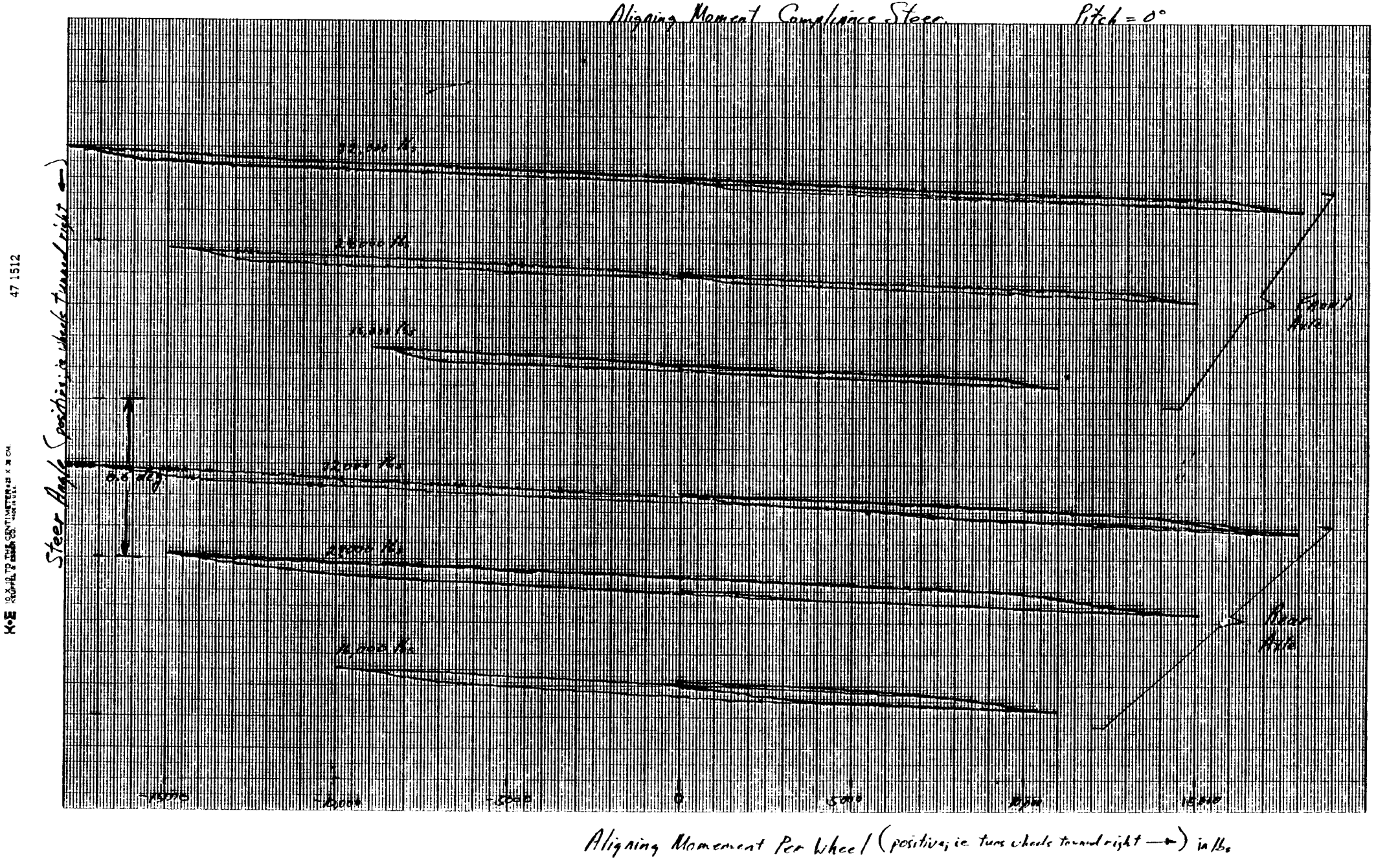


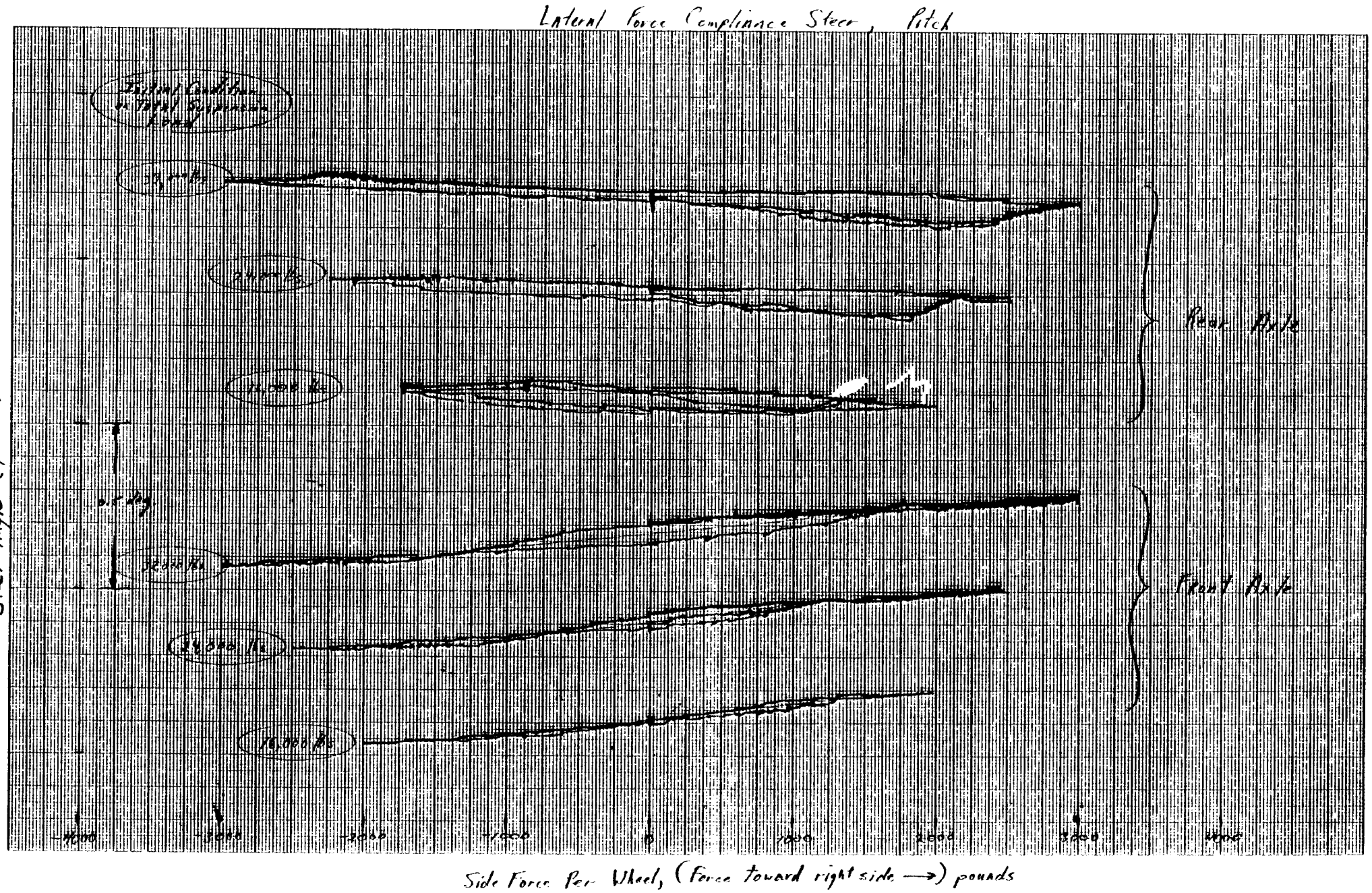
47 1512
K+E 10 X 10 TO THE CENTIMETER

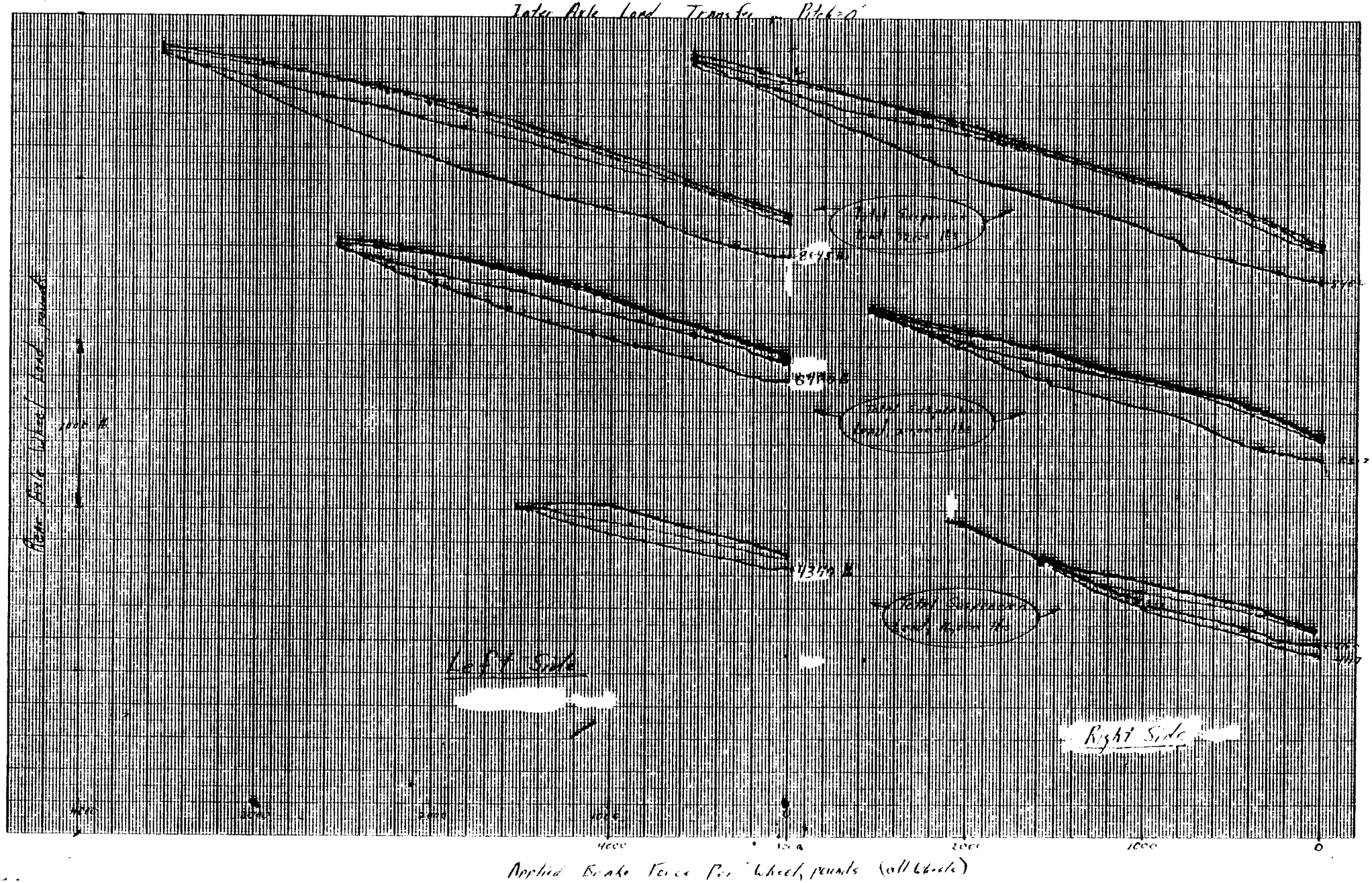

Right Side Differential Wheel Load, pounds
Roll Rate, Front Axle
Roll Axis


Roll Rate, Rear Axle
Pitch=0°
Total Suspension Load
Right Side Differential Wheel Load, pounds
Roll Angle
Rear Axle Roll Angle
Right Rear Wheel Load
47 1512

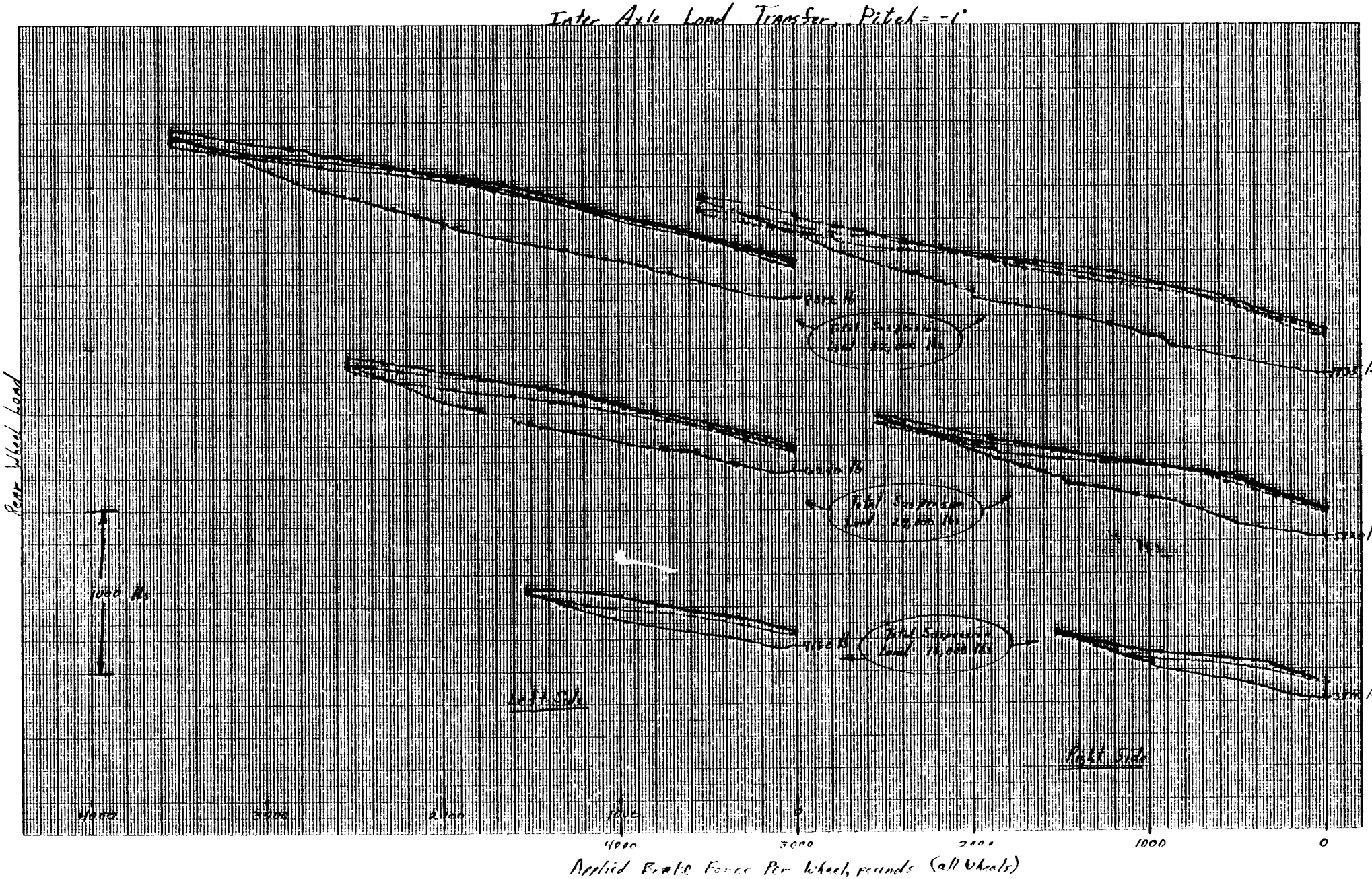

Roll Steer, Pitch = 0°
Steer Angle (Positive; Wheels turn right →)
0.5 Deg
Suspension Load
32,000 lbs
24,000 lbs
16,000 lbs
Front Axle
Suspension Load
32,000 lbs
24,000 lbs
16,000 lbs
Rear Axle
Roll Angle, (Right Spring Compressed: ←)
47 1512


Aligning Moment Compliance Steer. Pitch = 0°
Steer Angle (positive is wheels turned right ←)
0.5 deg
Steer Axis
Steer Axis
Aligning Moment Per Wheel (positive; ie turn wheels toward right →) in lbs
47 1512

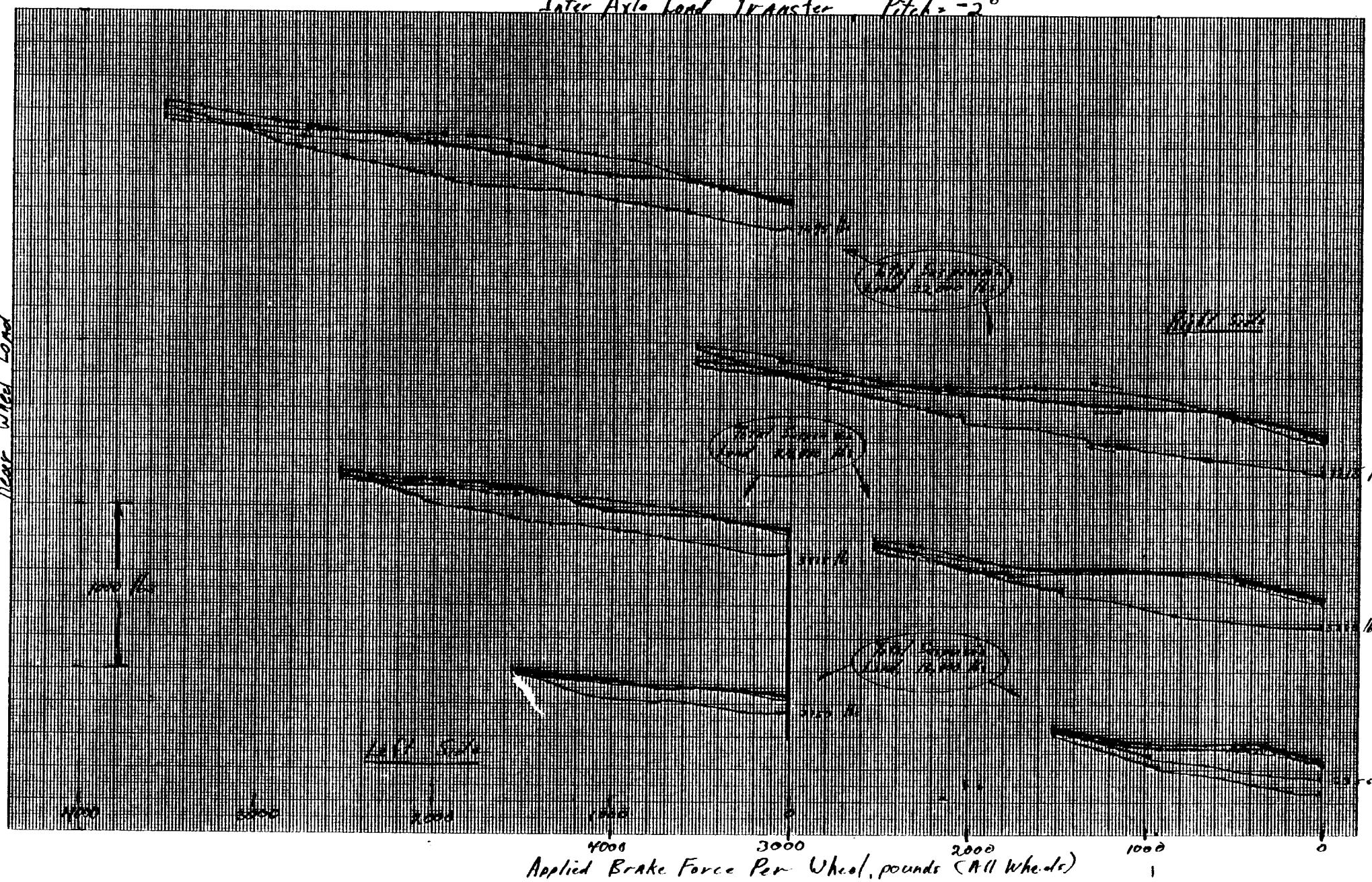

Lateral Force Compliance Steer, Pitch
Steer Angle (positive; in wheel forward right ⟶)
Rear Axle
Front Axle
Side Force Per Wheel, (Force toward right side ⟶) pounds



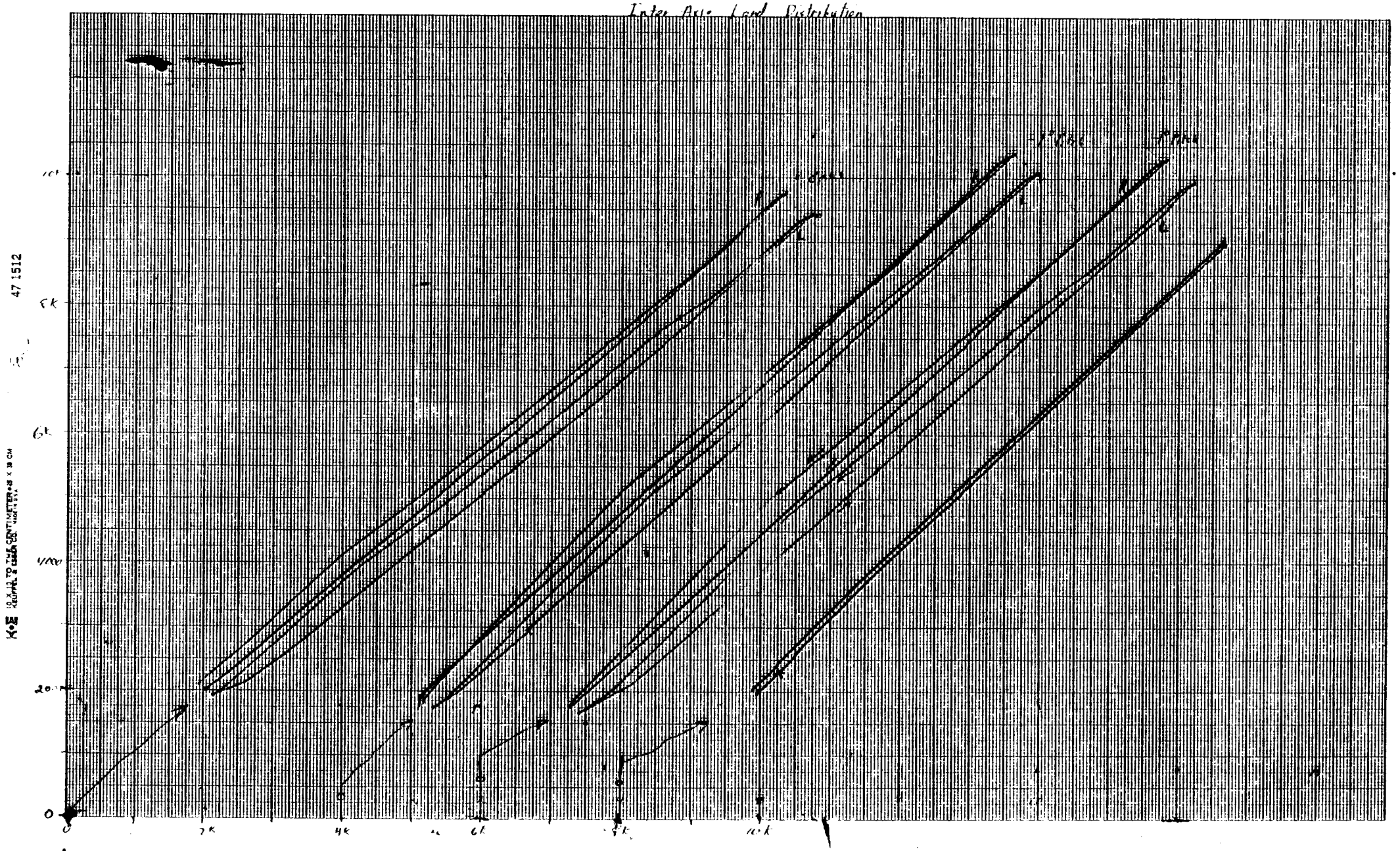
K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM. KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512


Rear Wheel Load
1000 lbs
Left Side
Right Side
4000
3000
2000
1000
0
Applied Brake Force Per Wheel, pounds (all wheels)

47 1512

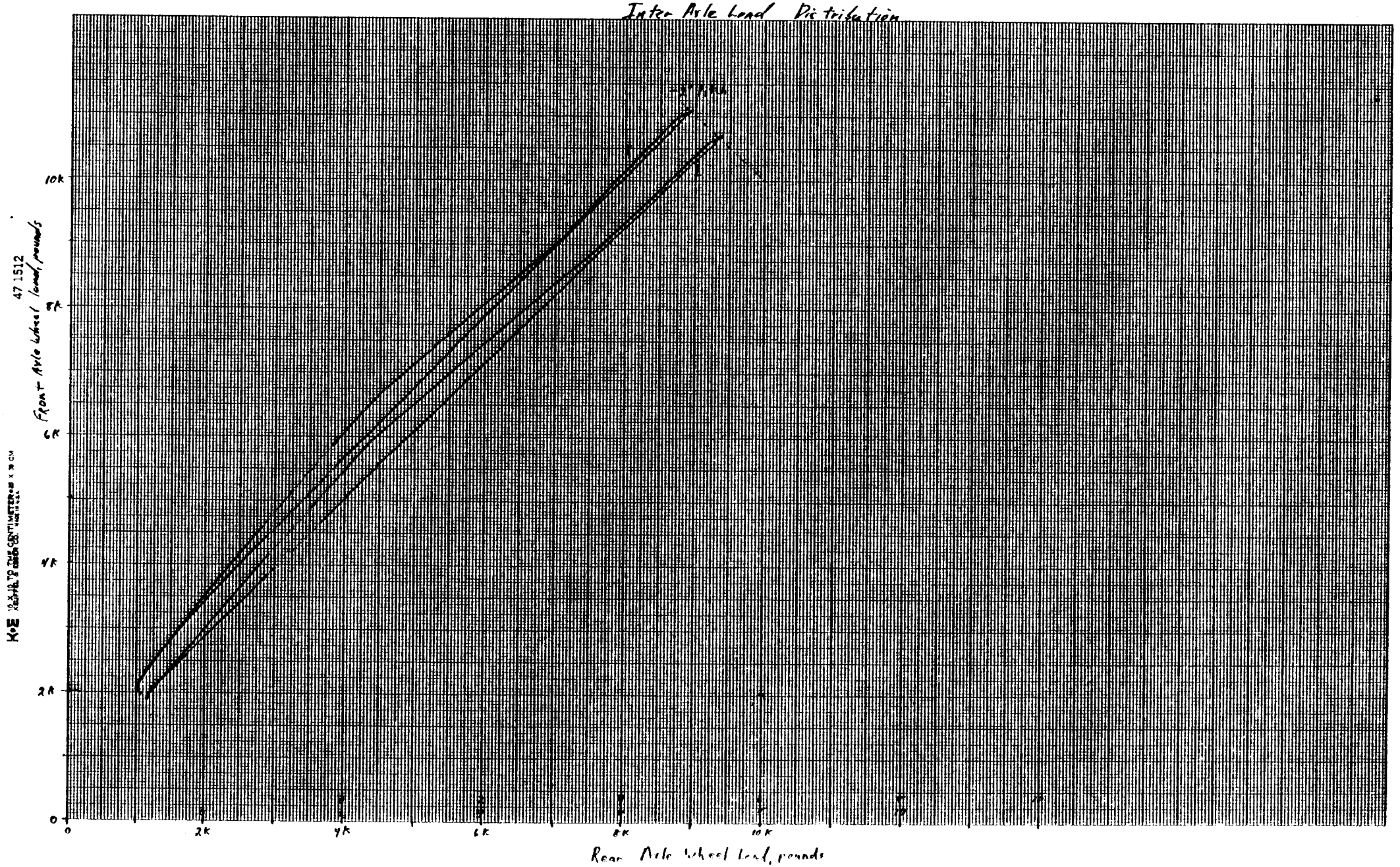

Inter Axle Load Transfer, Pitch = -2°
Rear Wheel Load
Left Scale
Right Scale
1000 lbs
4000
3000
2000
1000
0
Applied Brake Force Per Wheel, pounds (All Wheels)

Inter Axle Load Distribution



K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512

Inter Axle Load Distribution



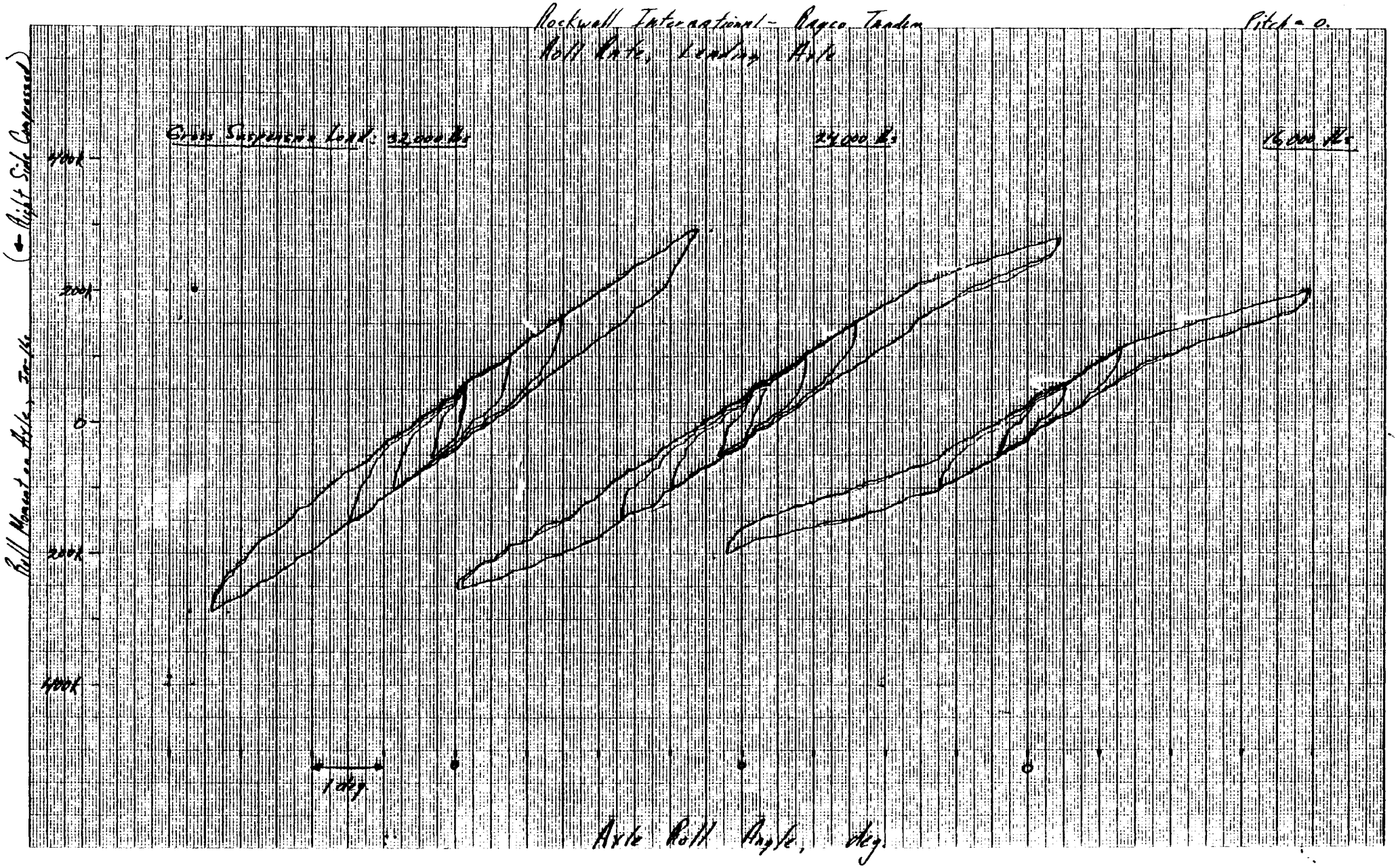
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512

Suspension: Reyco 4 spring #2
(from Rockwell)

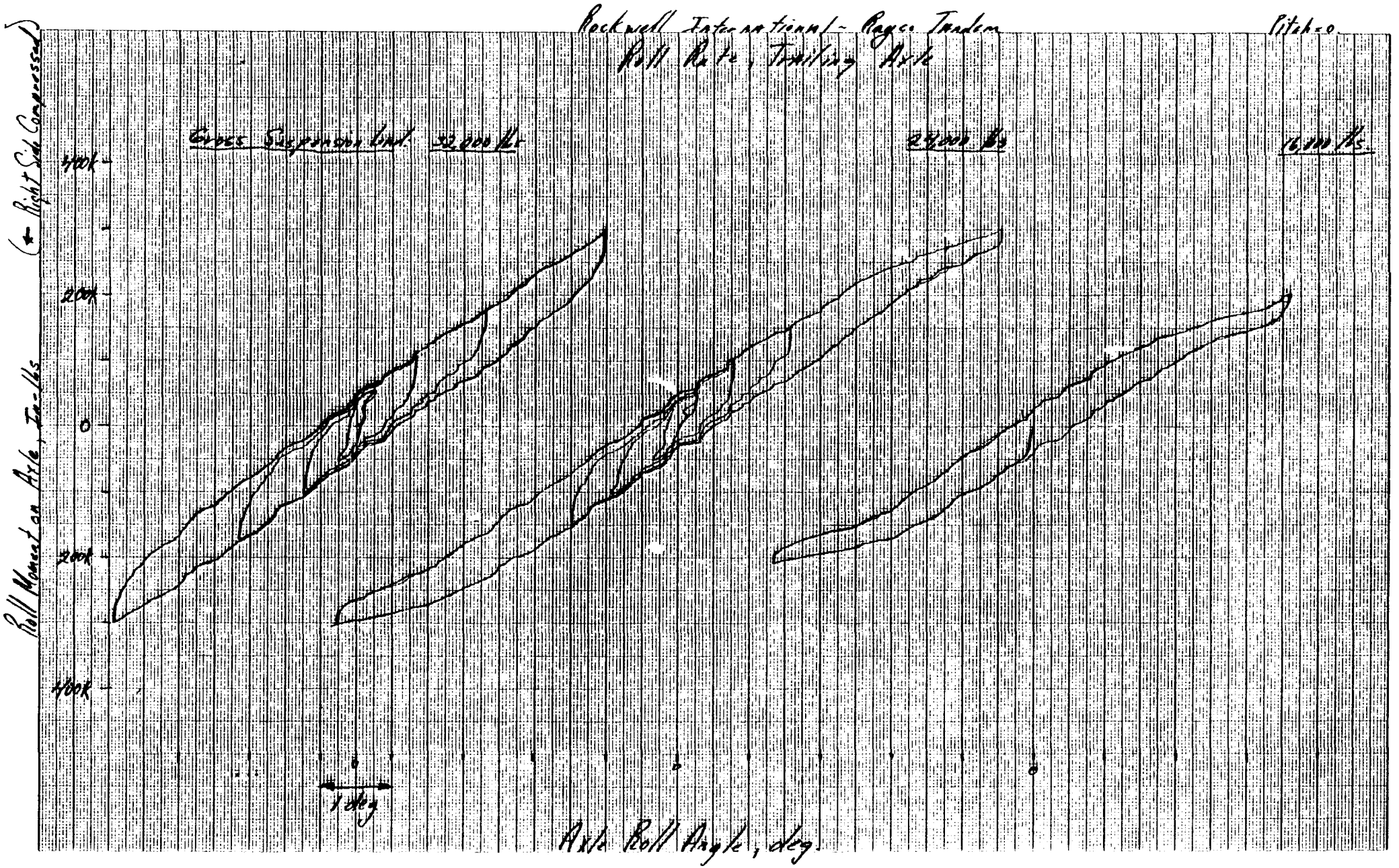
		Susp Load 32000	24000	16000
Vertical Rate (lb/in)		4600	4600	4600
Coulomb Friction (lb)		825	700	550
Roll Rate (in-lb/deg)	F	80K	75K	65K
	R	75K	72K	67K
Roll Center Ht (in below top of frame)	F	NA		
	R			
Roll Steer (deg/deg)	F	.02	-.01	-.04
	R	nil	-.005	-.01
Aligning Moment Compliance Steer (deg/in lb)	F	4.5×10^{-6}	5×10^{-6}	5×10^{-6}
	R	1×10^{-6}	1×10^{-6}	3.4×10^{-6}
Lateral Force Compliance (deg/lb)	F	2.2×10^{-5}	4.5×10^{-5}	7×10^{-5}
	R		nil	
Interaxle Load Transfer (Braking) (lb/lb) + to rear	L	.52	.56	.42
	R	.36	.38	.38

Pitch = 0

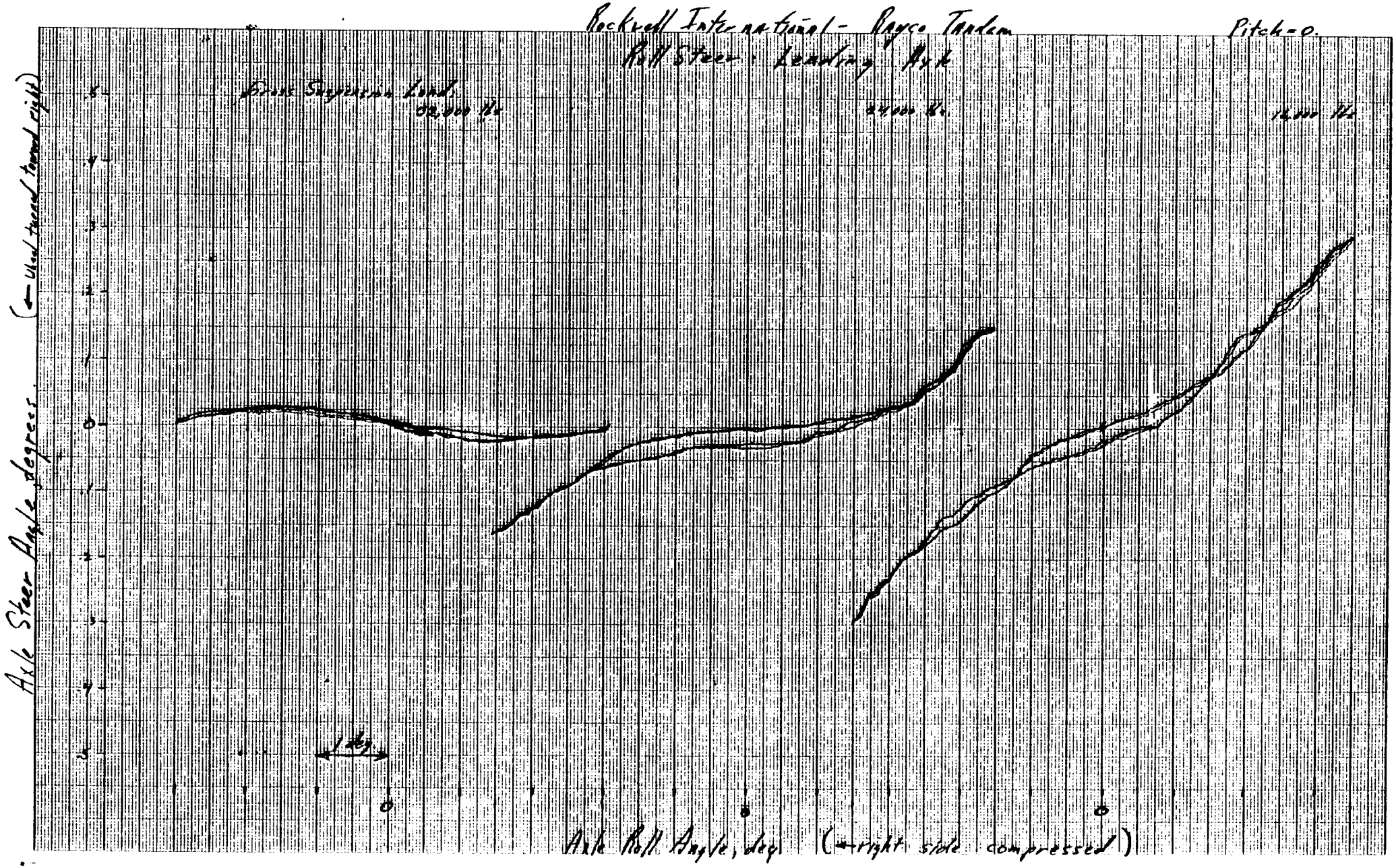
K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.



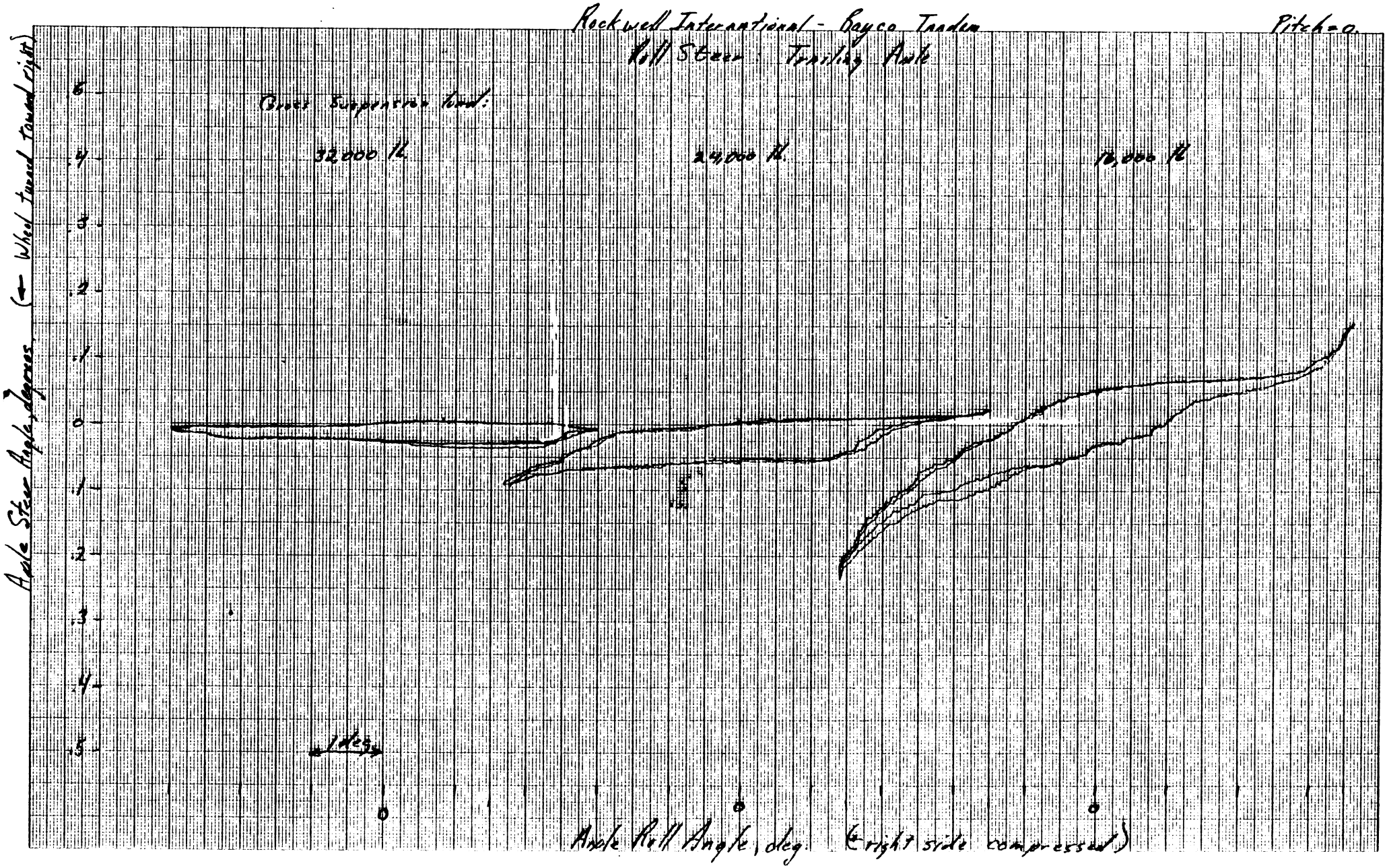
K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM. KEUFFEL & ESSER CO. MADE IN U.S.A. 47 1512



K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512

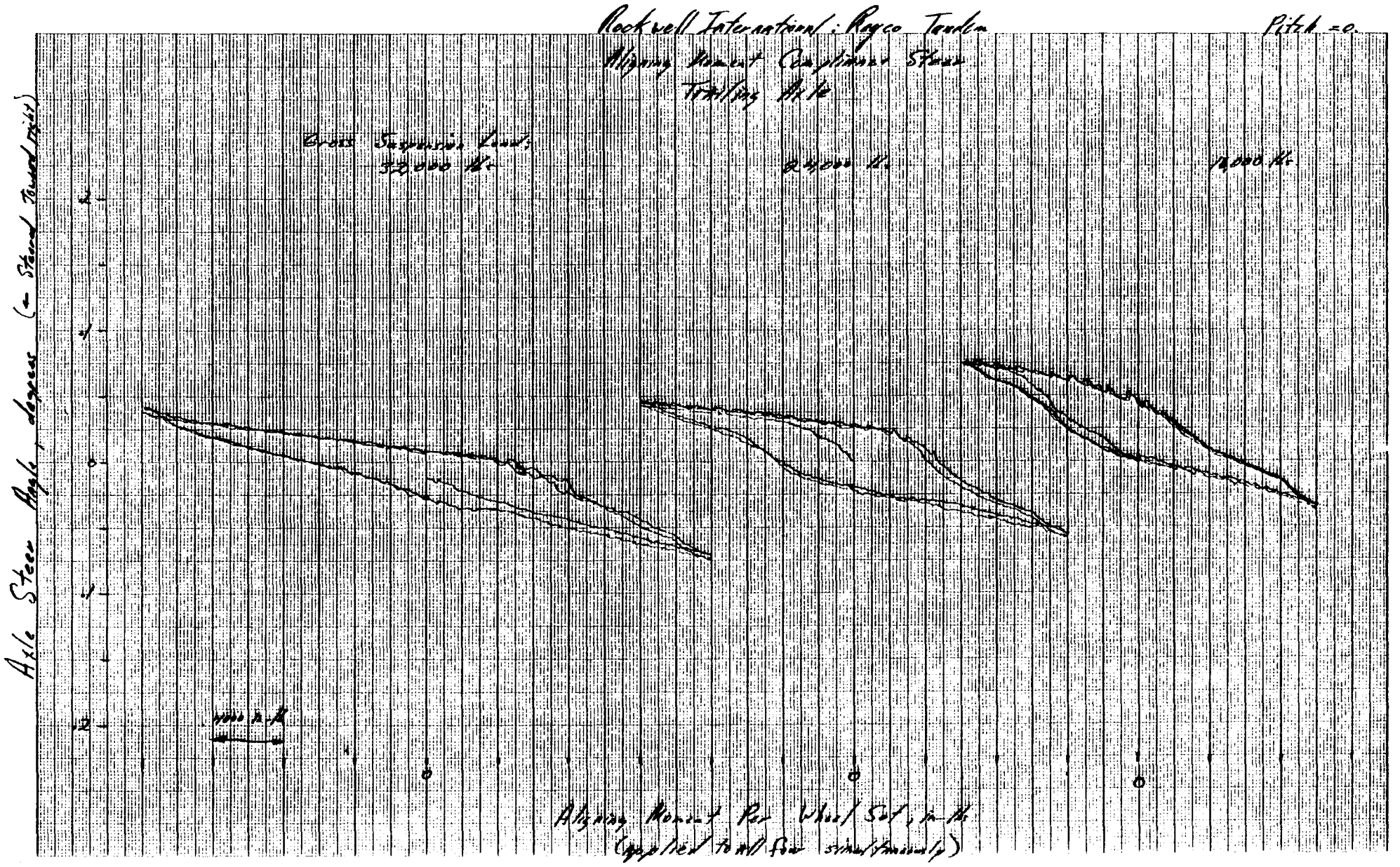


K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512



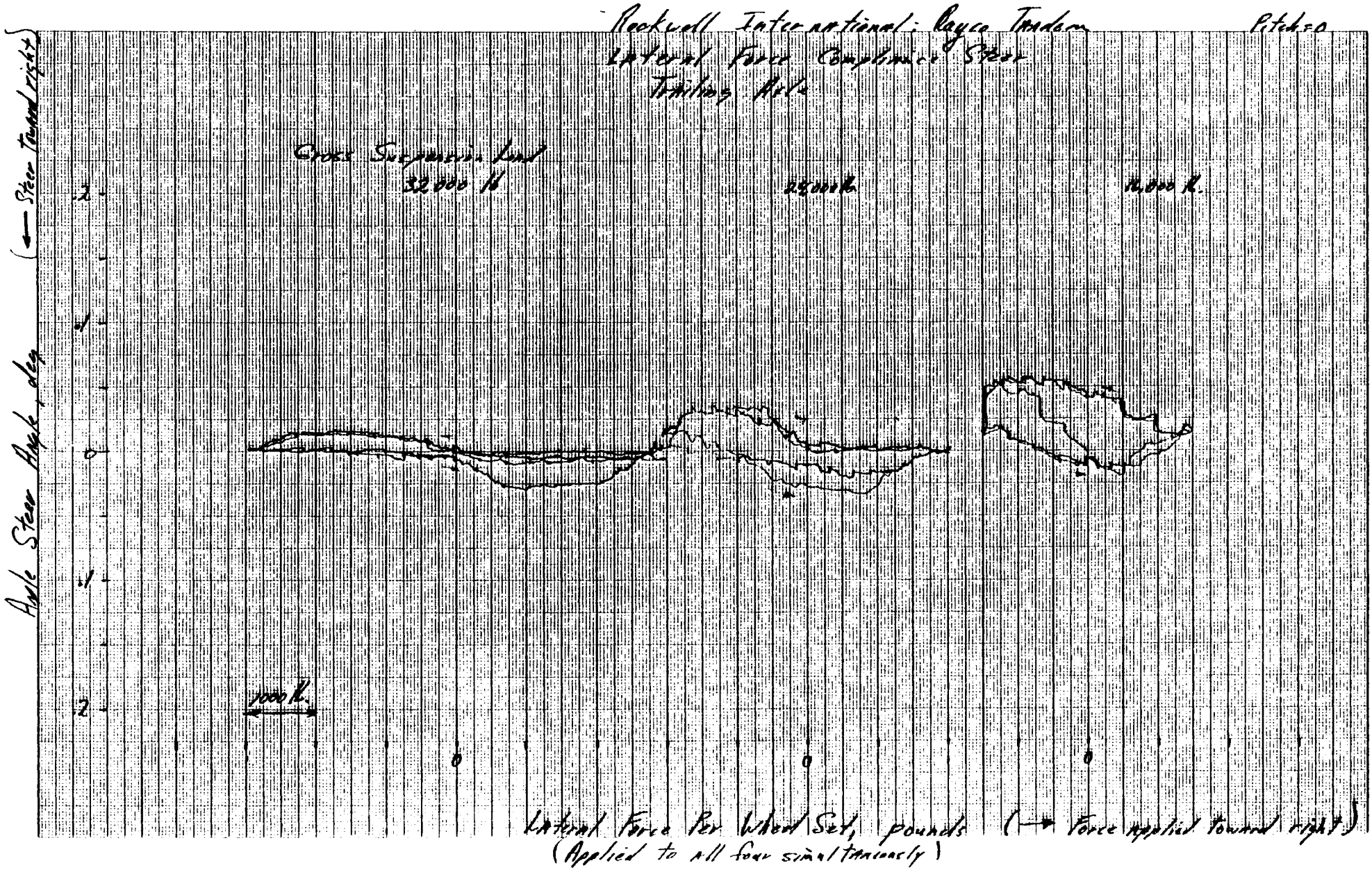
K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512

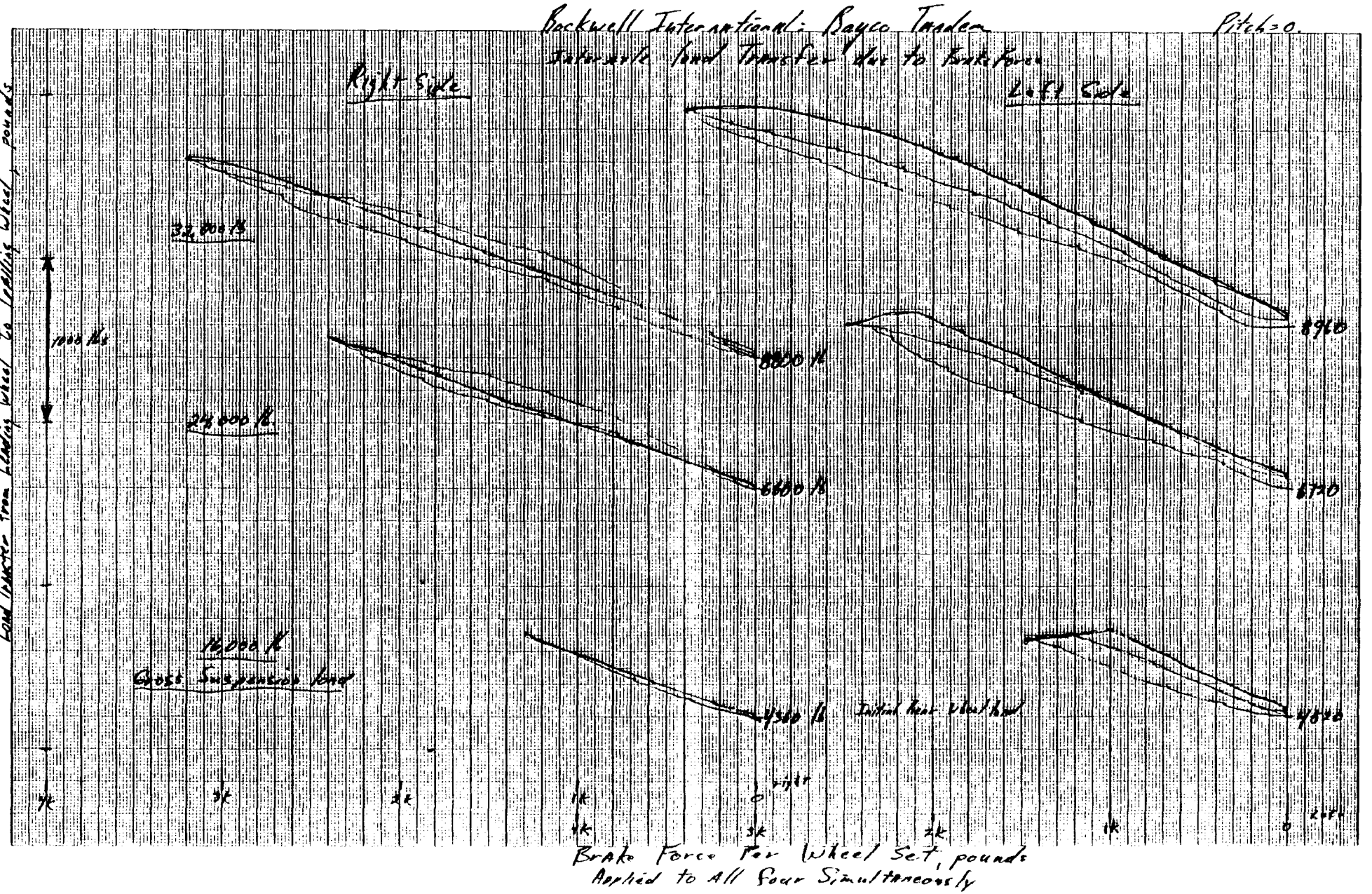
Bale Steer Angle, degs
Gas Stroud Tunnel
Rockwell International - Rye ca Tandem
Aspect Ratio 1.0
Aspect Ratio 1.5
Aspect Ratio 2.0
Aspect Ratio 2.5
Aspect Ratio 3.0
Aspect Ratio 3.5
Aspect Ratio 4.0
Aspect Ratio 4.5
Aspect Ratio 5.0
Aspect Ratio 5.5
Aspect Ratio 6.0
Aspect Ratio 6.5
Aspect Ratio 7.0
Aspect Ratio

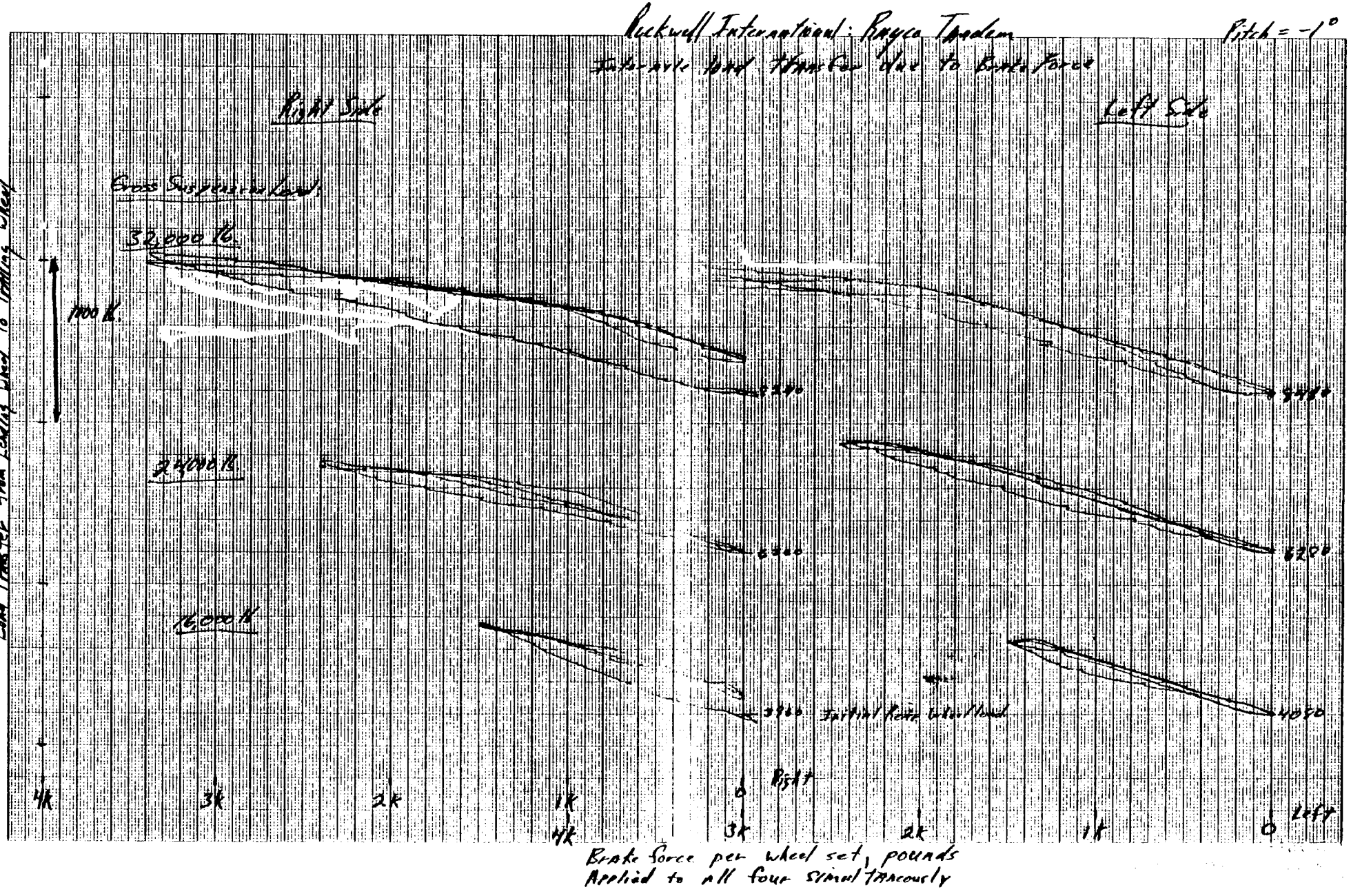


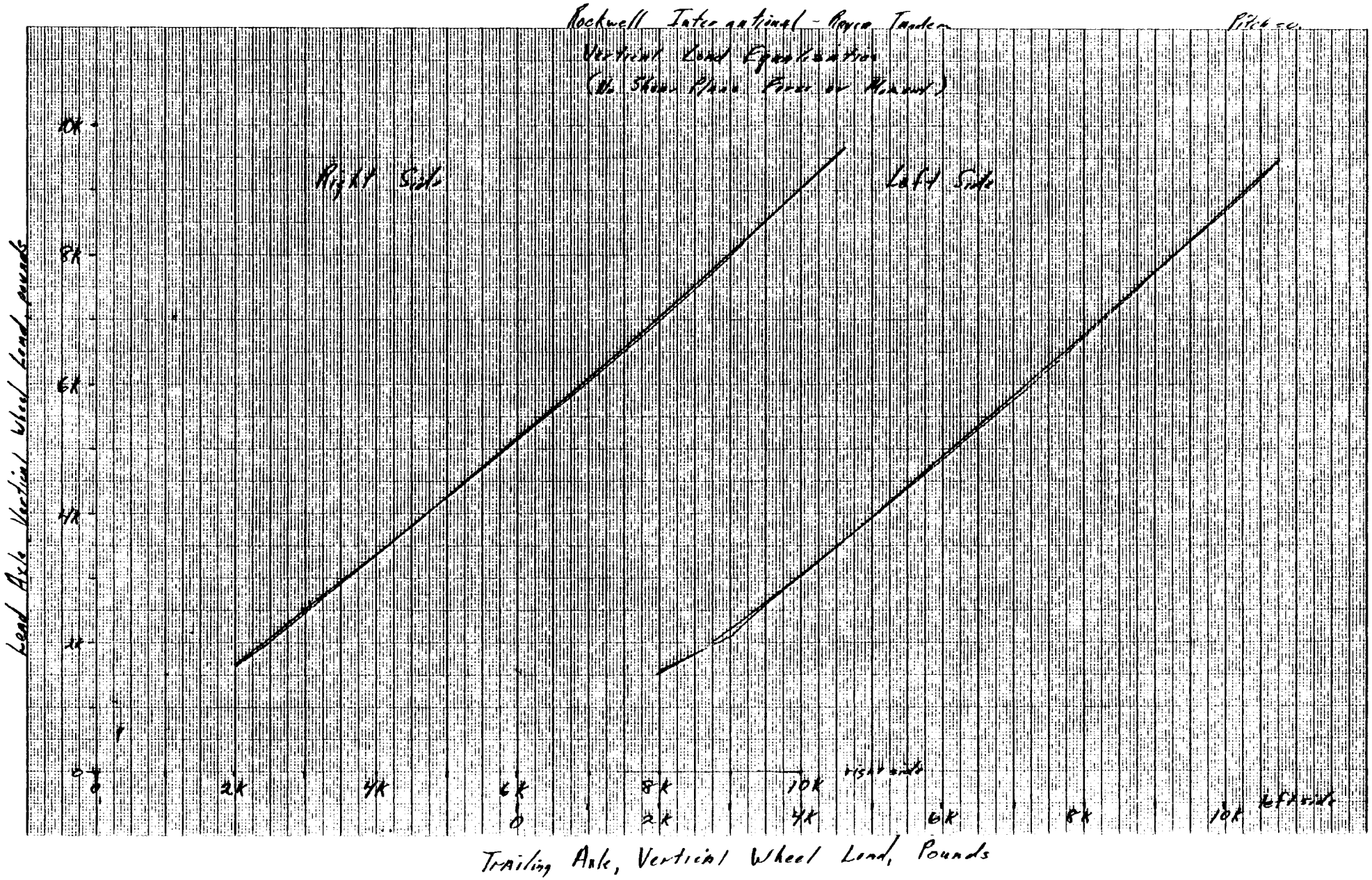
47 1512
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

Hale Stern Angle, deg.
(← Stern toward right)
-2
-1
0
1
2
Pitch = 0
Applied to all four simultaneously
Applied to all four simultaneously
Applied to all four simultaneously

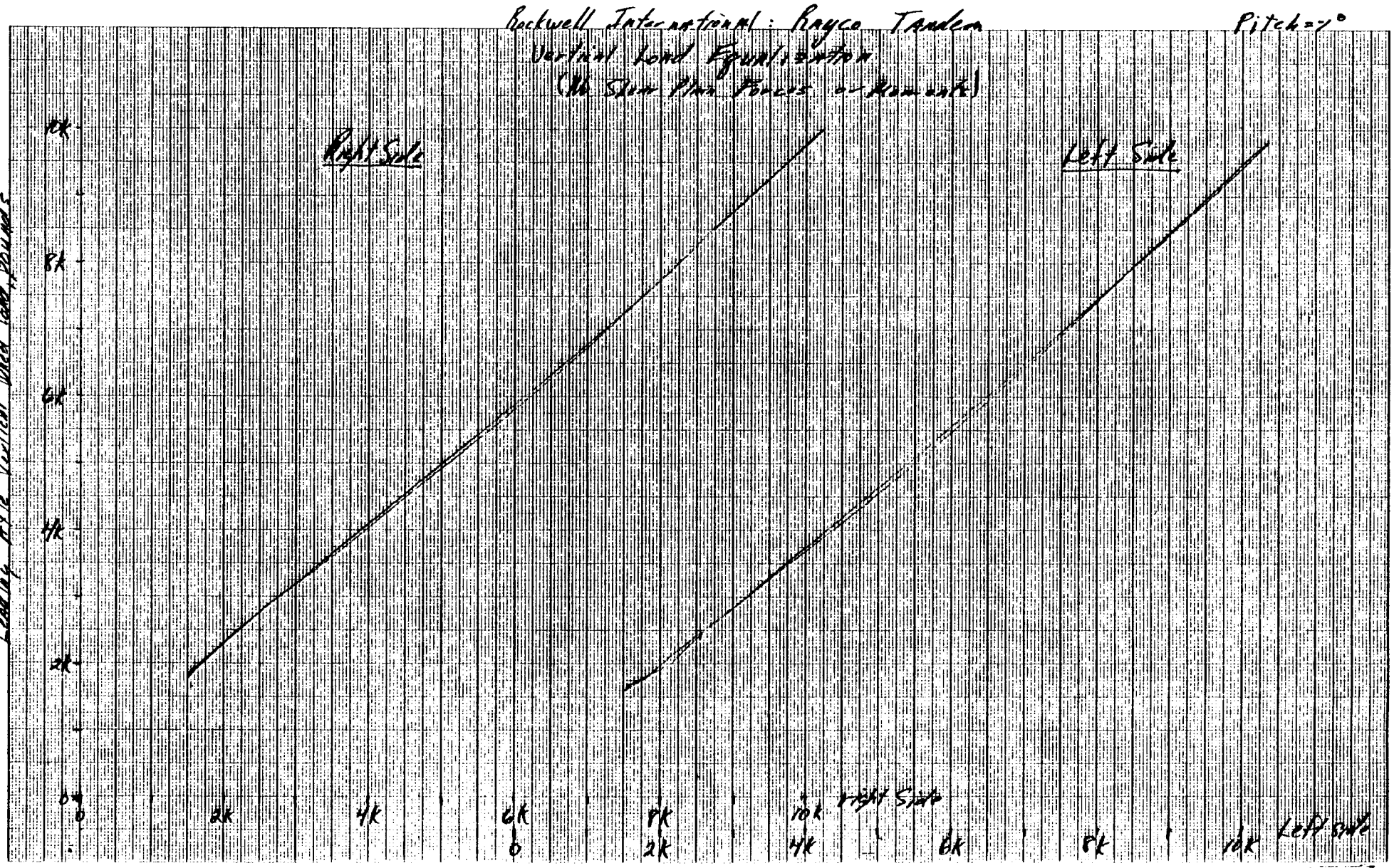

Rockwell International: Rayco Tandem
Pitch=0
Lateral Force Compliance Steer
Trailing Axle
Gross Suspension Load
32,000 lb
24,000 lb
16,000 lb
Axle Steer Angle, deg
(← Steer Toward right)
.2
.1
0
.1
.2
1000 lb
0
0
0
Lateral Force Per Wheel Set, pounds
(→ Force applied toward right)
(Applied to all four simultaneously)


Rockwell International: Bayco Tandem
Pitch=0.
Interaxle Load Transfer due to Brake Force
Right Side
Left Side
32,000 lb
24,000 lb
16,000 lb
Gross Suspension load
1000 lbs
8800 lb
6600 lb
4360 lb
Initial Rear Wheel load
8960
6720
4820
Load Transfer from Leading Wheel to Trailing Wheel, pounds
Brake Force Per Wheel Set, pounds
Applied to All Four Simultaneously
4k
3k
2k
1k
0
Right
Left


Rockwell International: Rayco Tandem
Pitch = -1°
Inter-axle load transfer due to Brake Force
Right Side
Left Side
Gross Suspension Load:
32,000 lb.
24,000 lb.
16,000 lb.
1000 lb.
Load Transfer from Leading Wheel to Trailing Wheel
Initial Rear Wheel Load
4k
3k
2k
1k
0
Right
Left
Brake force per wheel set, pounds
Applied to all four simultaneously



K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM. KEUFFEL & ESSER CO. MADE IN U.S.A. 47 1512


Rockwell International: Rayco Tandem
Vertical Load Equilibration
(No Steer Axle Forces or Moments)
Pitch = 7°
Right Side
Left Side
Leading Axle Vertical Wheel Load, pounds
Trailing Axle Vertical Wheel load, pounds.
0
2K
4K
6K
8K
10K
Right Side
Left Side

Suspension: Reyco 4-Spring (Mack)

		Susp Load 32000	24000	16000
Vertical Rate (lb/in)		8250	7000	6000
Coulomb Friction (lb)		1200	1000	650
ROLL RATE	F	120K	105K	90K
(in-lb/deg)	R	145K	120K	85K
ROLL CENTER HT	F	9.1	9.0	9.3
(in below top of frame)	R	9.7	10.0	10.6
ROLL STEER	F			
(DEG / DEG)	R			

ALIGNING MOMENT COMPLIANCE STEER F

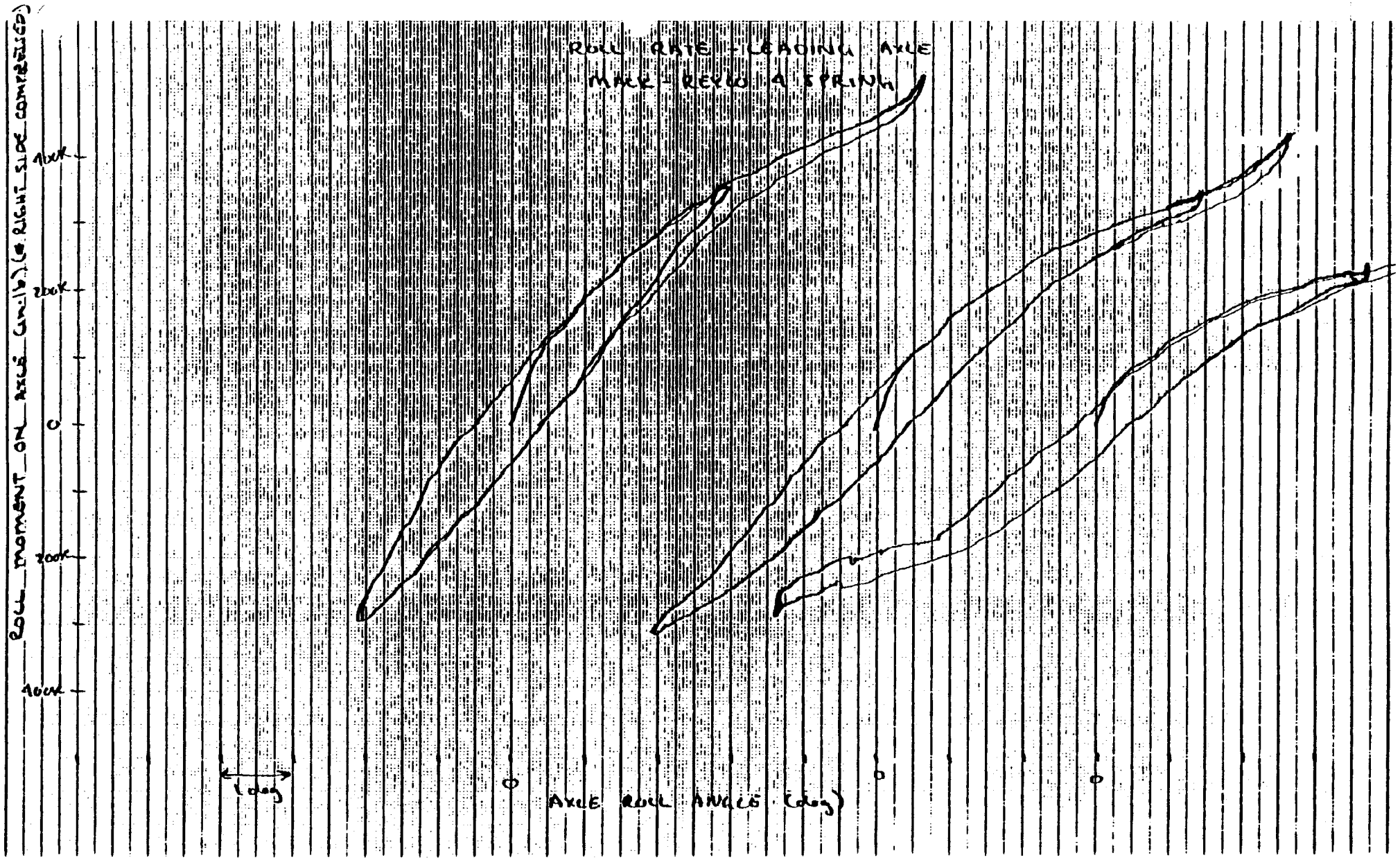
(deg / in lb) R

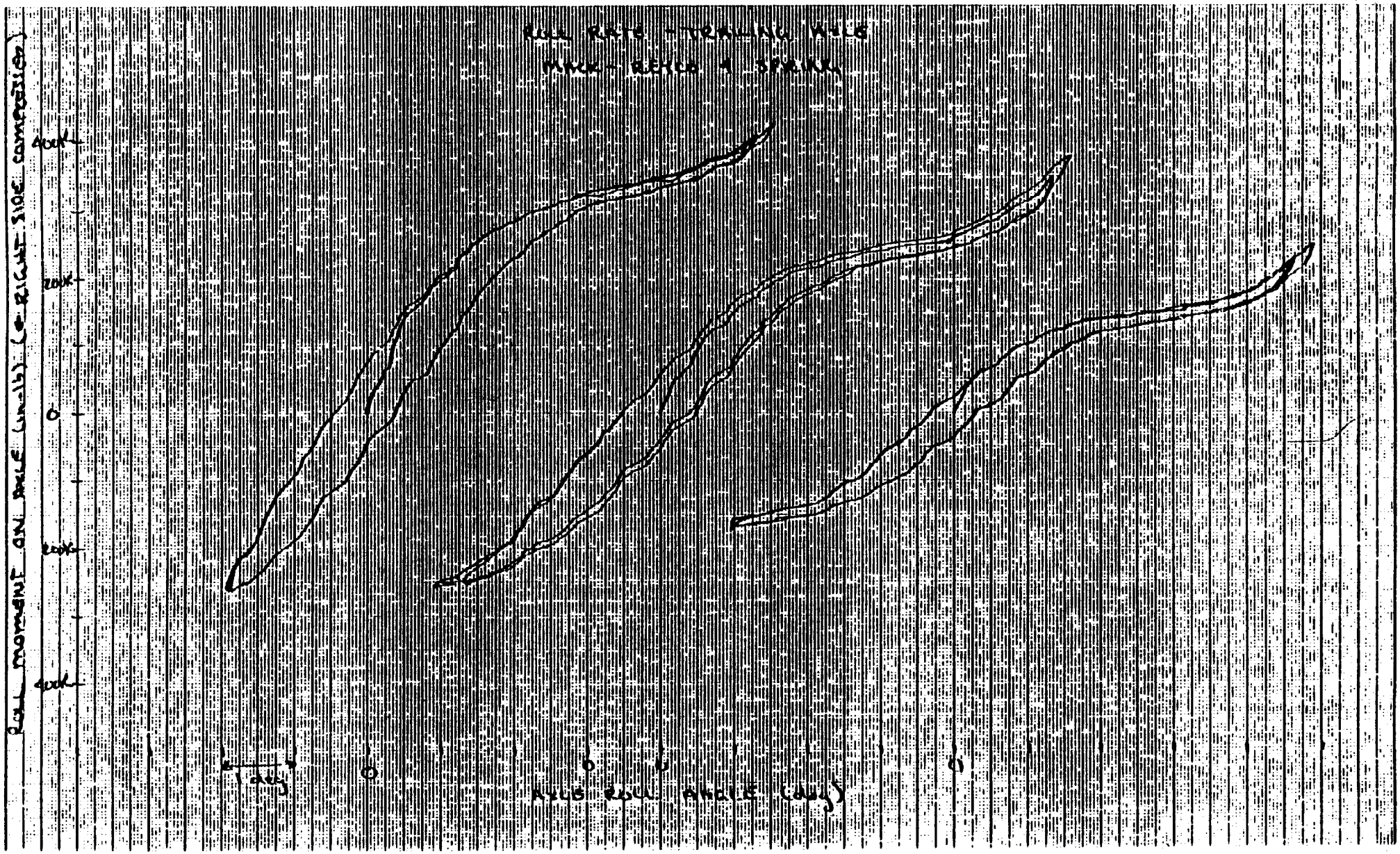
LATERAL FORCE COMPLIANCE F

(deg / lb) R

INTERAXLE LOAD TRANSFER (BOGIE)

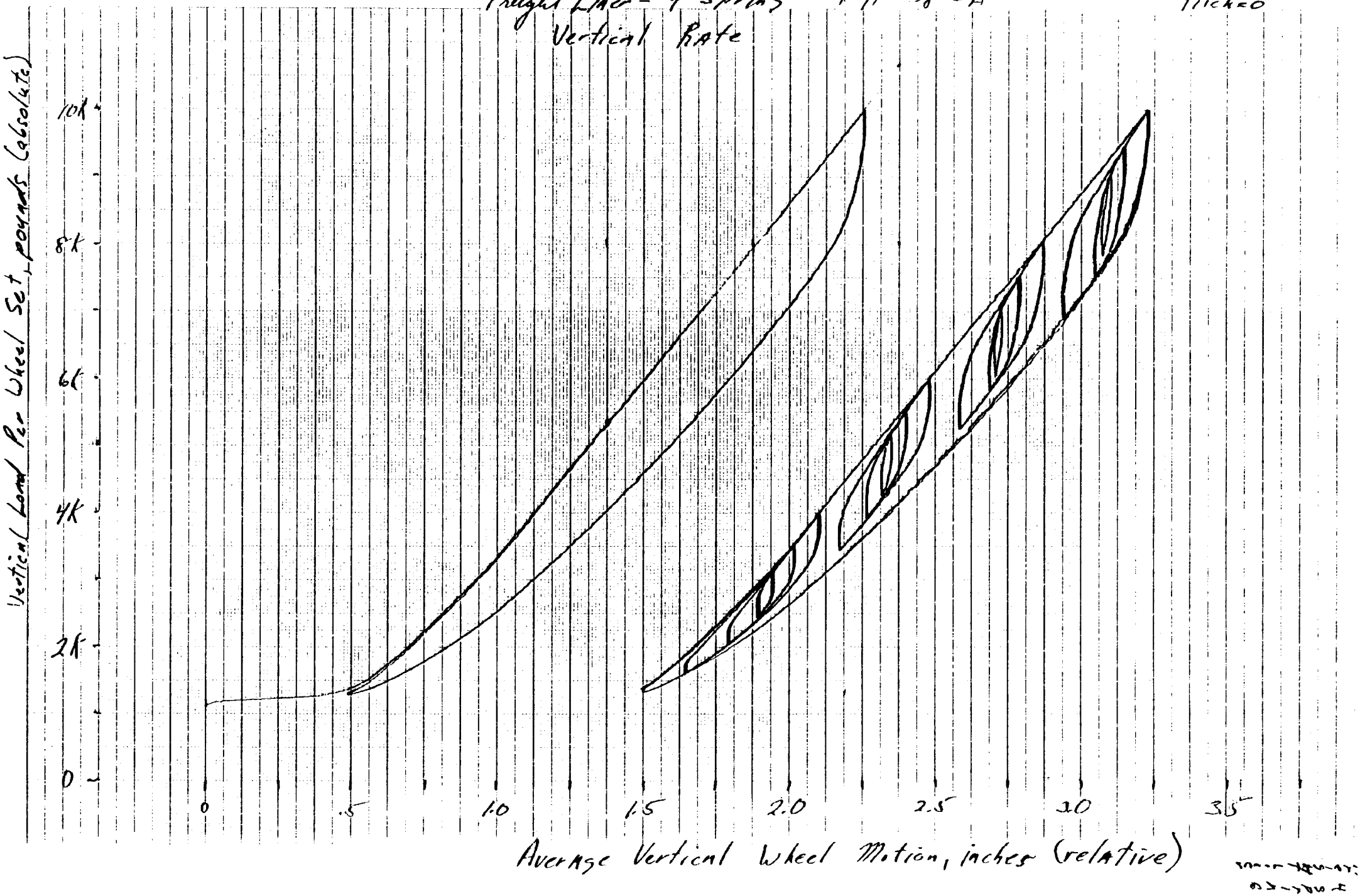
(lb / lb)

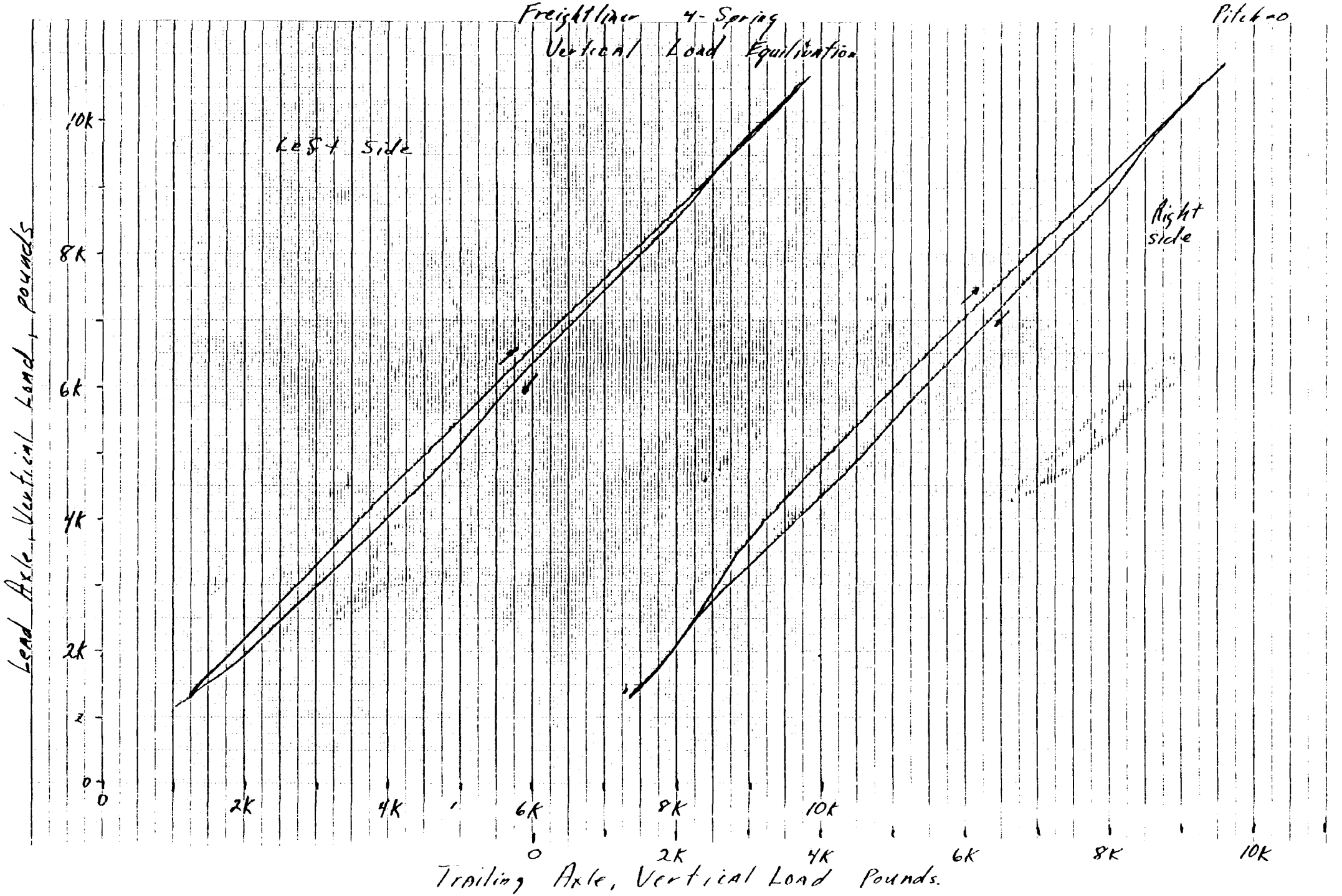

ROLL RATE - LEADING AXLE
MACK - REXCO 4 SPRING
ROLL MOMENT ON AXLE (in-lb) (+ RIGHT SIDE COMPRESSED)
100K
200K
0
200K
100K
1 deg
0
0
0
AXLE ROLL ANGLE (deg)

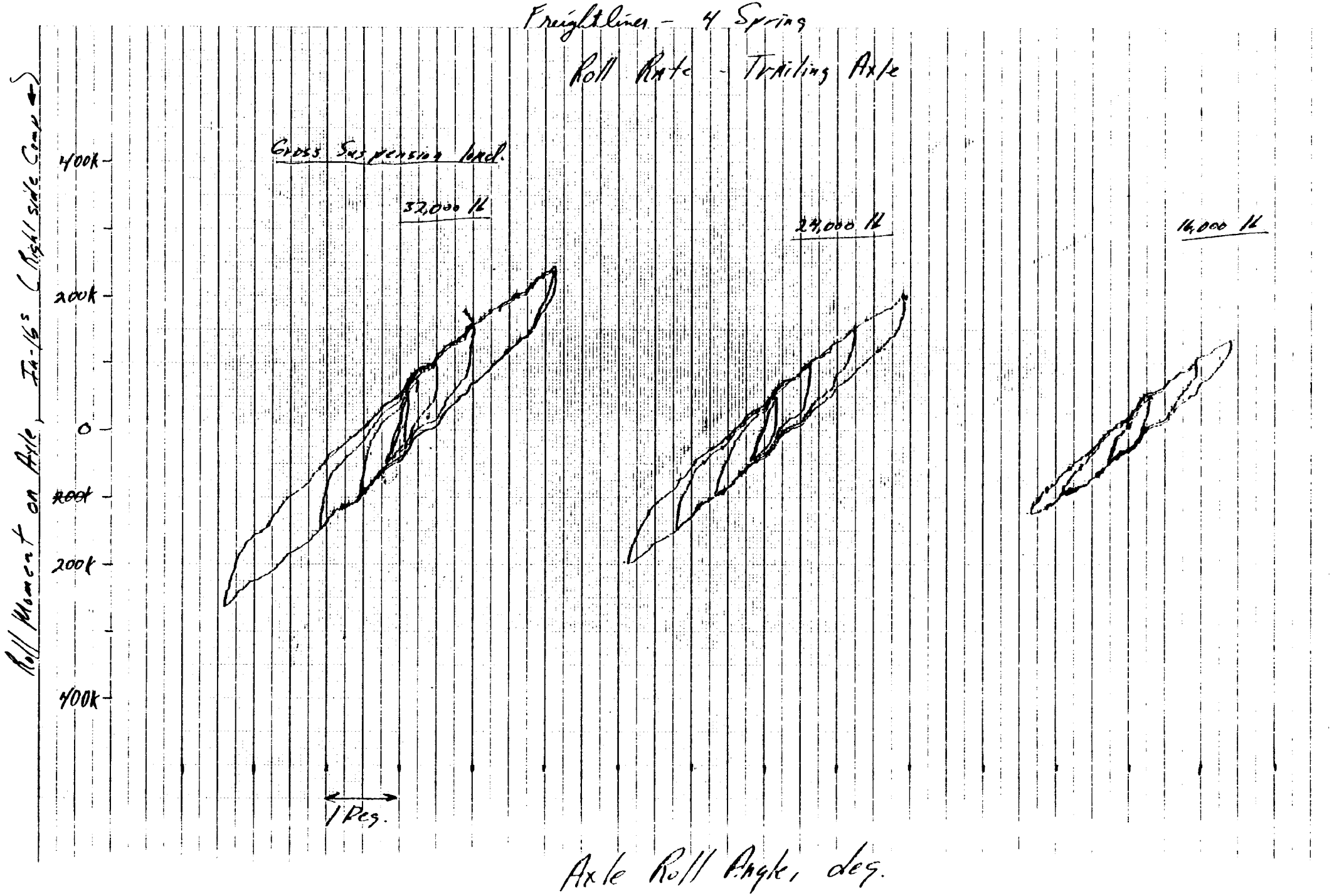

ROLL RATE - TRAILING AXLE
MACK - REYCO + SPRING
ROLL MOMENT ON AXLE (in-lb) (+ RIGHT SIDE COMPRESSION)
400K
200K
0
200K
400K
1 deg
0
0
0
0
AXLE ROLL ANGLE (deg)

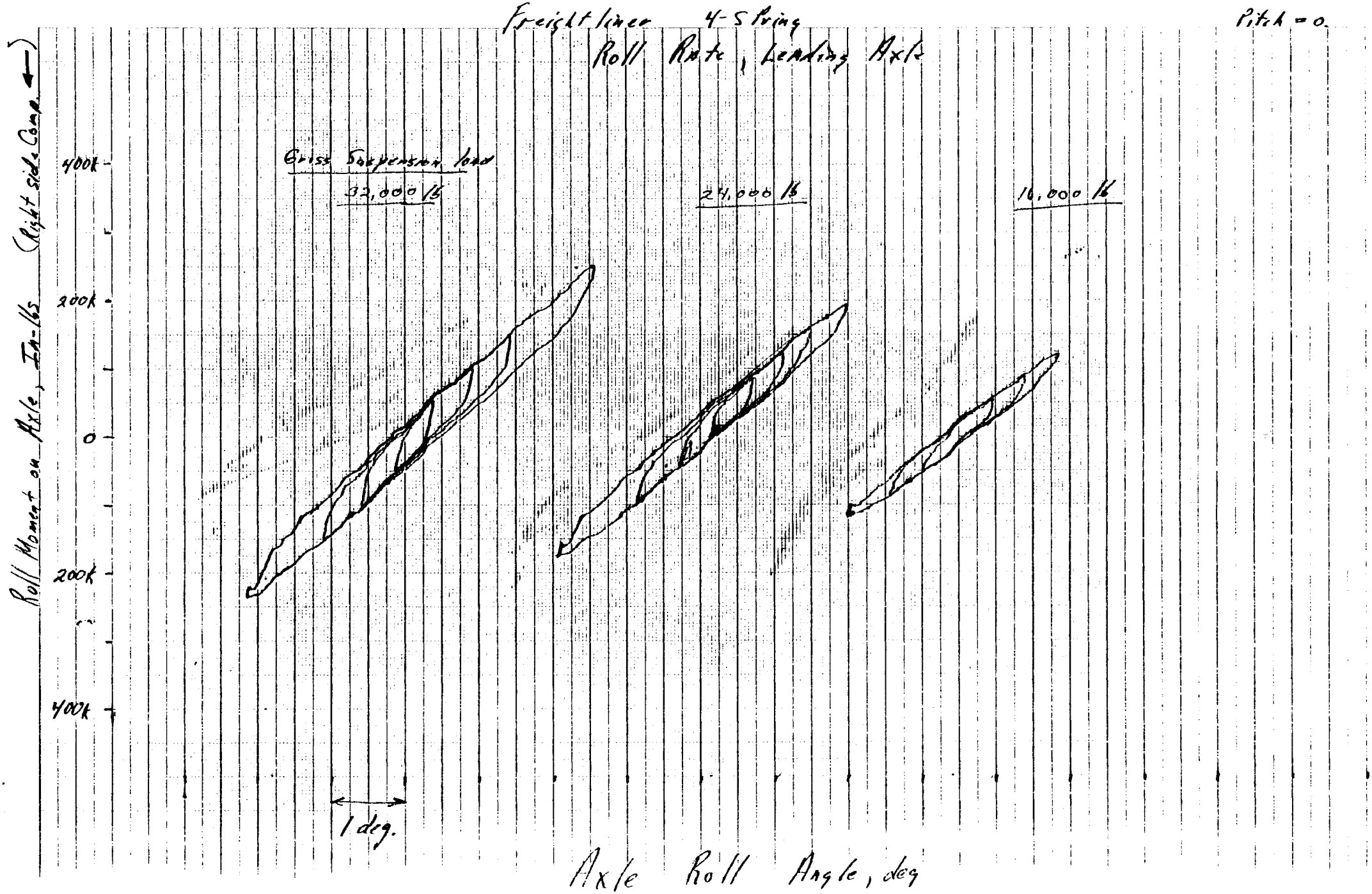
SUSPENSION: FREIGHTLINER 4 SPRING (FH-38-A)

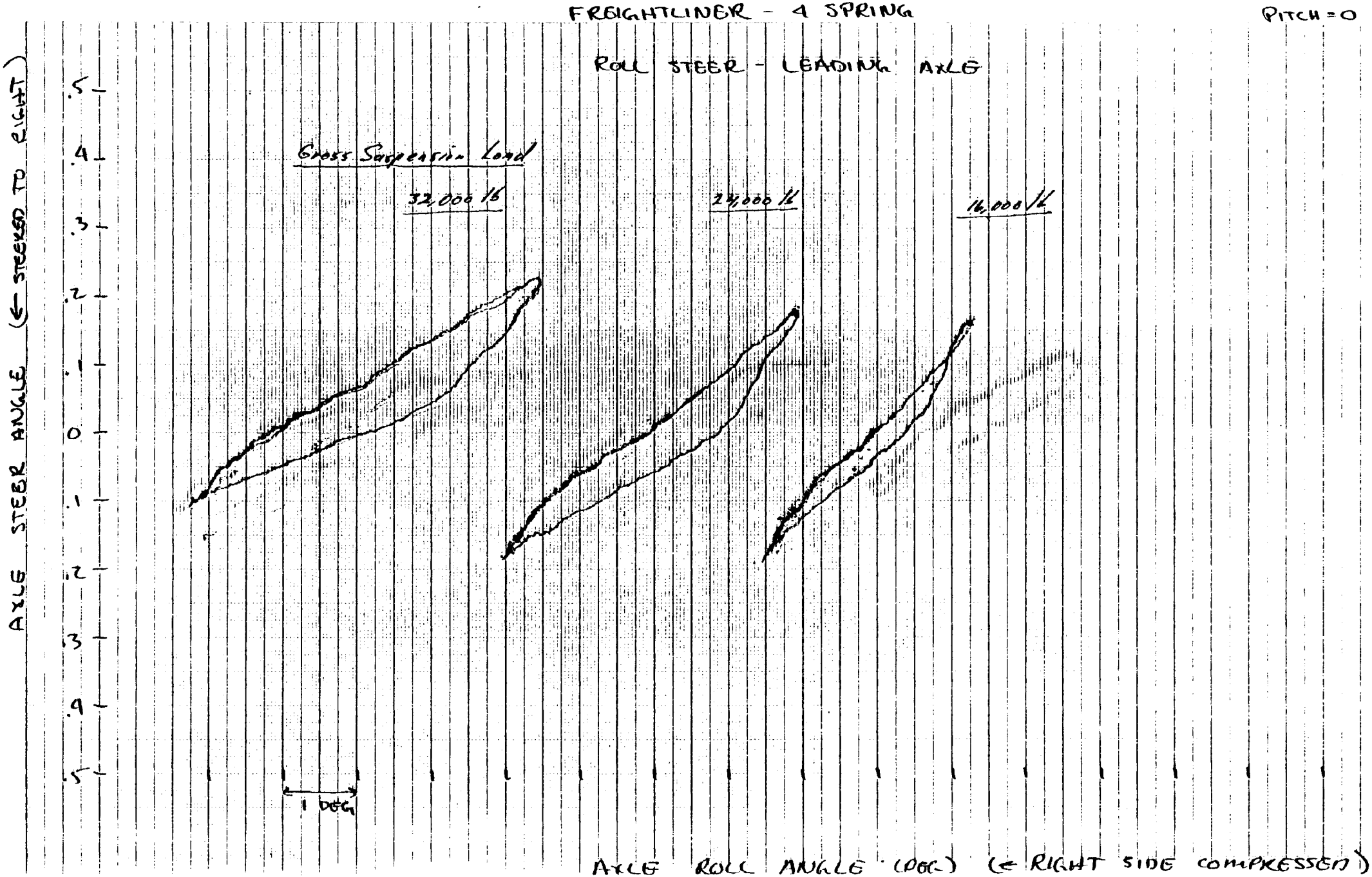
		Susp Load 32000	24000	16000
Vertical Rate (lb/in)		5300	5300	5300
Coulomb Friction (lb)		800	700	500
ROLL RATE (in lb/deg)	F	95K	90K	85K
	R	105K	95K	90K
ROLL CENTER HT (in below top of frame)	F	———	NA ———	
	R			
ROLL STEER (DEG / DEG)	F	-.04	-.06	-.07
	R	-.04	-.05	-.06
ALIGNING MOMENT COMPLIANCE STEER (deg / in lb)	F	5×10^{-6}	5.5×10^{-6}	5.5×10^{-6}
	R	2.5×10^{-6}	4.5×10^{-6}	5.5×10^{-6}
LATERAL FORCE COMPLIANCE (deg/lb)	F	2.2×10^{-5}	3×10^{-5}	4×10^{-5}
	R	7×10^{-6}	1×10^{-5}	1.3×10^{-5}
INTERAXLE LOAD TRANSFER (BYMOM) (lb/lb)	L	.34	.29	.30
	R	.26	.32	.20

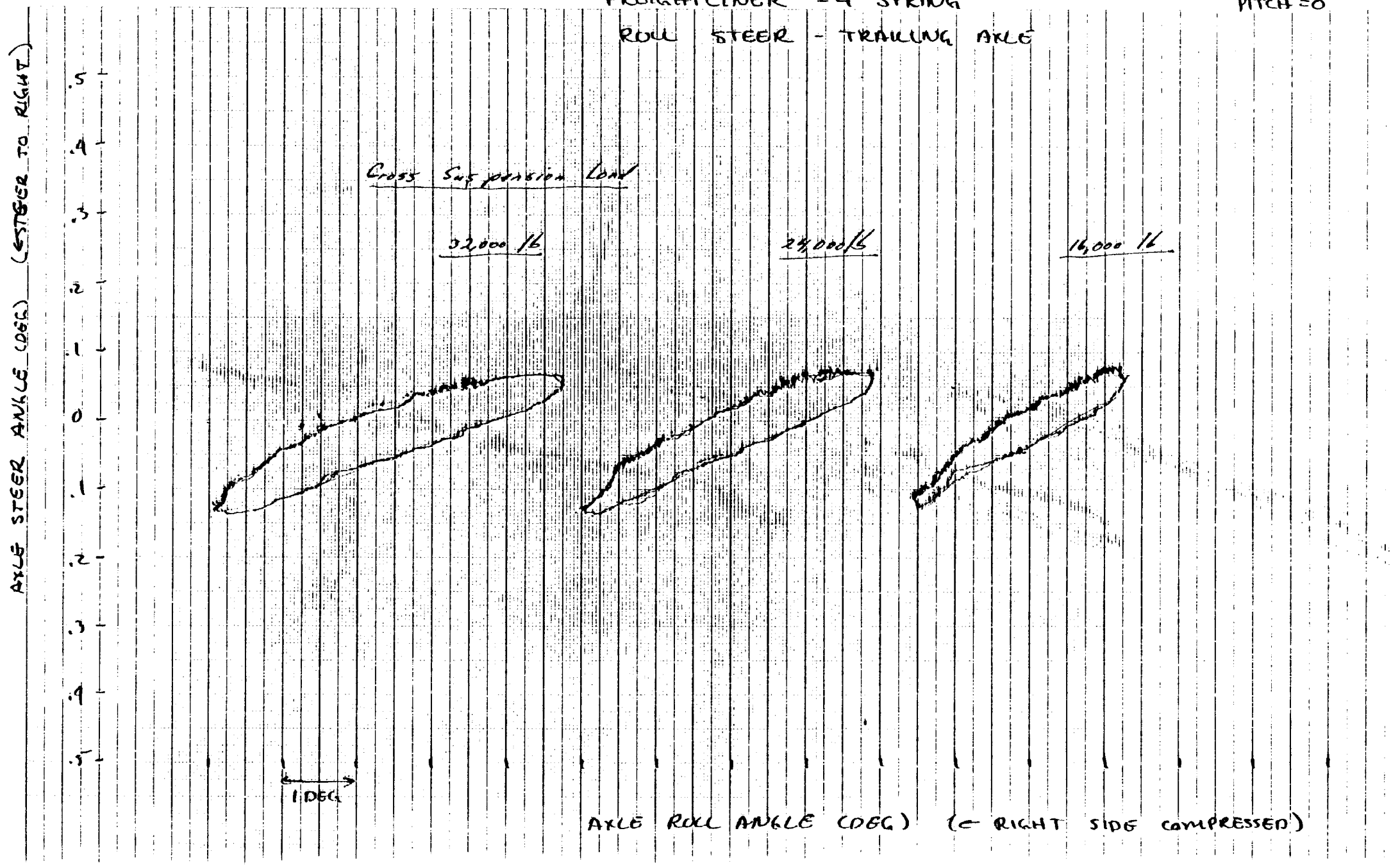

Freight Liner - 4 Spring FH-38-A
Vertical Rate
Vertical Load Per Wheel Set, pounds (absolute)
10K
8K
6K
4K
2K
0
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
Average Vertical Wheel Motion, inches (relative)

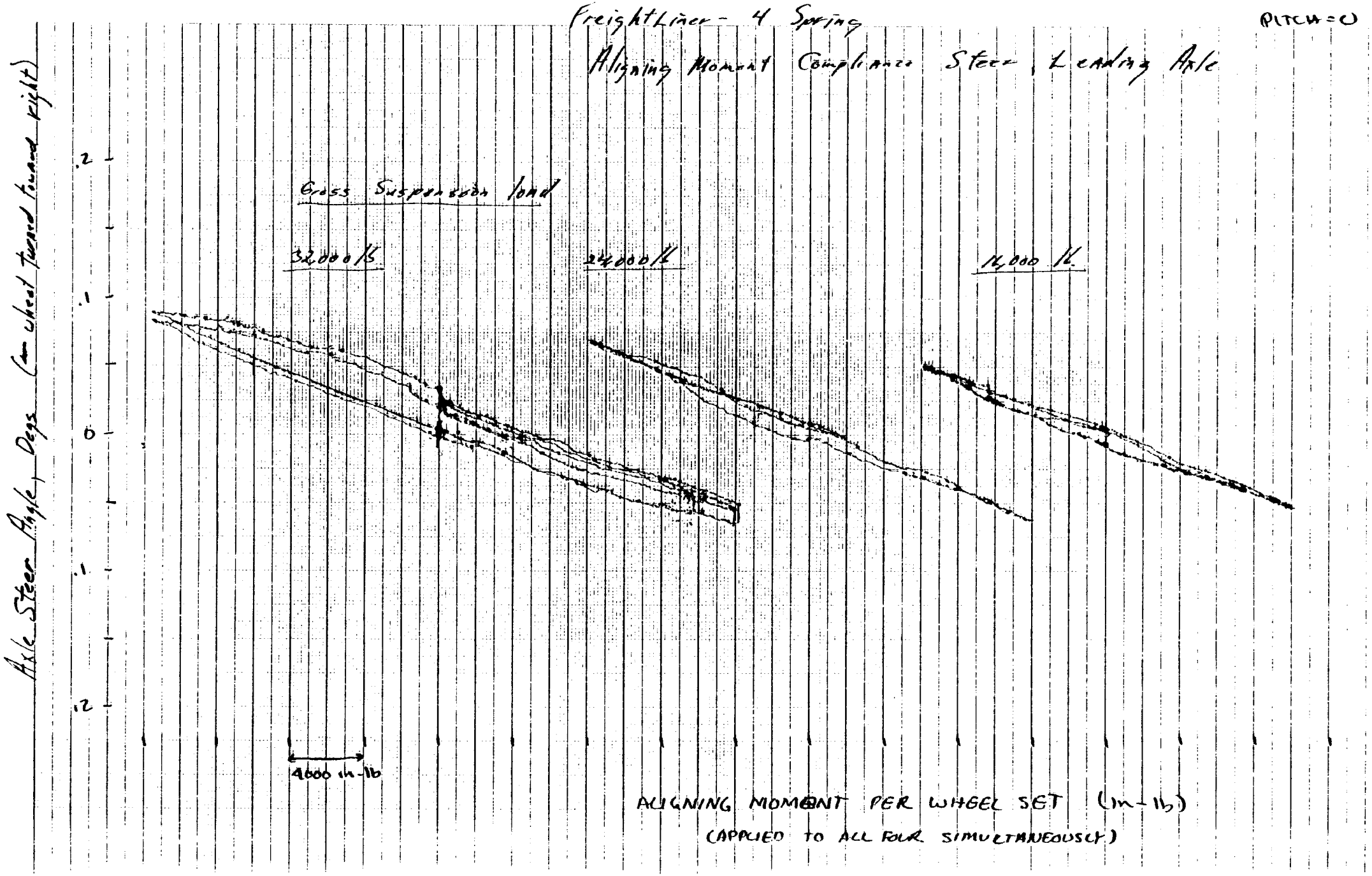

Freightliner 4-Spring
Vertical Load Equilibration
Pitch-0
Left Side
Right side
Lead Axle, Vertical Load, pounds
Trailing Axle, Vertical Load Pounds
10K
8K
6K
4K
2K
0
2K
4K
6K
8K
10K
0
2K
4K
6K
8K
10K

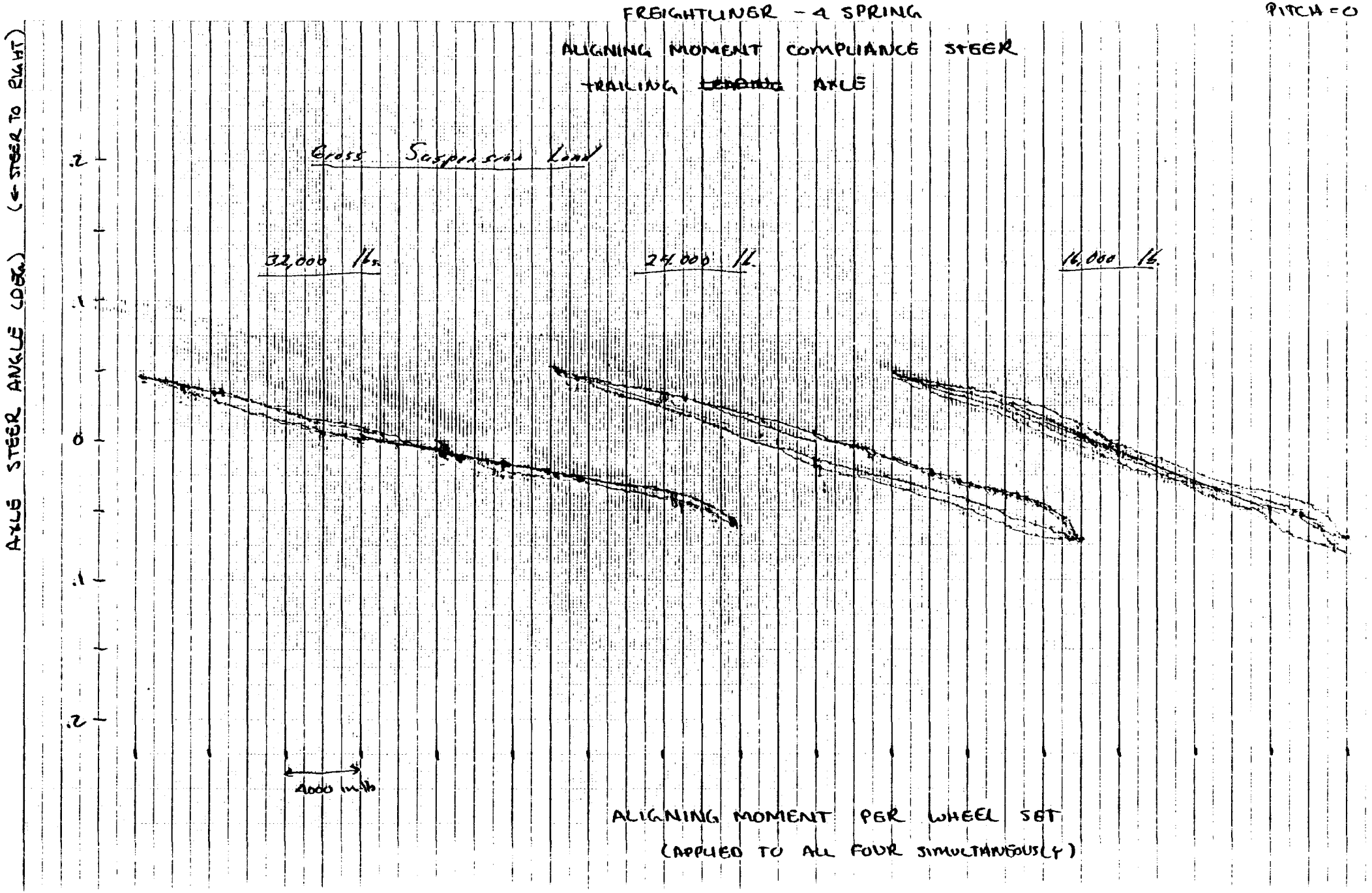

Freightliner - 4 Spring
Roll Rate - Trailing Axle
Gross Suspension load.
32,000 lb
24,000 lb
16,000 lb
400k
200k
0
200k
400k
Roll Moment on Axle, In-lbs (Right side Comp ←)
1 Deg.
Axle Roll Angle, deg.

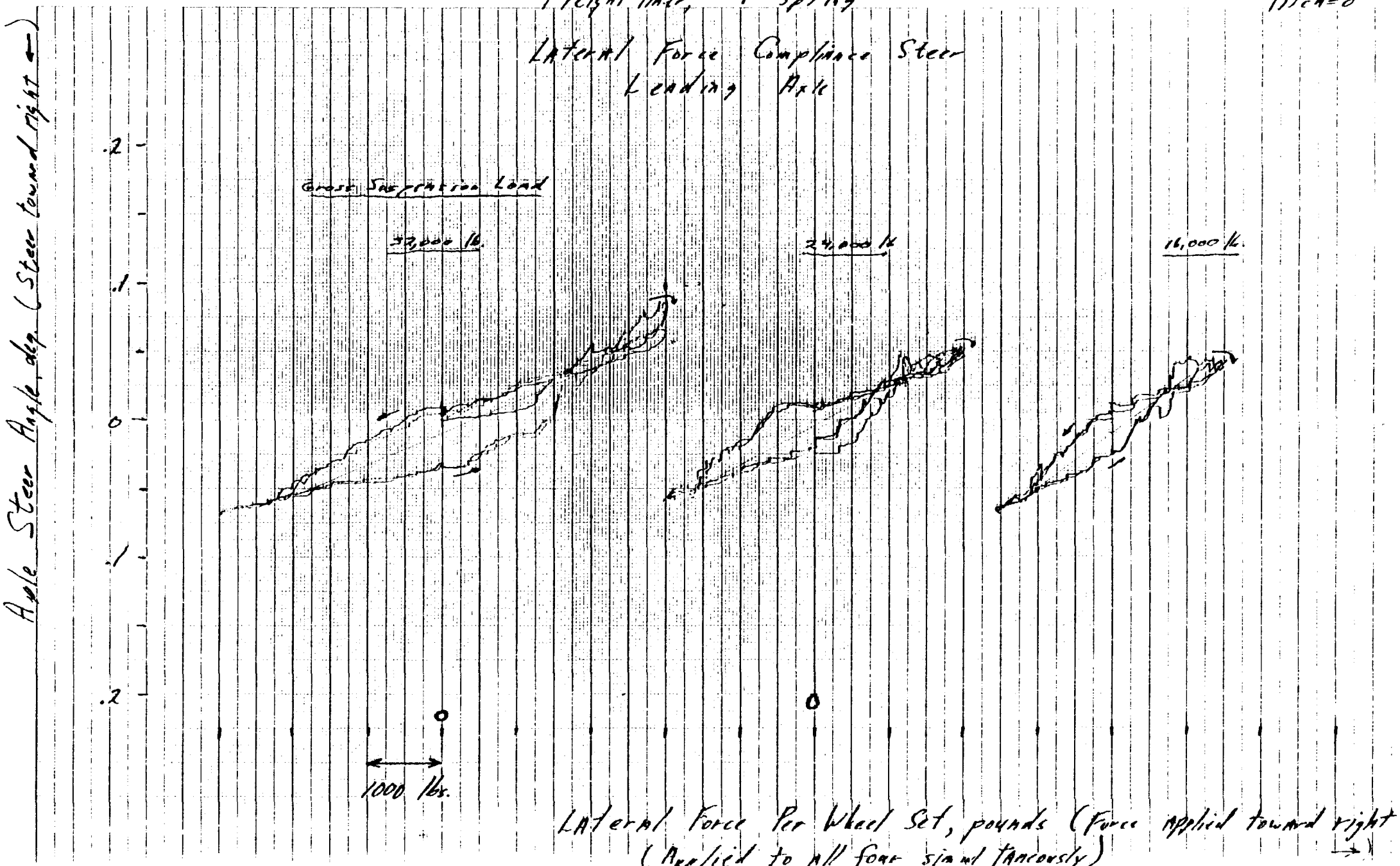

Freight liner 4-S Ring
Roll Rate, Leading Axle
Pitch = 0.
Roll Moment on Axle, In-lbs (Right side Comp. ←)
Gross Suspension Load
32,000 lb
24,000 lb
16,000 lb
400k
200k
0
200k
400k
1 deg.
Axle Roll Angle, deg

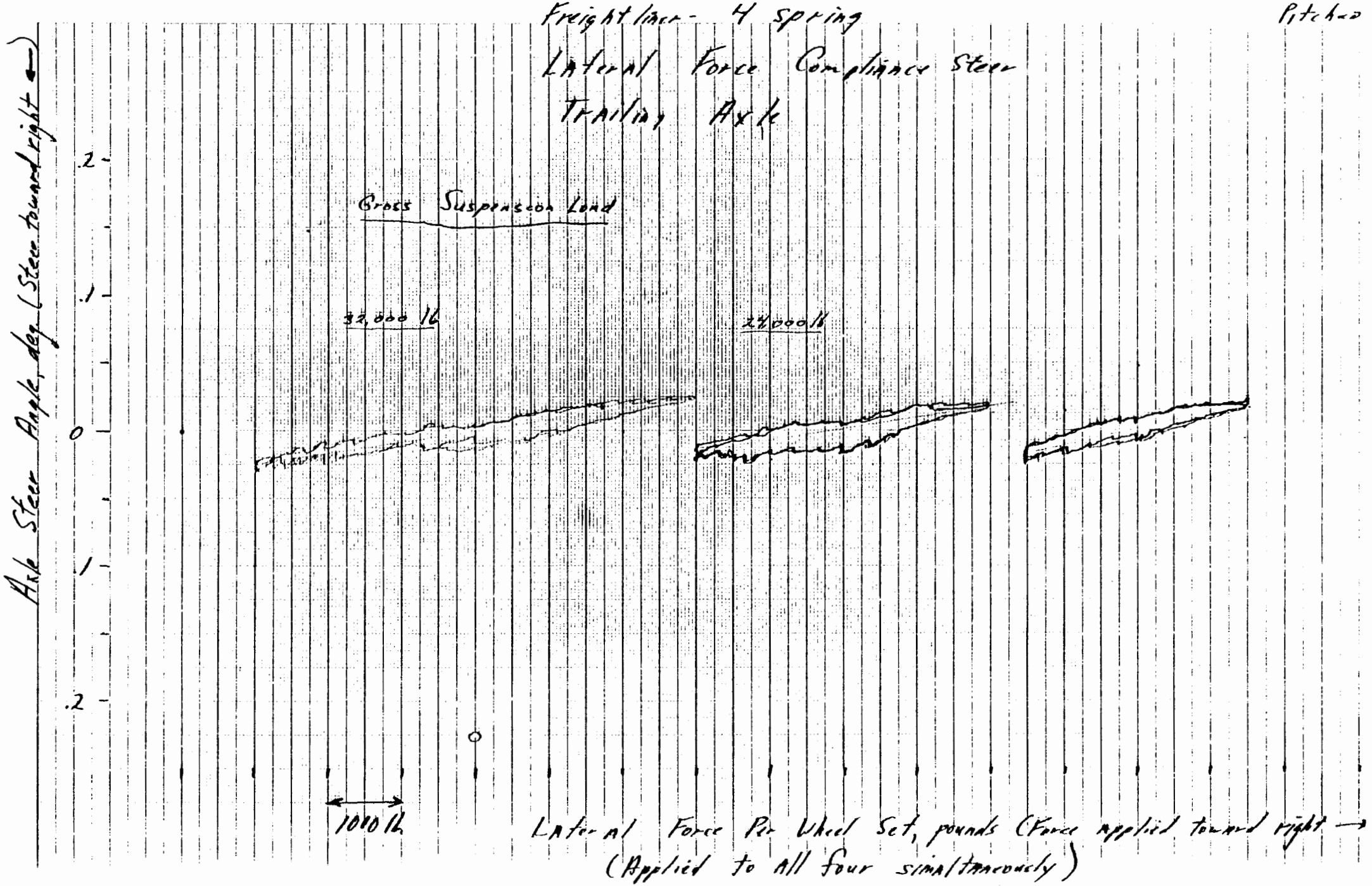

FREIGHTLINER - 4 SPRING
PITCH = 0
ROLL STEER - LEADING AXLE
Gross Suspension Load
32,000 lb
24,000 lb
16,000 lb
AXLE STEER ANGLE (← STEERED TO RIGHT)
.5
.4
.3
.2
.1
0
.1
.2
.3
.4
.5
1 DEG
AXLE ROLL ANGLE (DEG) (← RIGHT SIDE COMPRESSED)

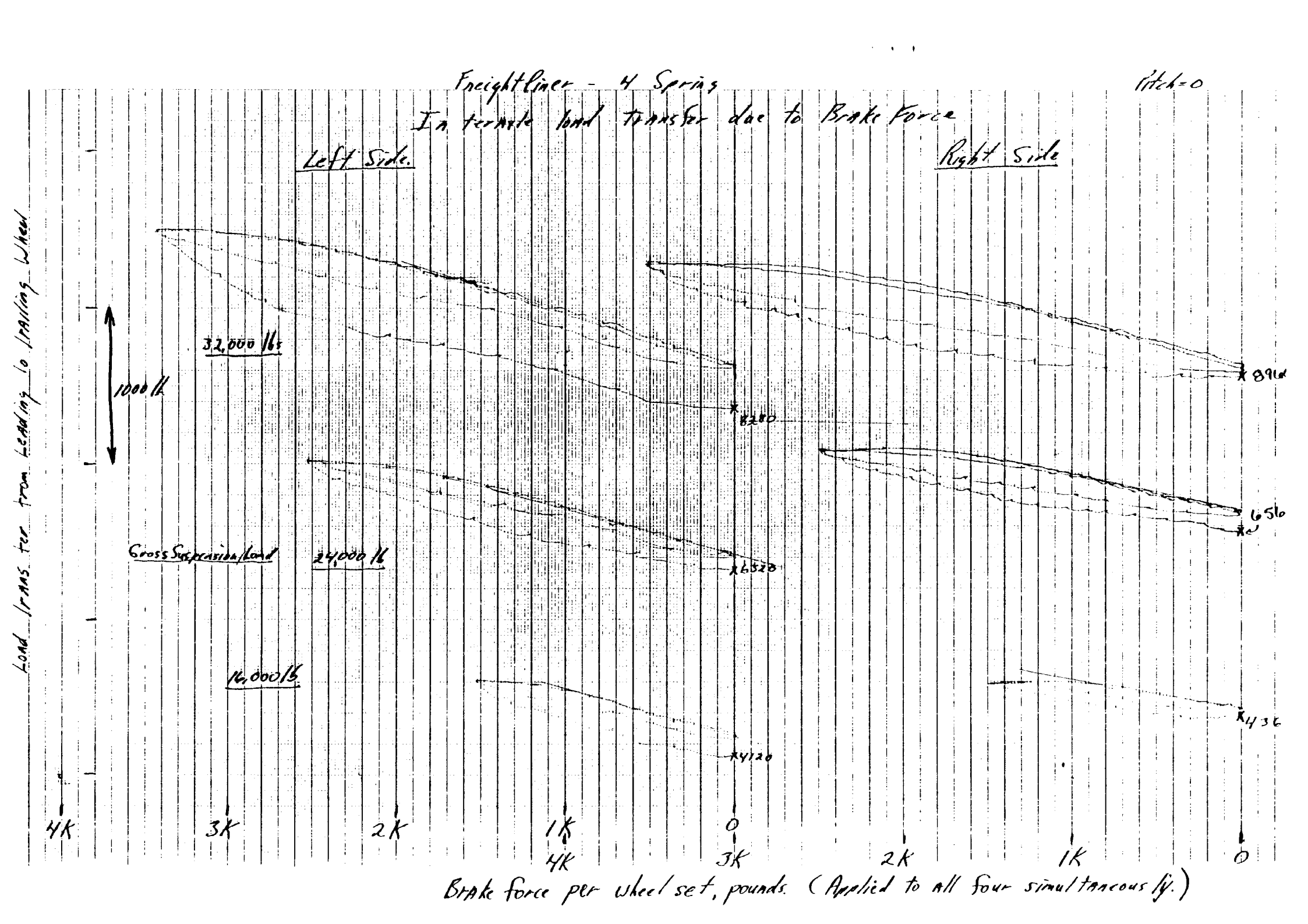

FREIGHTLINER - 4 SPRING
ROLL STEER - TRAILING AXLE
PITCH = 0
Cross Suspension Load
32,000 lb
24,000 lb
16,000 lb
AXLE STEER ANGLE (DEG) (+STEER TO RIGHT)
.5
.4
.3
.2
.1
0
.1
.2
.3
.4
.5
1 DEG
AXLE ROLL ANGLE (DEG) (+ RIGHT SIDE COMPRESSED)

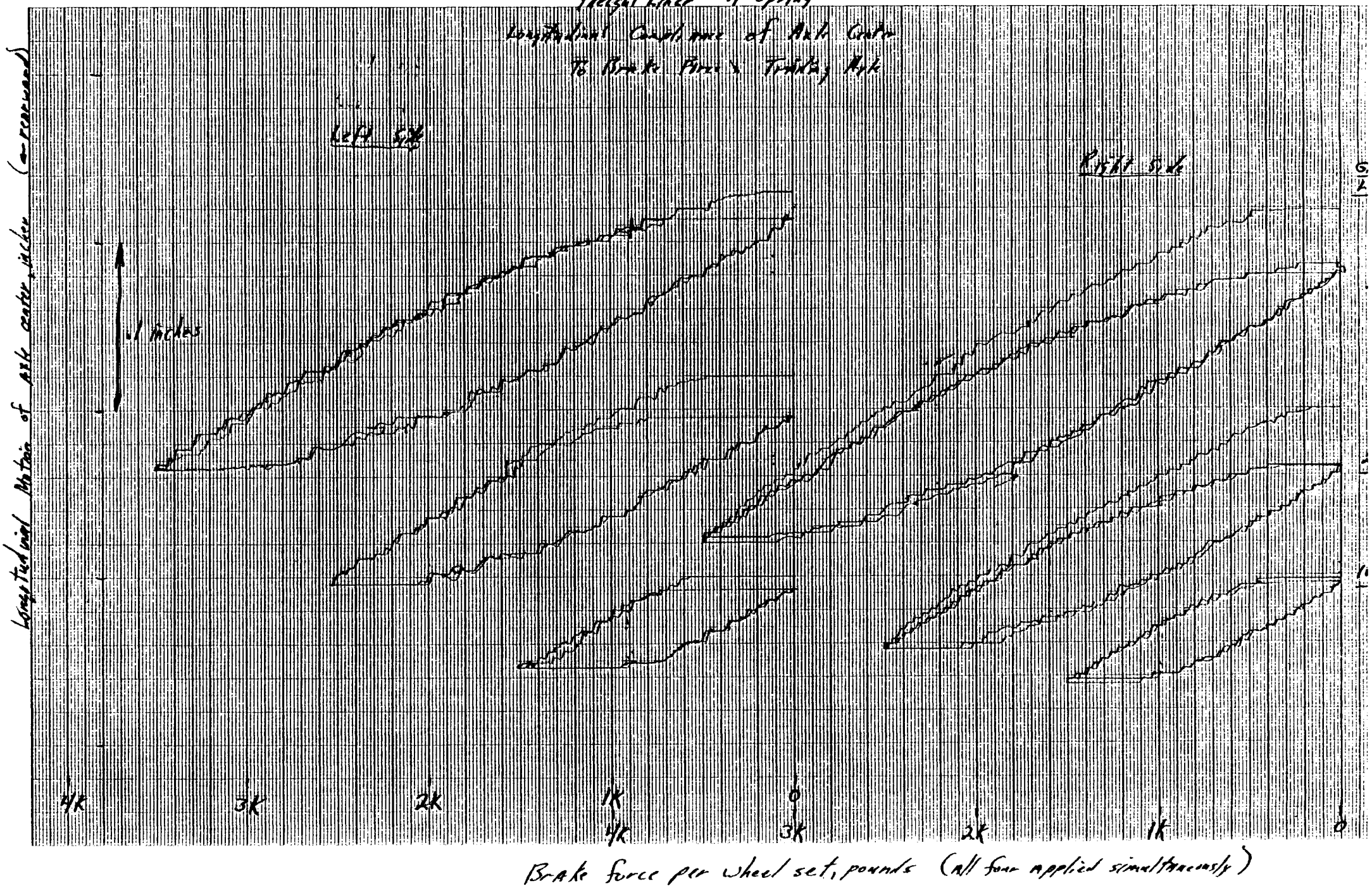

Freightliner - 4 Spring
Aligning Moment Compliance Steer, Leading Axle
PITCH = 0
Axle Steer Angle, Degs (+ wheel turned toward right)
.2
.1
0
.1
.2
Gross Suspension load
32,000 lb
24000 lb
16,000 lb
4000 in-lb
ALIGNING MOMENT PER WHEEL SET (in-lb)
(APPLIED TO ALL FOUR SIMULTANEOUSLY)

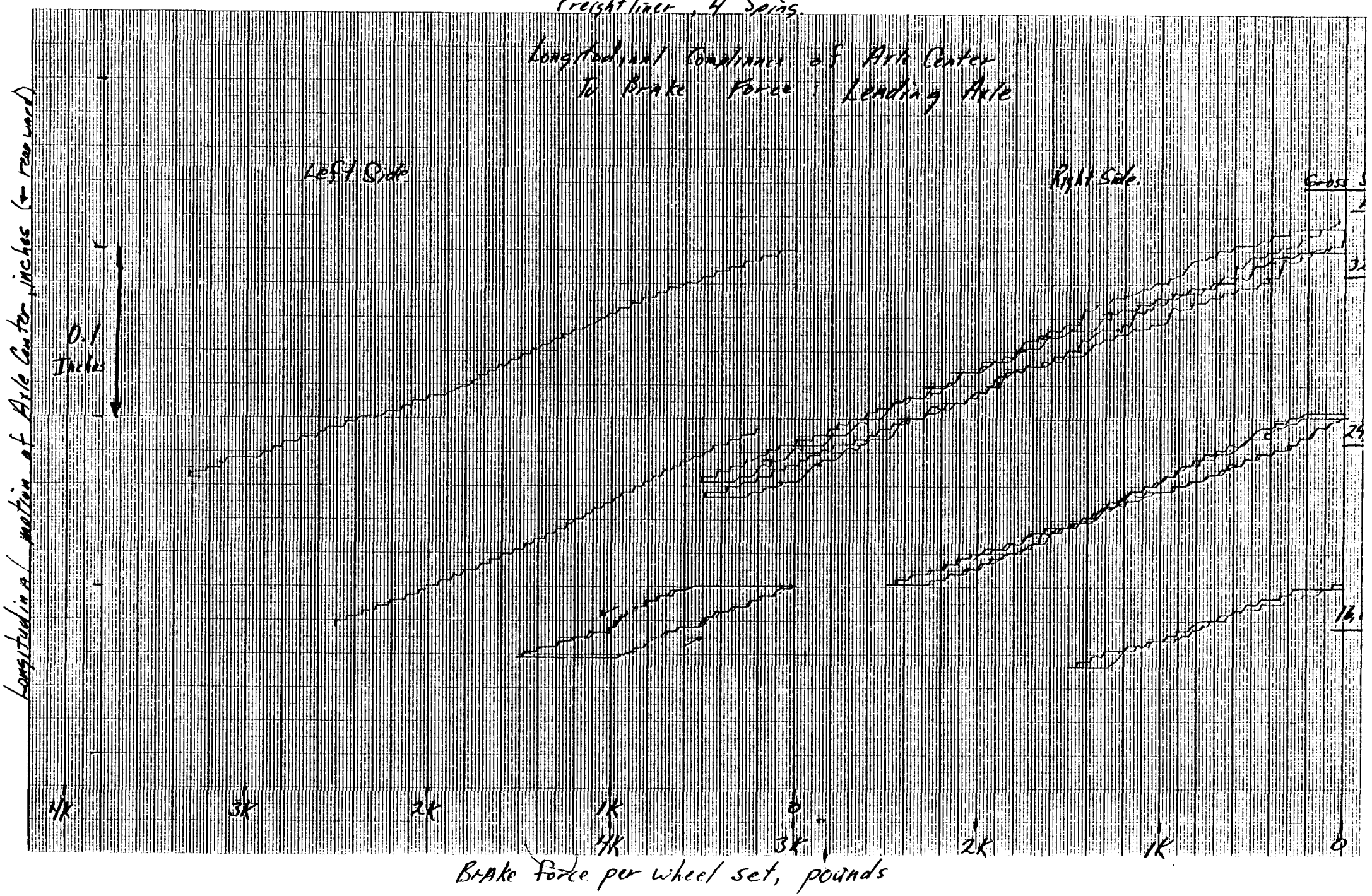

FREIGHTLINER - 4 SPRING
PITCH = 0
ALIGNING MOMENT COMPLIANCE STEER
TRAILING ~~LEADING~~ AXLE
AXLE STEER ANGLE (DEG) (← STEER TO RIGHT)
.2
.1
0
.1
.2
Gross Suspension Load
32,000 lbs
24,000 lb.
16,000 lb.
4000 in-lb
ALIGNING MOMENT PER WHEEL SET
(APPLIED TO ALL FOUR SIMULTANEOUSLY)


Freight liner, 4-Spring
Lateral Force Compliance Steer
Leading Axle
Pitch=0
Axle Steer Angle, deg (Steer toward right ←)
.2
.1
0
.1
.2
Gross Suspension Load
37,000 lb.
24,000 lb.
16,000 lb.
1000 lbs.
Lateral Force Per Wheel Set, pounds (Force applied toward right →)
(Applied to all four simultaneously)


Freight Car - 4 spring
Lateral Force Compliance Steer
Training Axle
Pitch
Axle Steer Angle, deg (Steer toward right ←)
.2
.1
0
.1
.2
Gross Suspension Load
32,000 lb
24000 lb
1000 lb
Lateral Force Per Wheel Set, pounds (Force applied toward right →)
(Applied to all four simultaneously)


Freightliner - 4 Spring
Pitch = 0
Alternate load transfer due to Brake Force
Left Side.
Right Side
32,000 lbs
1000 lb
Gross Suspension Load
24,000 lb
16,000 lb
8280
8910
6520
6510
4120
4360
4K
3K
2K
1K
0
Load Trans fer from Leading to Trailing Wheel
Brake force per wheel set, pounds. (Applied to all four simultaneously.)


Freight Liner - 4 Spring
Longitudinal Compliance of Axle Center
To Brake Force & Trailing Axle
Left Side
Right Side
.1 inches
Longitudinal Motion of axle center, inches (← rearward)
4K
3K
2K
1K
0
4K
3K
2K
1K
0
Brake force per wheel set, pounds (all four applied simultaneously)


Freightliner, 4 Springs.
Longitudinal Compliance of Axle Center
To Brake Force: Leading Axle
Left Side
Right Side
Gross
0.1 Inches
Longitudinal motion of Axle Center, inches (+ rearward)
4K
3K
2K
1K
0
4K
3K
2K
1K
Brake force per wheel set, pounds

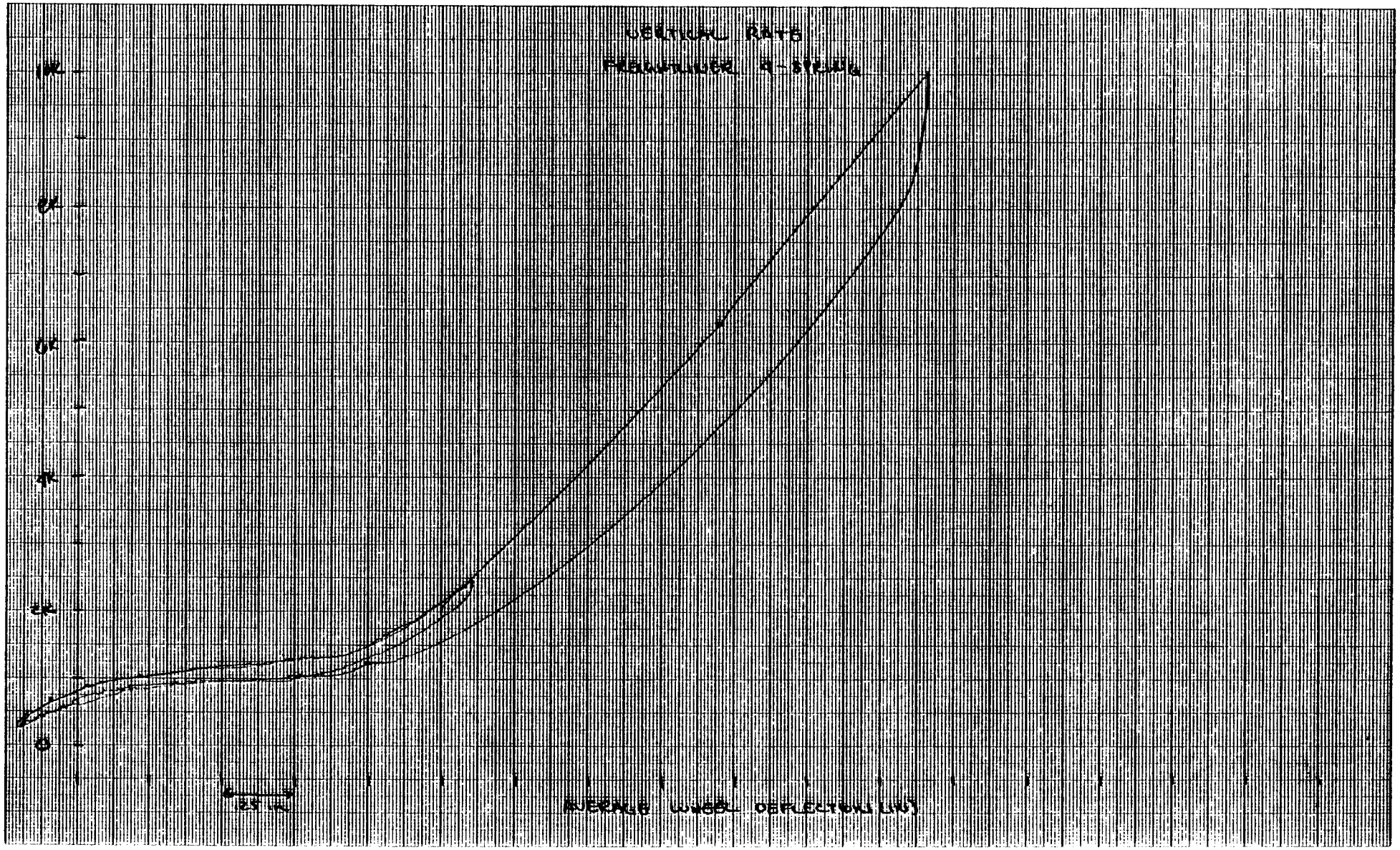
Suspension: FREIGHTLINER 4 SPRING

		Susp Load 32000	24000	16000
Vertical Rate (lb/in)		5400	5400	5400
Coulomb Friction (lb)		850	800	600
ROLL RATE (in-lb/deg)	F	90K	85K	75K
	R	90K	80K	70K
ROLL CENTER HT (in below top of frame)	F	12.3	12.9	13.2
	R	10.2	10.5	10.8
ROLL STEER (DEG / DEG)	F			
	R			

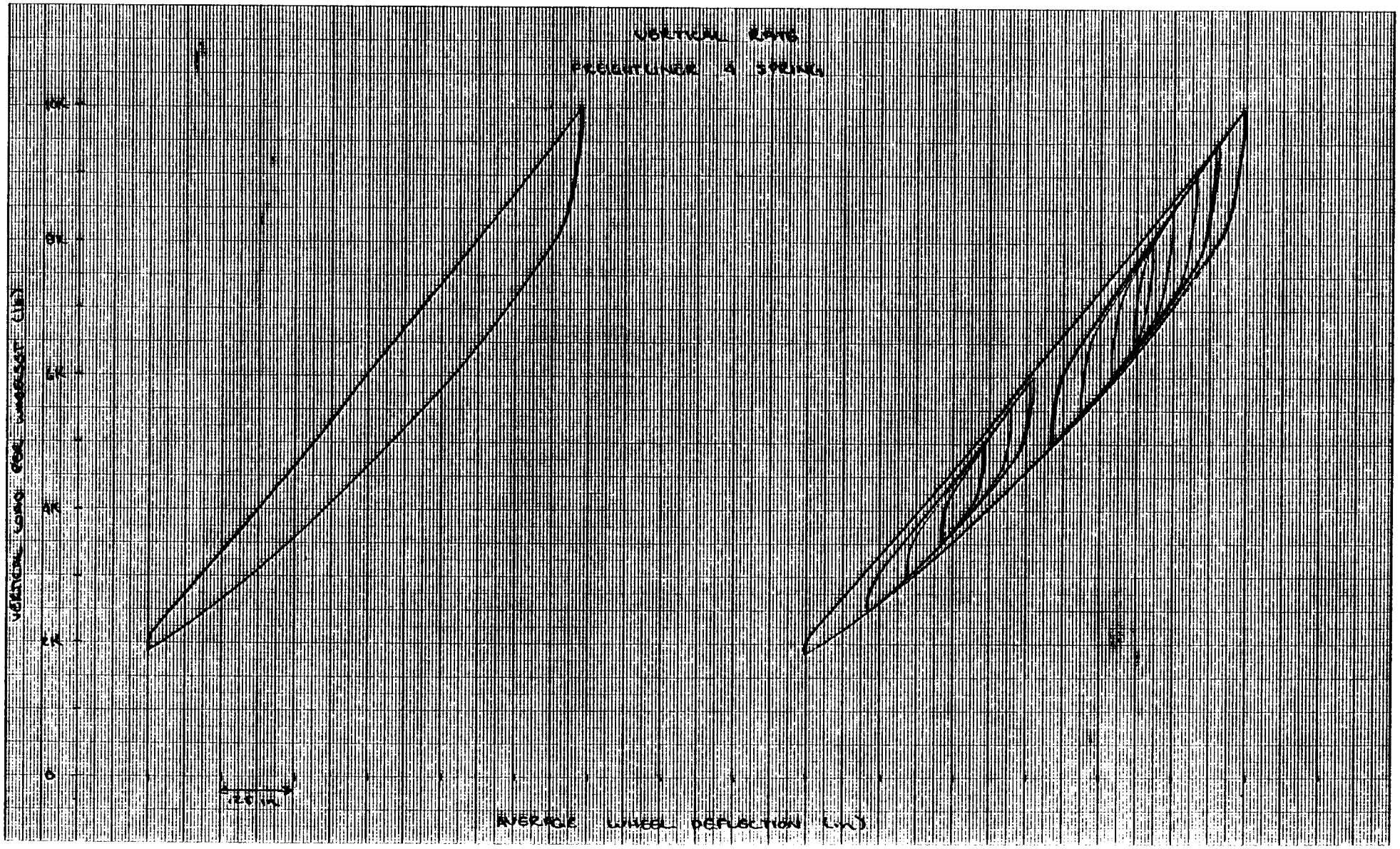
ALIGNING MOMENT COMPLIANCE STEER F
(deg/in lb) R

LATERAL FORCE COMPLIANCE F
(deg/lb) R

INTERAXLE LOAD TRANSFER (BRAKE)
(lb/lb)

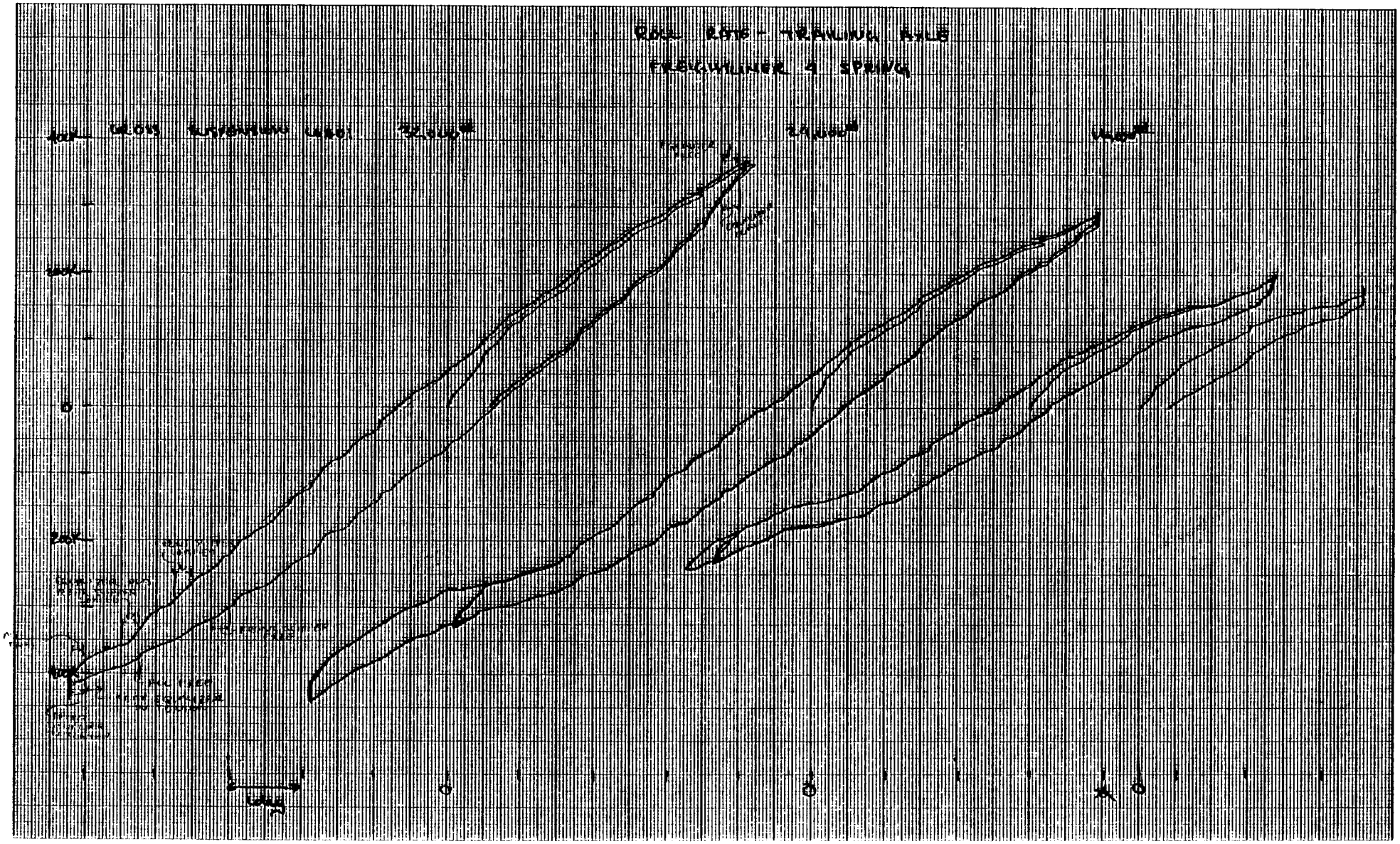


K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512



K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM. KEUFFEL & ESSER CO. MADE IN U.S.A. 47 1512

Gulf Rate-Level Line
Mississippi Rate Line
Gulf Ports
Southeastern Cities
Southern
Mississippi
Alabama
Georgia
Florida
Louisiana
Texas
Arkansas
Tennessee
Kentucky
Virginia
West Virginia
Ohio
Indiana
Illinois
Missouri
Kansas
Oklahoma
New Mexico
Arizona
California
Nevada
Utah
Colorado
Wyoming
Montana
Idaho
Oregon
Washington
North Dakota
South Dakota
Nebraska
Minnesota
Iowa
Wisconsin
Michigan
Pennsylvania
New York
Maryland
Delaware
New Jersey
Connecticut
Rhode Island
Massachusetts
Vermont
New Hampshire
Maine
North Carolina
South Carolina
Pacific Coast
Mountain
Central
Eastern
Southwestern
Northwestern
Western
Southern
Northern
Gulf
Atlantic
Pacific
Mississippi River
Ohio River
Missouri River
Colorado River
Columbia River
Rio Grande
Great Lakes
Chesapeake Bay
Puget Sound
San Francisco Bay
Los Angeles
San Diego
Seattle
Portland
San Francisco
Los Angeles
San Diego
New Orleans
Mobile
Pensacola
Tampa
Jacksonville
Savannah
Charleston
Norfolk
Baltimore
Philadelphia
New York
Boston
Portland
Bangor
Montreal
Toronto
Buffalo
Cleveland
Detroit
Chicago
Milwaukee
Minneapolis
St. Paul
Duluth
Kansas City
St. Louis
Memphis
Nashville
Louisville
Cincinnati
Pittsburgh
Wheeling
Charleston
Richmond
Roanoke
Knoxville
Chattanooga
Birmingham
Montgomery
Atlanta
Macon
Augusta
Columbia
Greenville
Asheville
Charlotte
Raleigh
Wilmington
Norfolk
Newport News
Richmond
Petersburg
Lynchburg
Roanoke
Bristol
Johnson City
Kingsport



K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512

Suspension: PETERBILT 4-SPRING

		Susp Load 32000	24000	16000
Vertical Rate (lb/in)		7600	7600	7600
Coulomb Friction (lb)		1450	1250	800
ROLL RATE	F	95K	90K	75K
(in-lb/deg)	R	95K	80K	70K
ROLL CENTER HT	F	10.5	10.5	10.8
(in below top of frame)	R	12.3	13.7	14.3
ROLL STEER	F			
(DEG / DEG)	R			

ALIGNING MOMENT COMPLIANCE STEER F

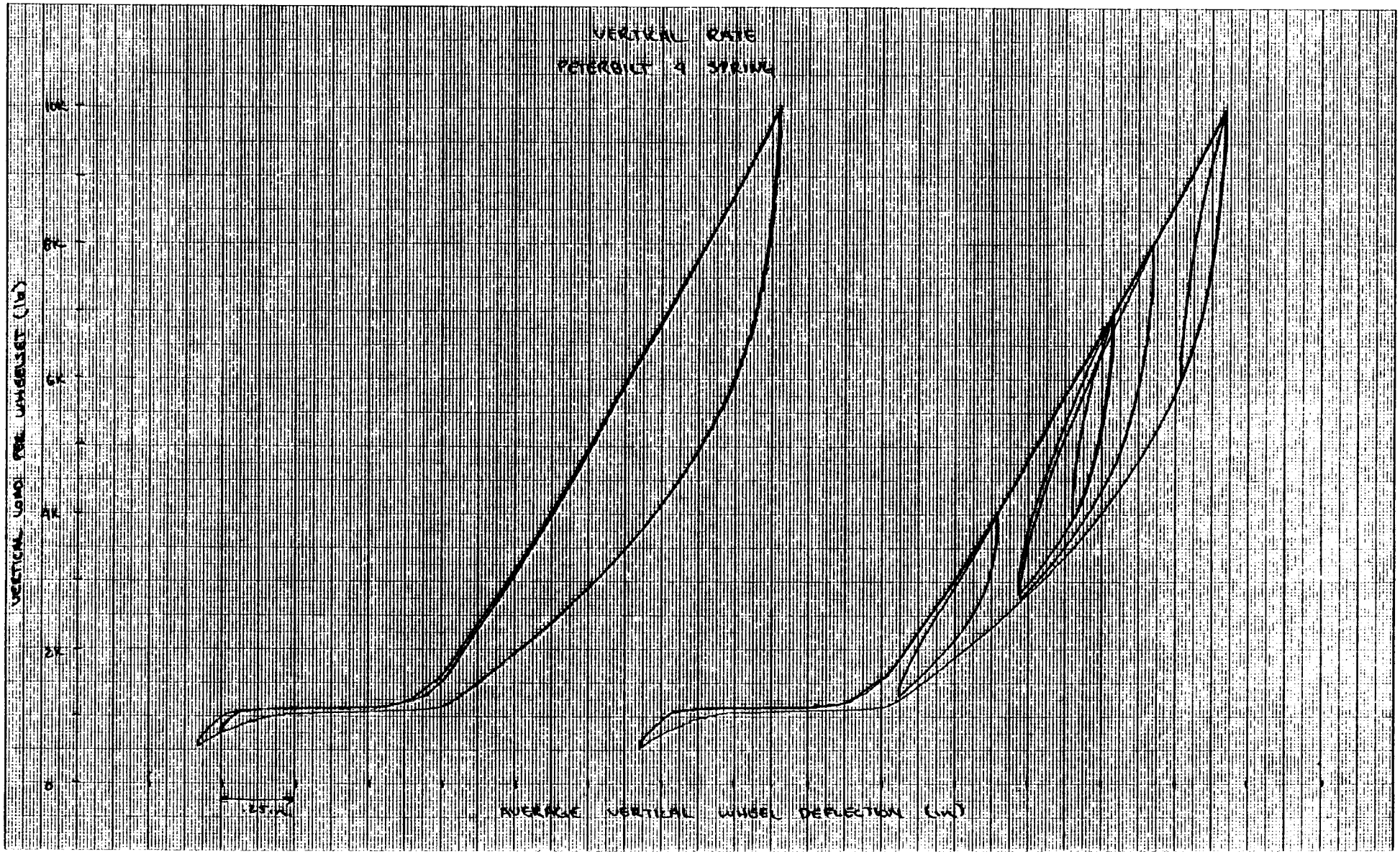
(deg/in lb) R

LATERAL FORCE COMPLIANCE F

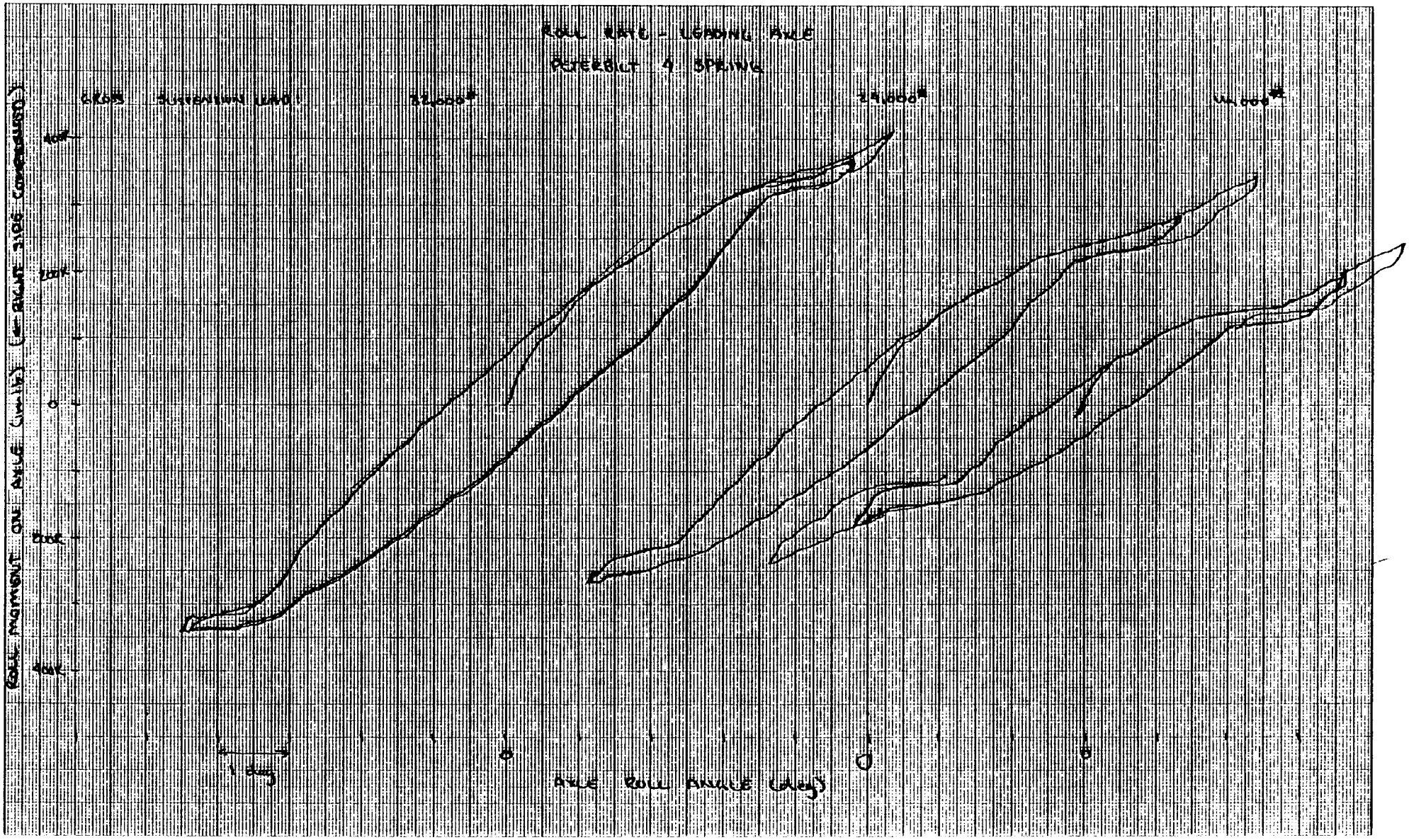
(deg/lb) R

INTERAXLE LOAD TRANSFER (BOGIE)

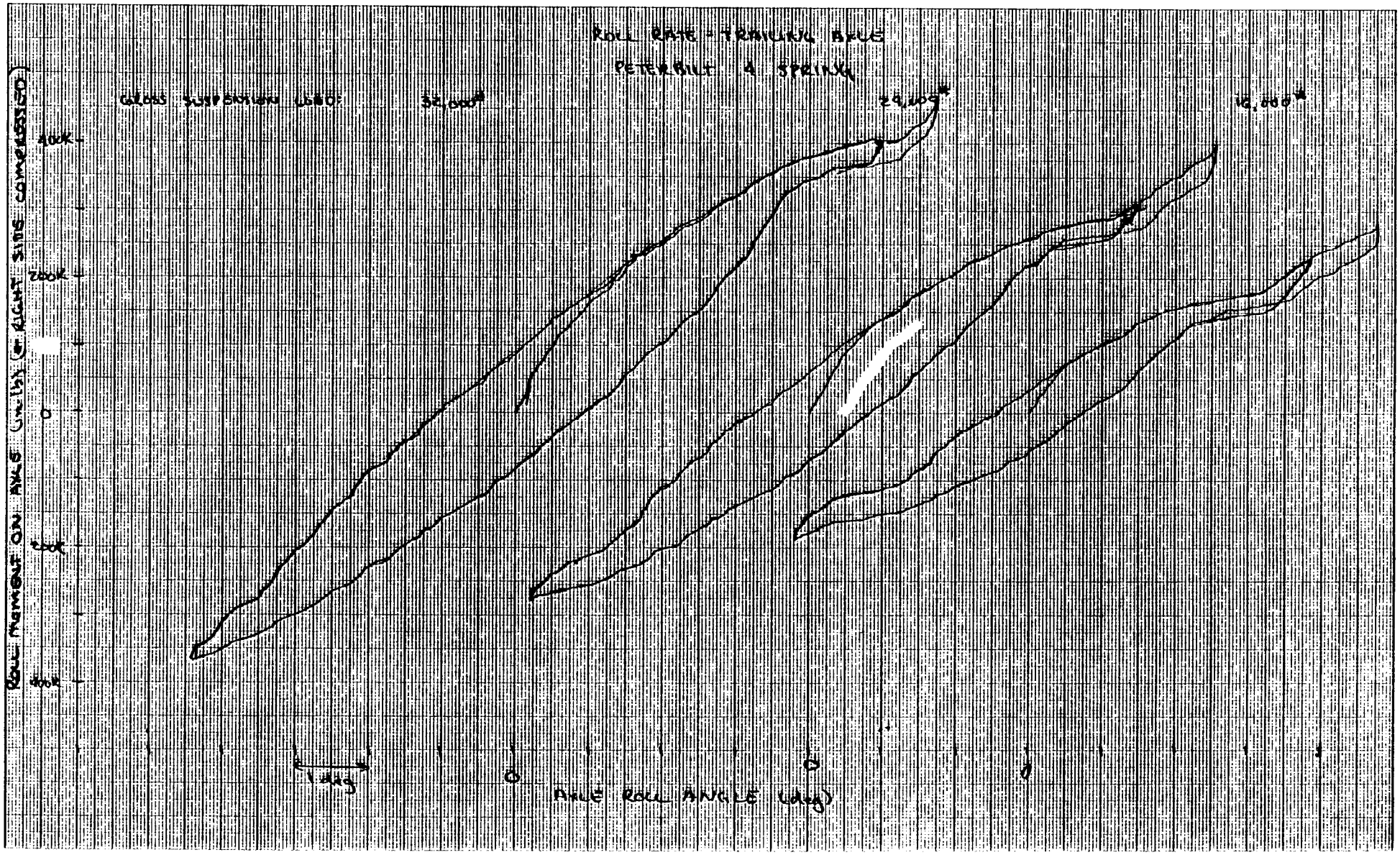
(lb/lb)



K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1510



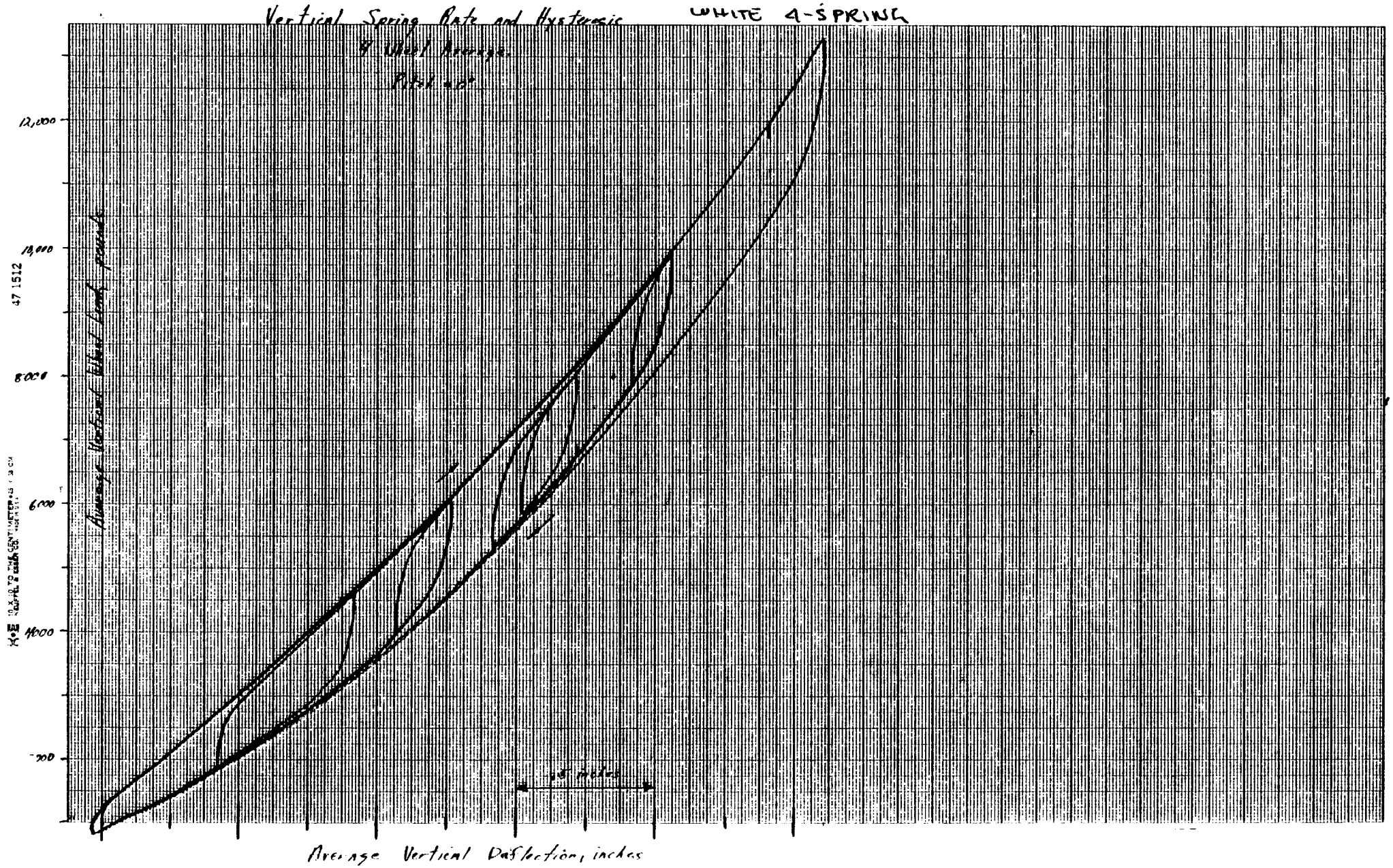
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1510

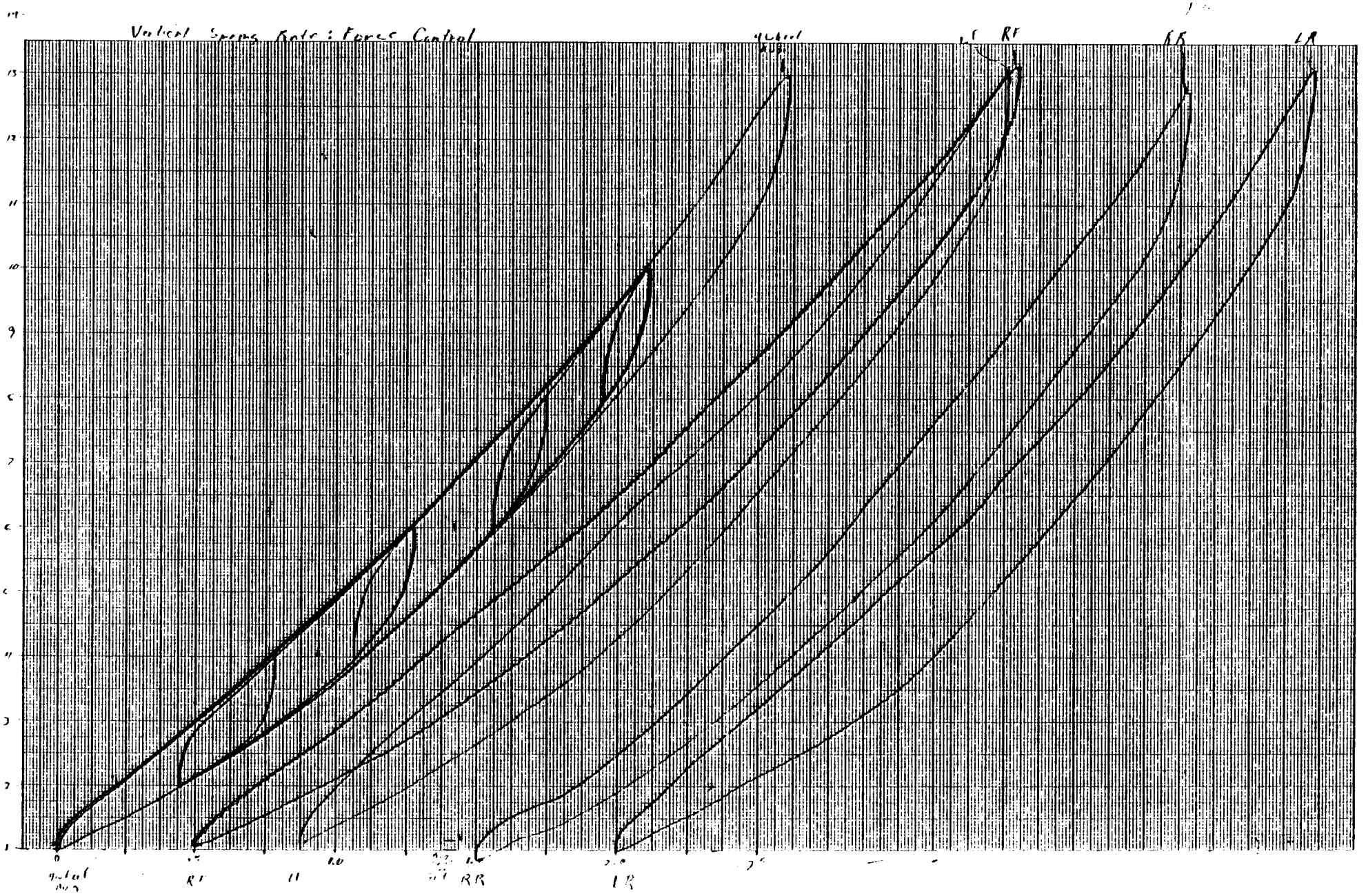


K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM. KEUFFEL & ESSER CO. MADE IN U.S.A. 47 1510

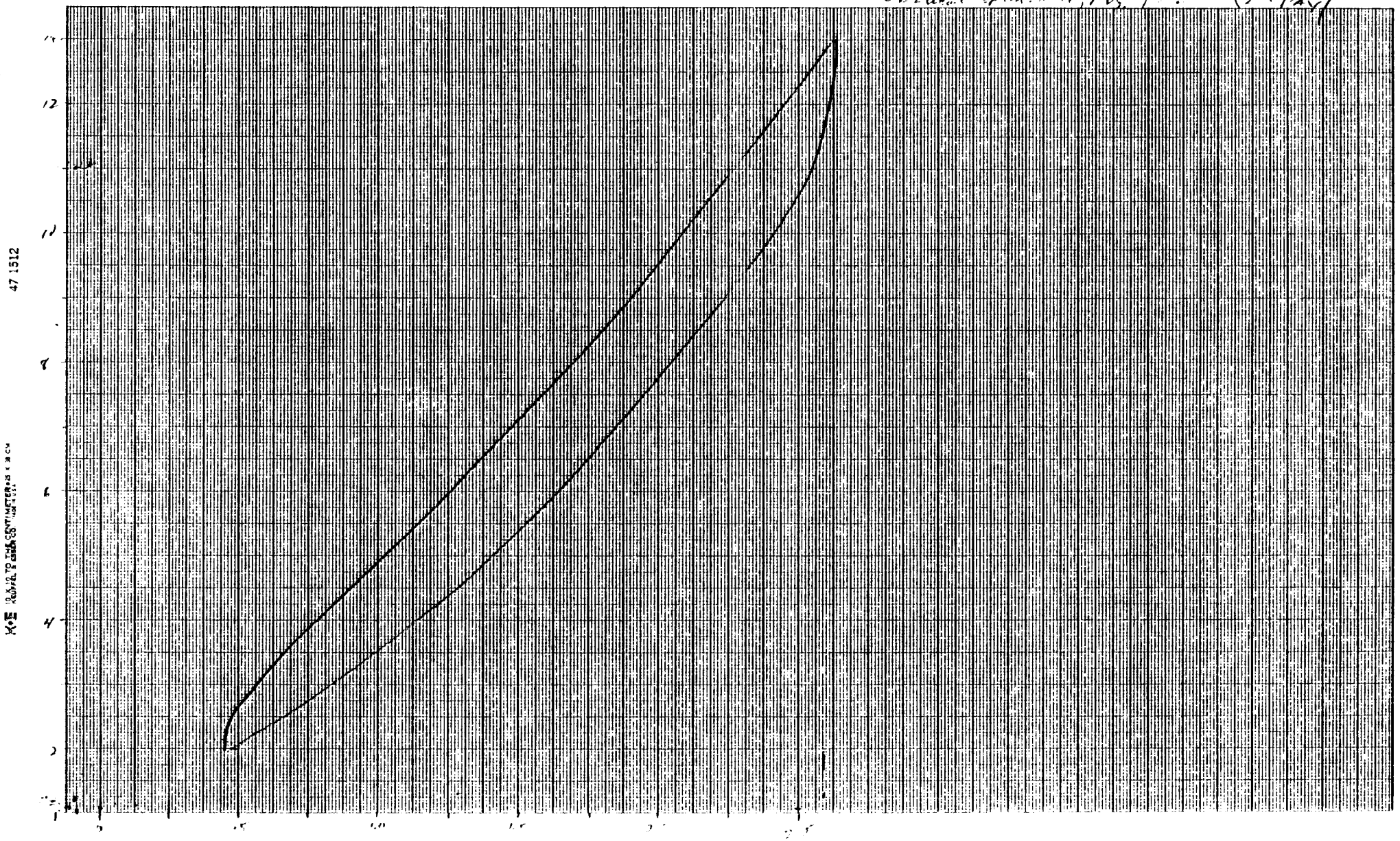
Suspension: White 4-Spring

		Susp Load 32000	24000	16000
Vertical Rate (lb/in)		4700	4400	4000
Coulomb Friction (lb)		850	800	600
ROLL RATE (in-lb/deg)	F	77.4K	73.8K	64.8K
	R	68.4K	69.8K	54K
ROLL CENTER HT (in below top of frame)	F	7.79	8.14	8.31
	R	7.60	8.11	9.49
ROLL STEER (DEG / DEG)	F	.09	.08	.01
	R	.01	.03	.04
ALIGNING MOMENT COMPLIANCE STEER (deg/in lb)	F	←	NA	→
	R			
LATERAL FORCE COMPLIANCE (deg/lb)	F	10^{-5}	nil	nil
	R	—	nil	—
INTERAXLE LOAD TRANSFER (FRONT) (lb/lb) + = Transfer rear @ 0° Pitch	L	.31	.32	.26
	R	.35	.34	.36


Vertical Spring Rate and Hysteresis
WHITE 4-SPRING
4 Wheel Average.
Pitch = 0°
12,000
10,000
8000
6000
4000
Average Vertical Wheel Load, pounds
Average Vertical Deflection, inches
47 1512

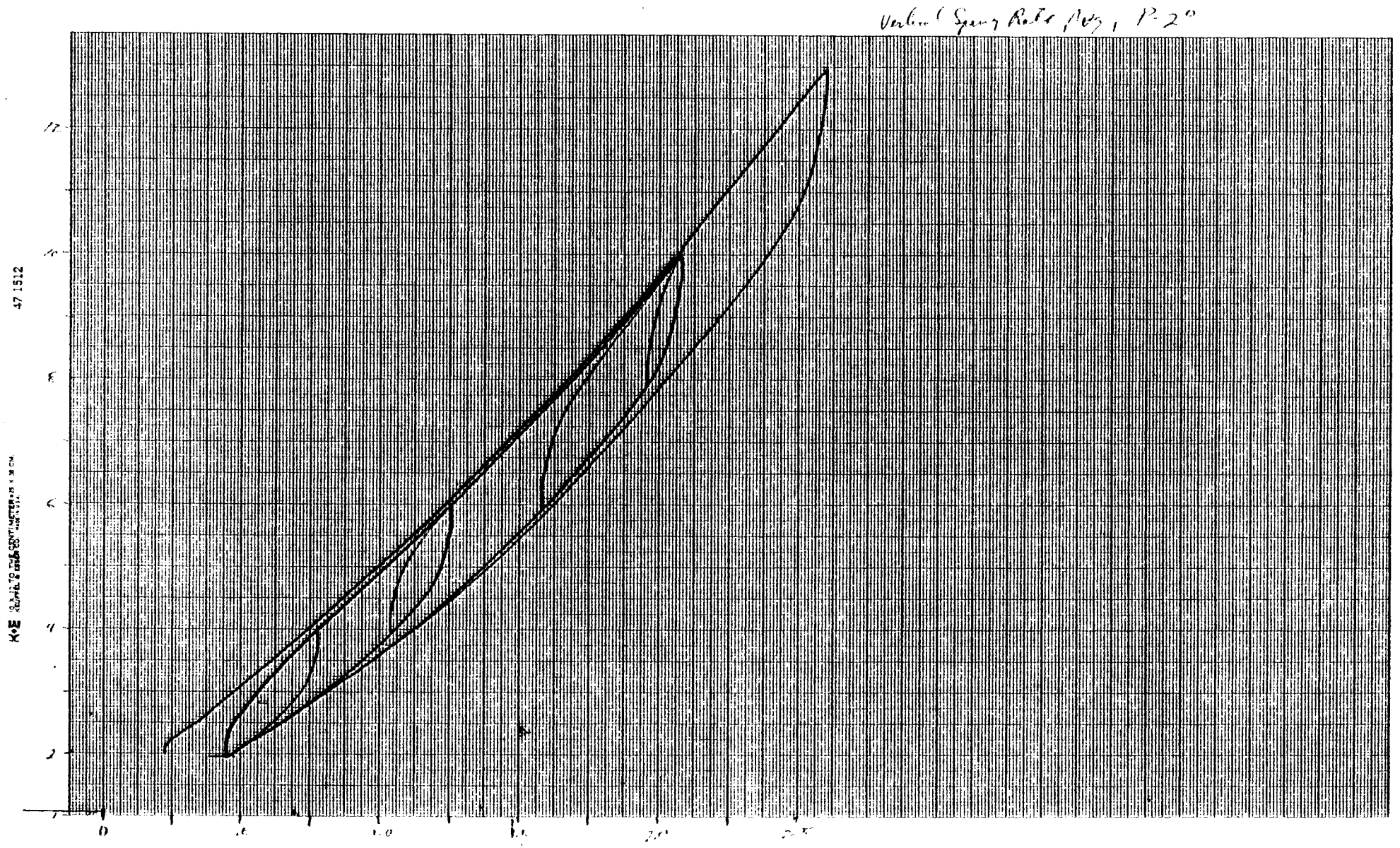

Vertical Spring Rate : Force Control
RF
RR
LR

Vertical Spun Rule, Avg. [illegible] (2nd Pay)

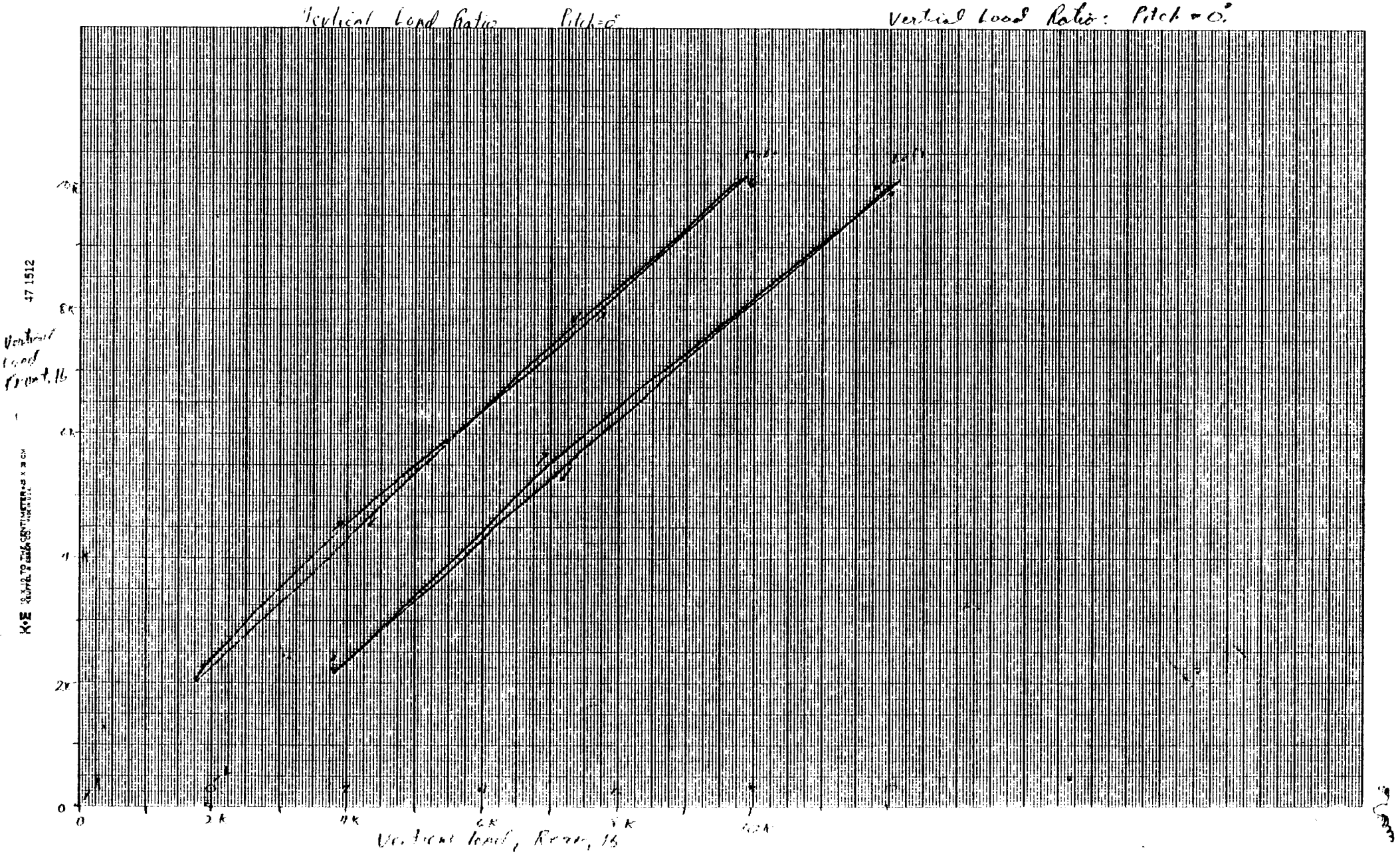


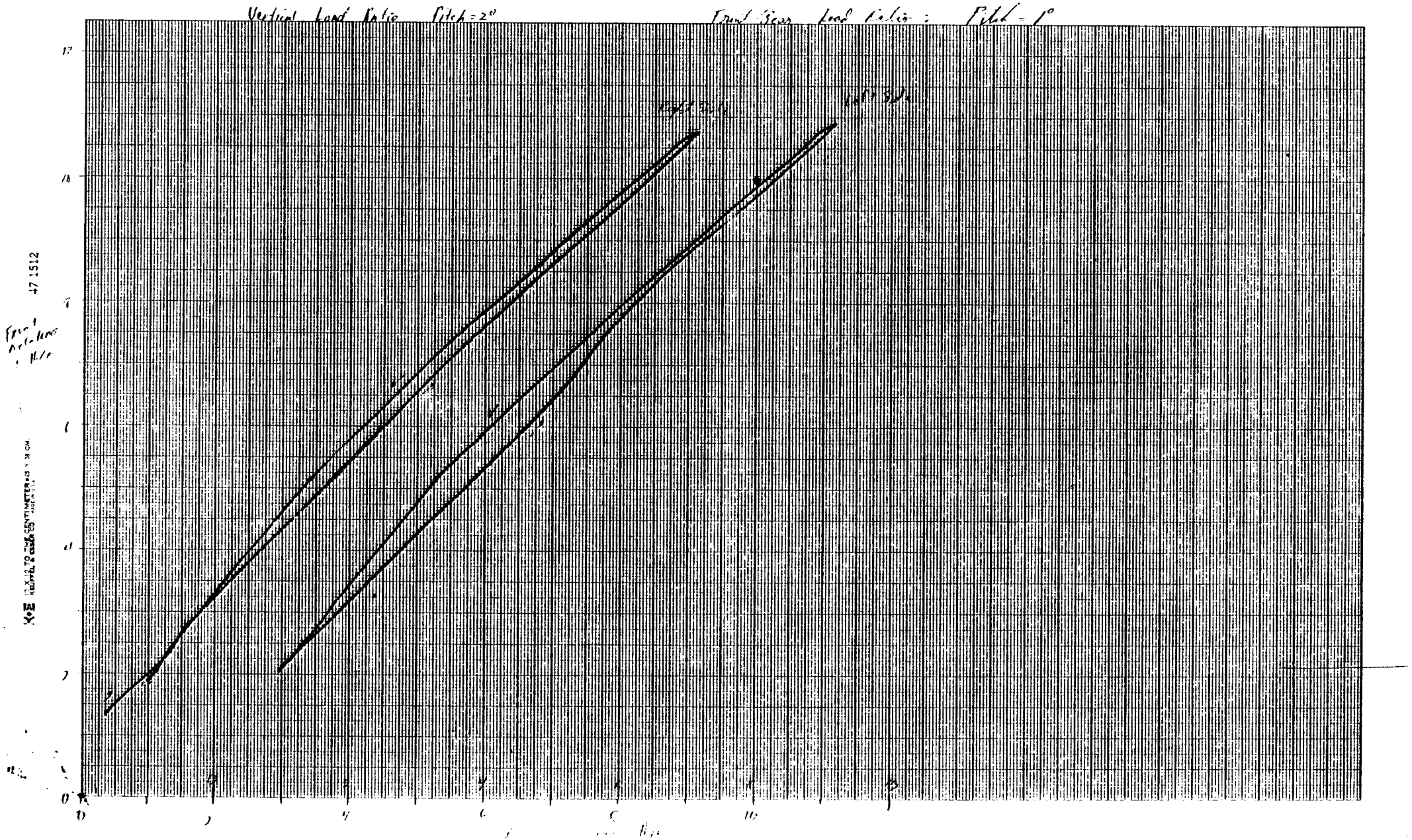
K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512

Vertical Spring Rate Avg, P-2°



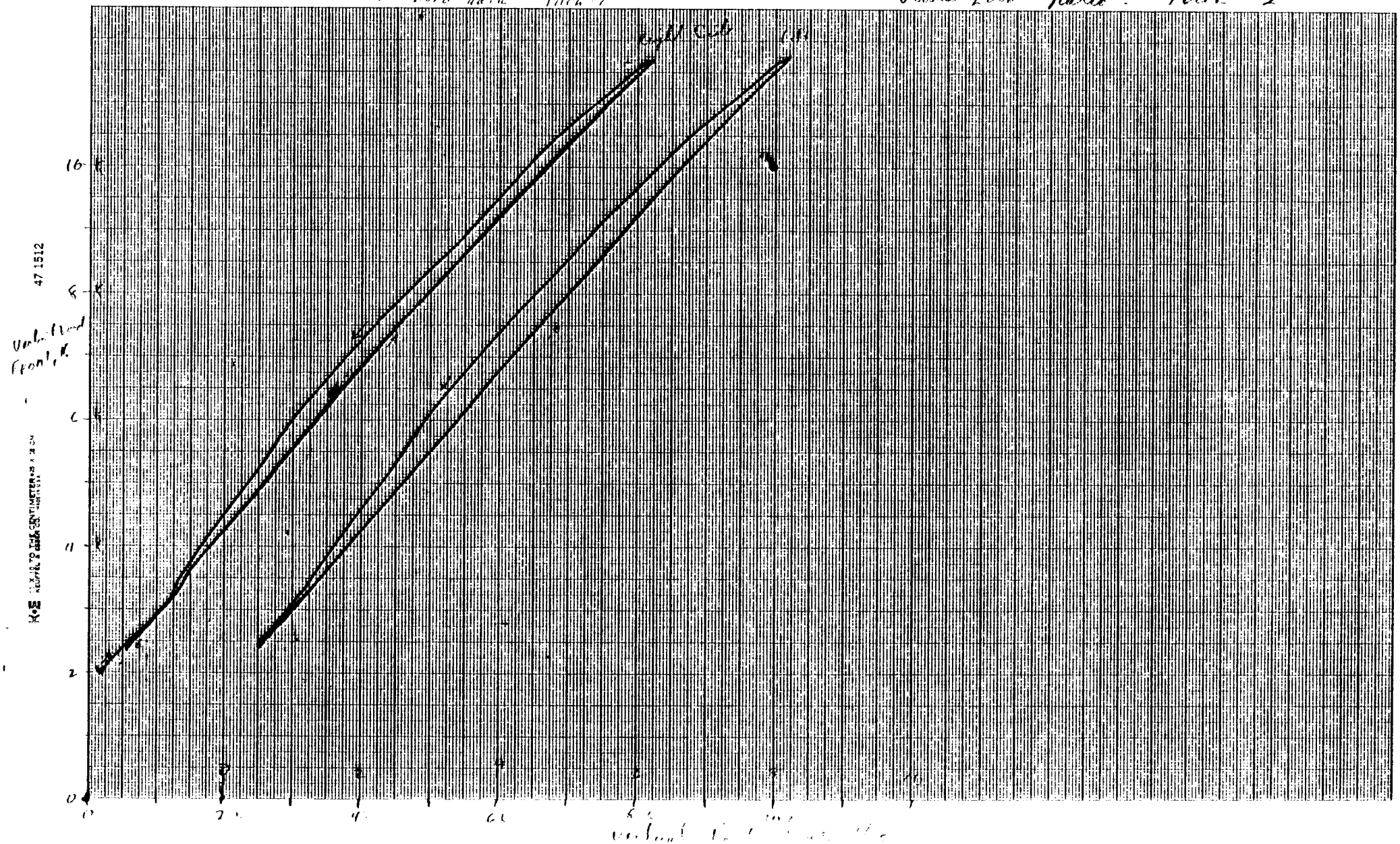
K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM.
47 1512


Vertical Load Ratio Pitch=0°
Vertical Load Ratio: Pitch = 0°
Vertical Load Front, lb
Vertical Load, Rear, lb
0
2k
4k
6k
8k
10k
47 1512
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.

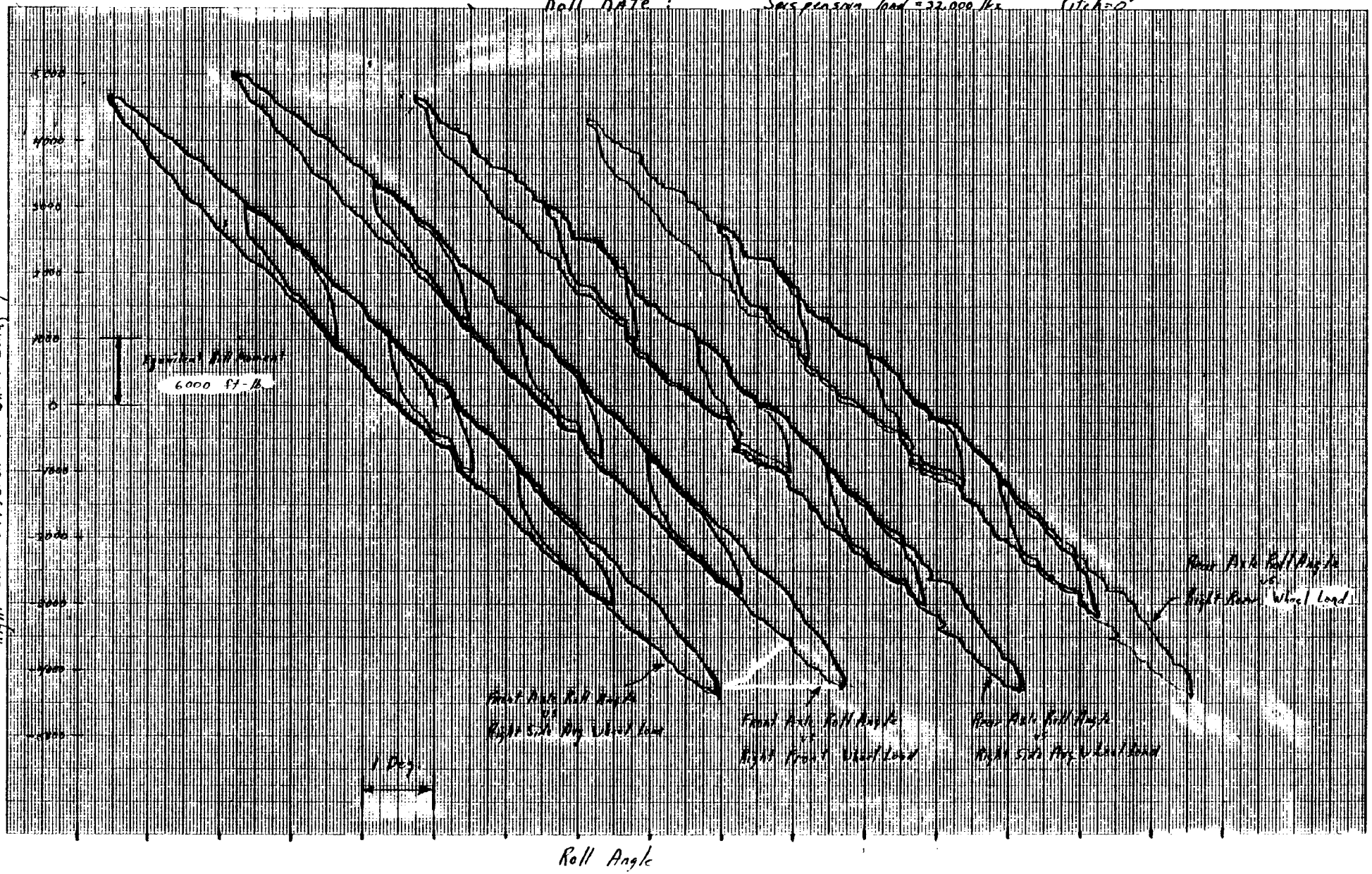

Vertical Load Ratio Pitch = 2°
Front Spar Load Ratio : Pitch = 1°
47 1512

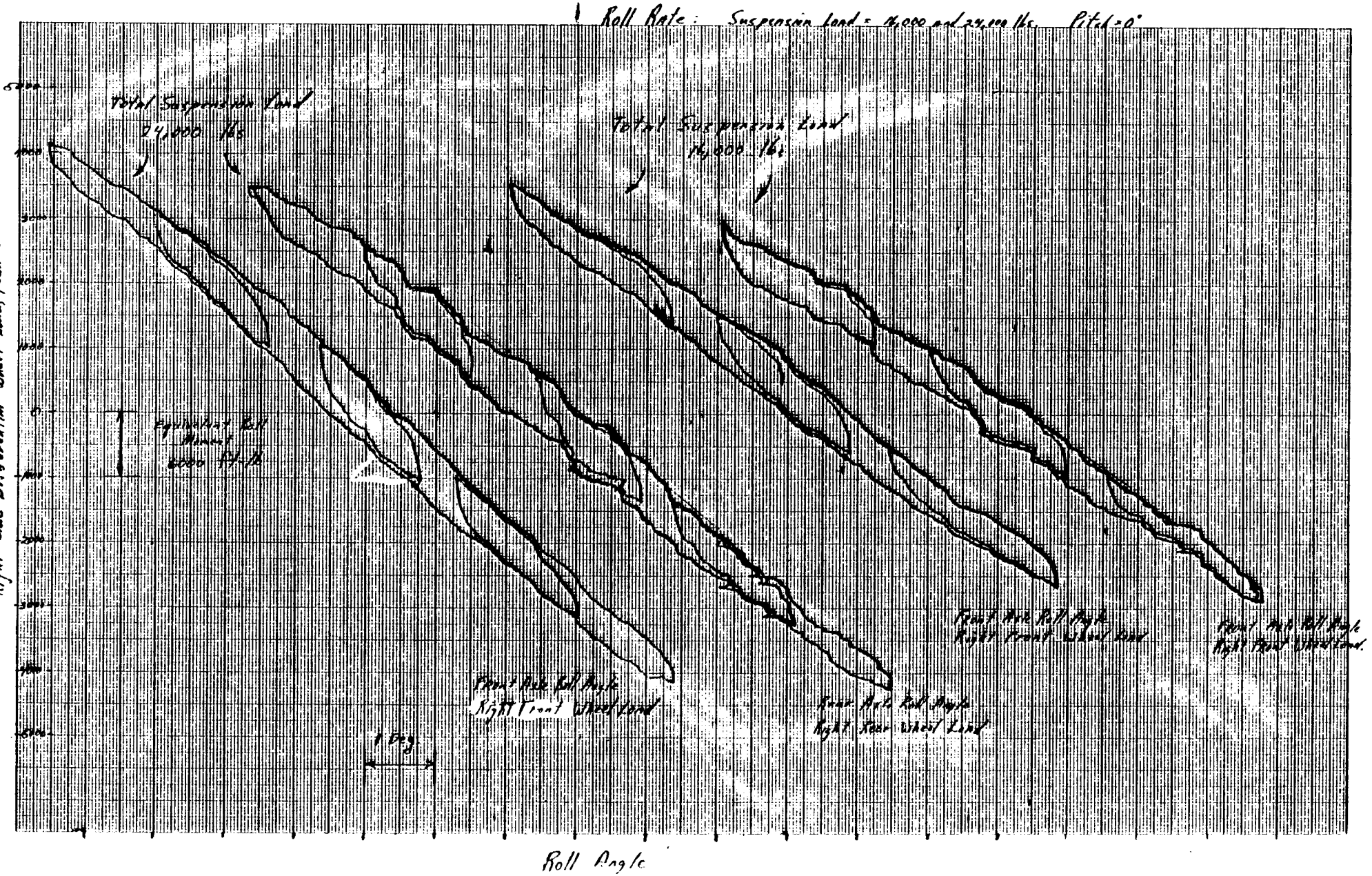
Vertical Load Ratio Pitch = 1°

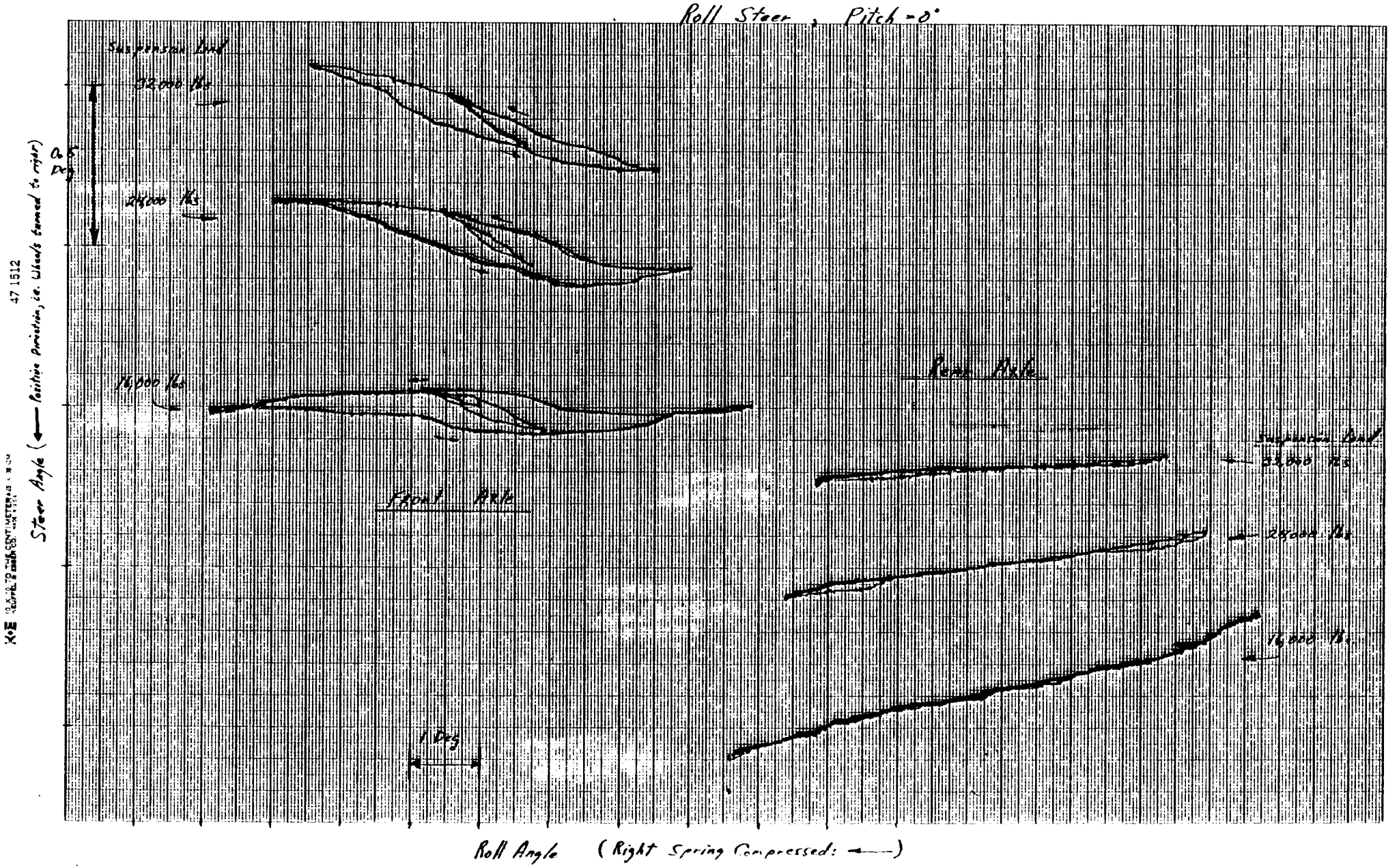
Vertical Load Ratio: Pitch = 2°

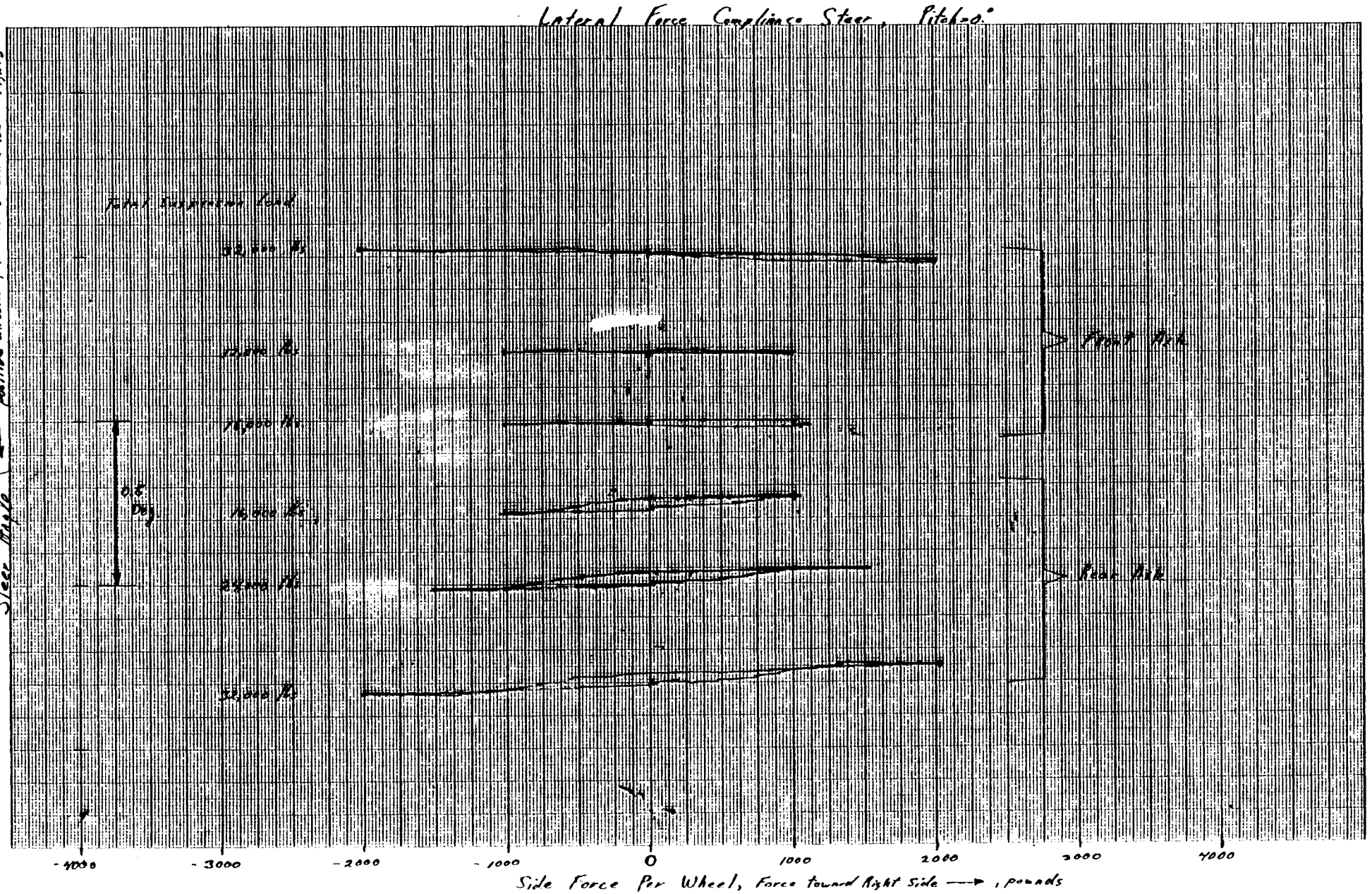


K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512

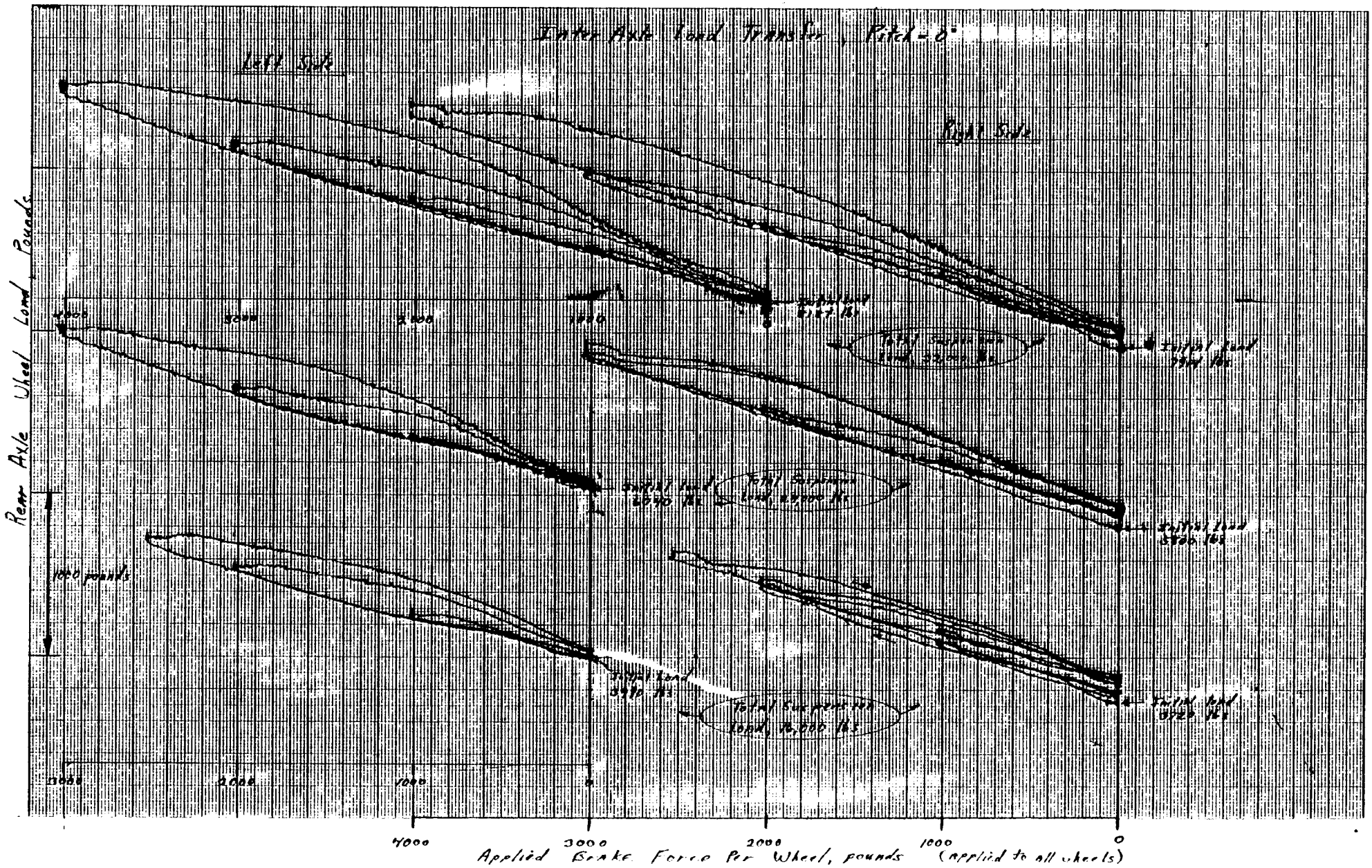

Roll Rate ;
Suspension load = 32,000 lbs
Pitch = 0°
Right Side Differential Wheel Load, pounds
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
Figure-8 Roll Moment
6,000 ft-lb
1 Deg.
Front Axle Roll Angle
vs.
Right Side Rear Wheel Load
Front Axle Roll Angle
vs.
Right Front Wheel Load
Rear Axle Roll Angle
vs.
Right Side Rear Wheel Load
Rear Axle Roll Angle
vs.
Right Rear Wheel Load
Roll Angle

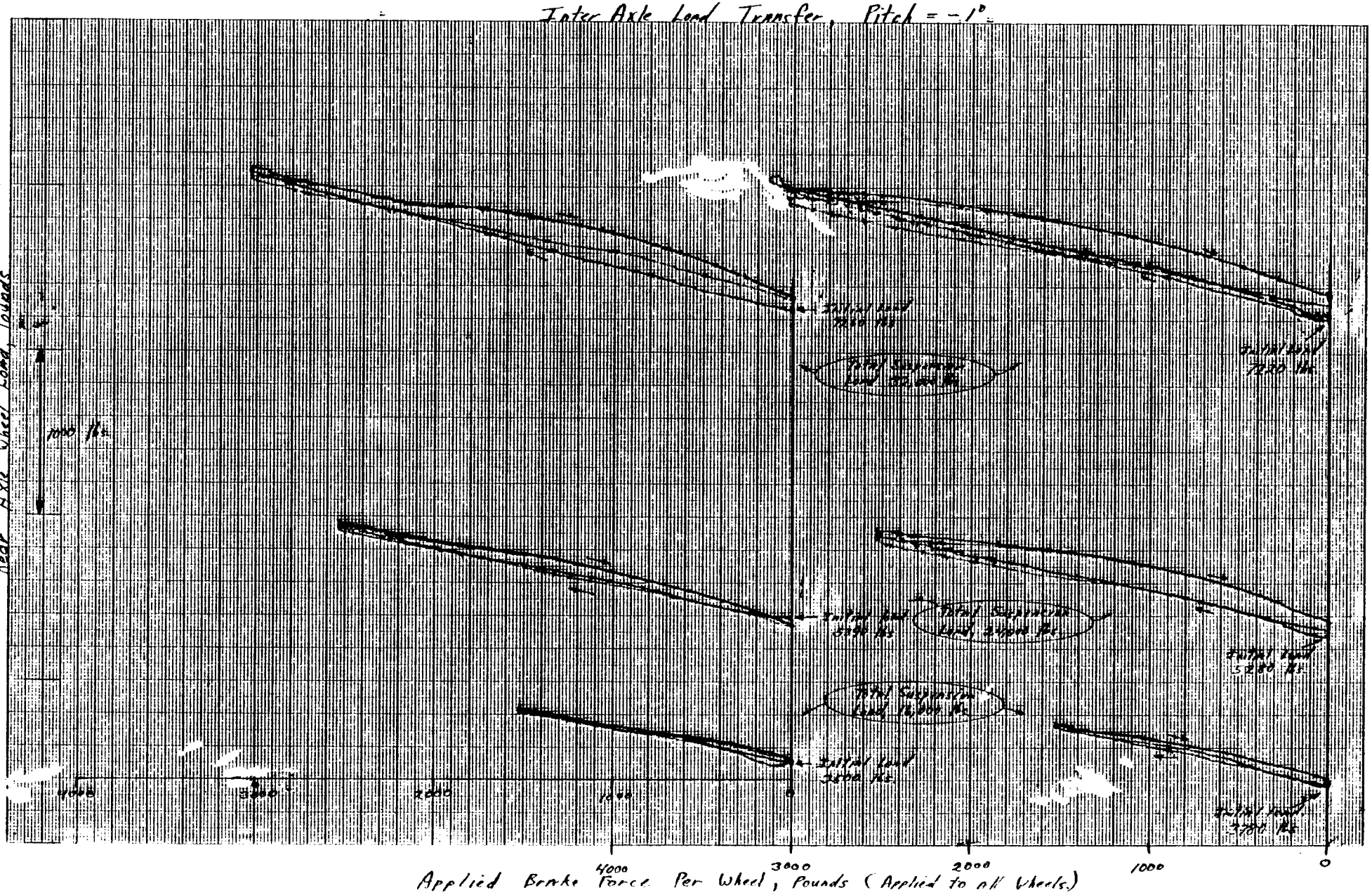

Roll Rate: Suspension load = 14,000 and 24,000 lbs. Pitch = 0°
Total Suspension Load 24,000 lbs
Total Suspension Load 14,000 lbs
Equivalent Roll Moment 6000 ft-lb
Front Axle Roll Angle Right Front Wheel Load
Front Axle Roll Angle Right Front Wheel Load
Front Axle Roll Angle Right Rear Wheel Load
1 Deg.
Right Side Differential Wheel Load, pounds
Roll Angle
47 1512


Roll Steer, Pitch -0°
Suspension Load
32000 lbs
24000 lbs
16000 lbs
Rear Axle
Front Axle
Suspension Load
32000 lbs
24000 lbs
16000 lbs
1 Deg
Steer Angle (← Positive Deviation, i.e. Wheels turned to right)
Roll Angle (Right Spring Compressed: ←)

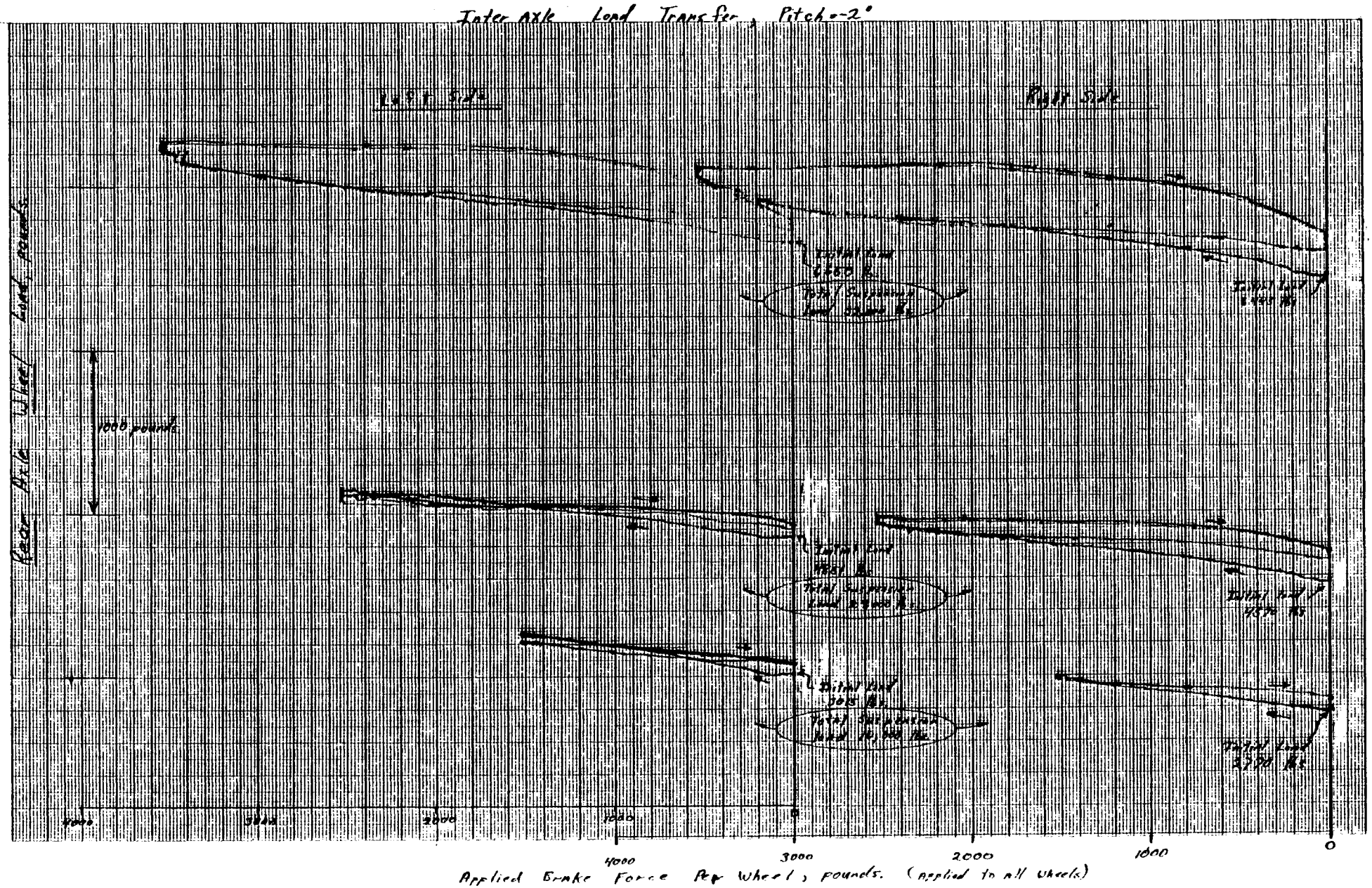


K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM. KEUFFEL & ESSER CO. MADE IN U.S.A. 47 1512

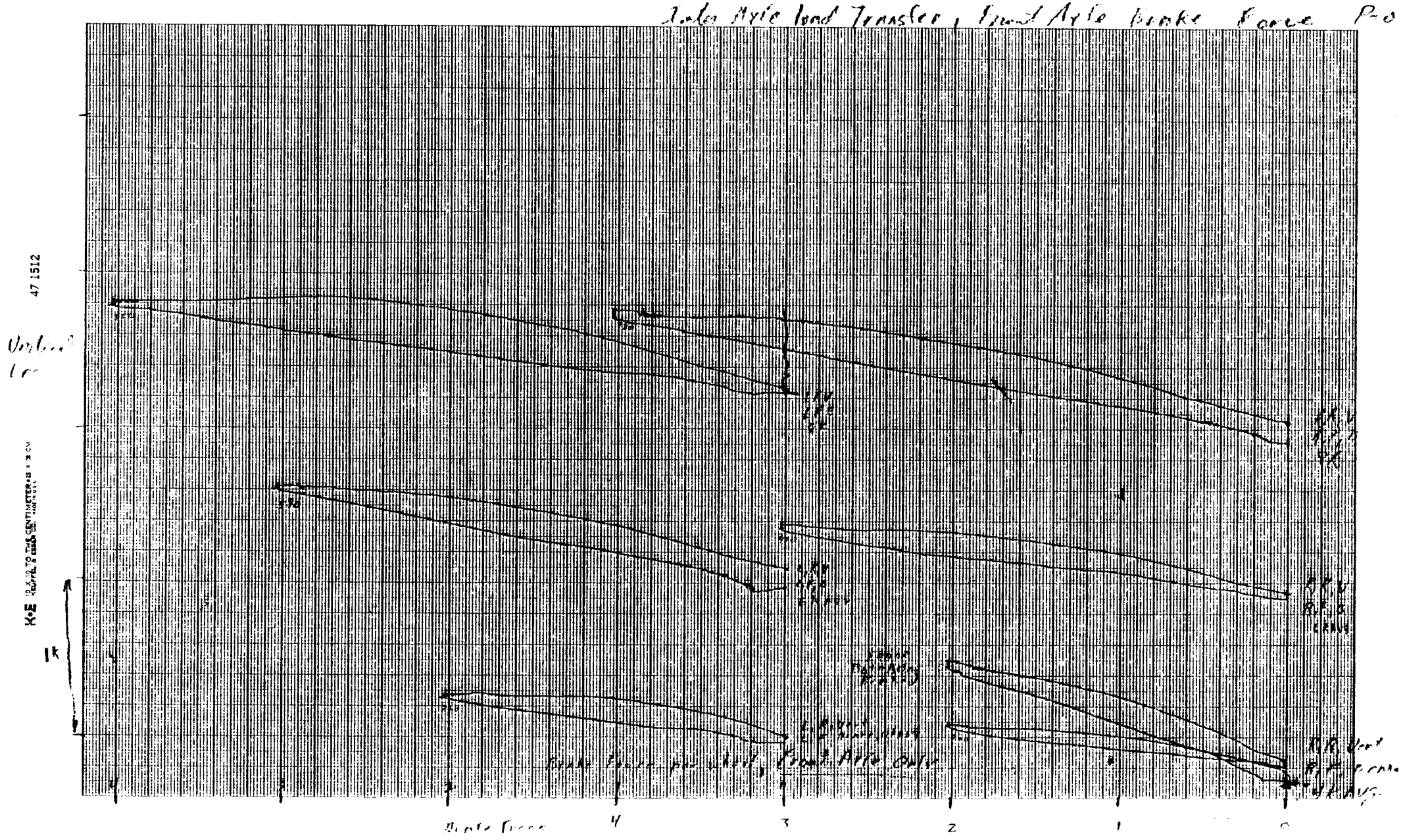

Inter Axle Load Transfer, Pitch = 0°
Left Side
Right Side
Rear Axle Wheel Load, Pounds
1000 pounds
4000
3000
2000
1000
0
Applied Brake Force Per Wheel, pounds (applied to all wheels)



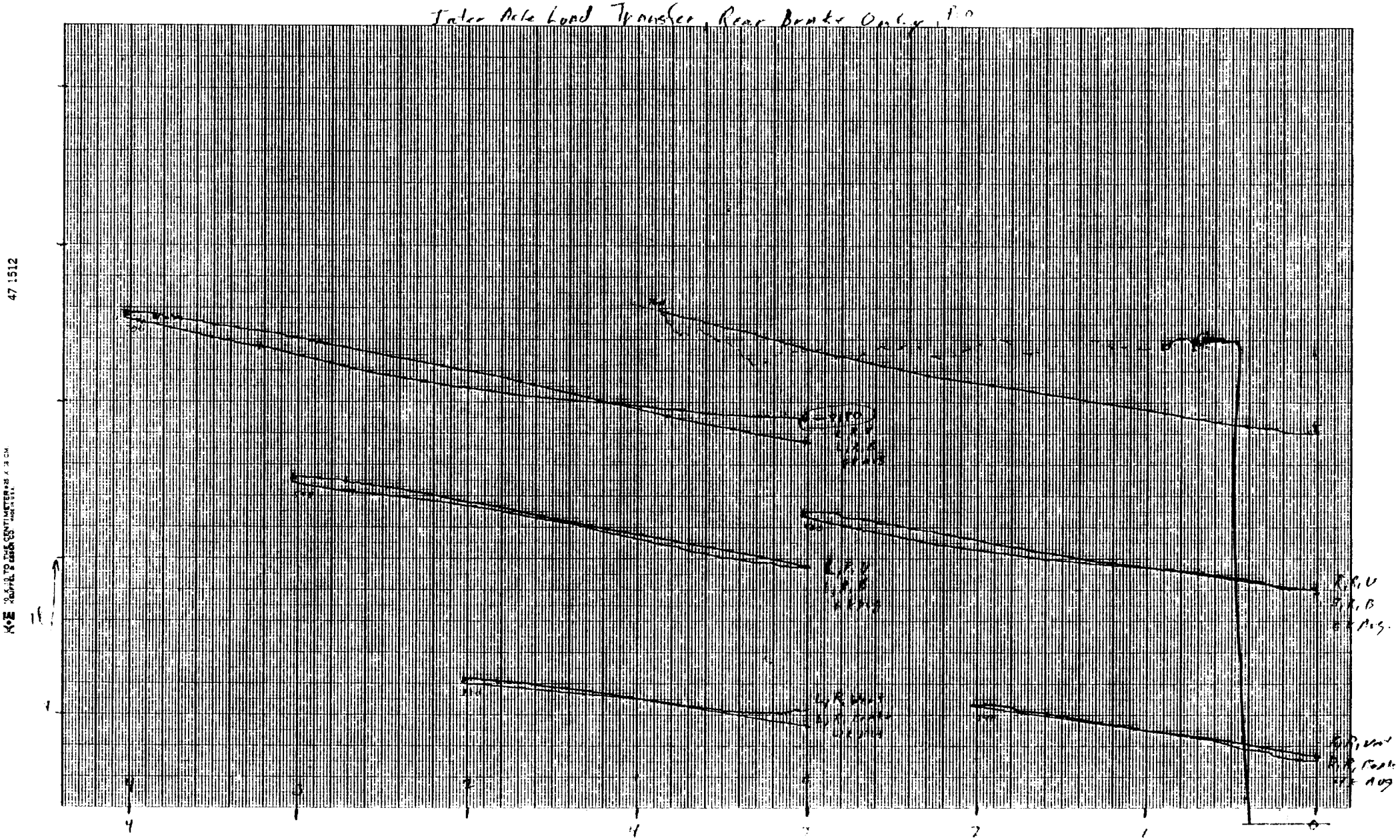
K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM. KEUFFEL & ESSER CO. MADE IN U.S.A. 47 1512



K+E 10 X 10 TO THE CENTIMETER 25 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512


Axle load Transfer, Front Axle Brake Force
Brake Force per wheel, Front Axle Only
1k
4
3
2
1
0
47 1512
K+E 10 X 10 TO THE CENTIMETER

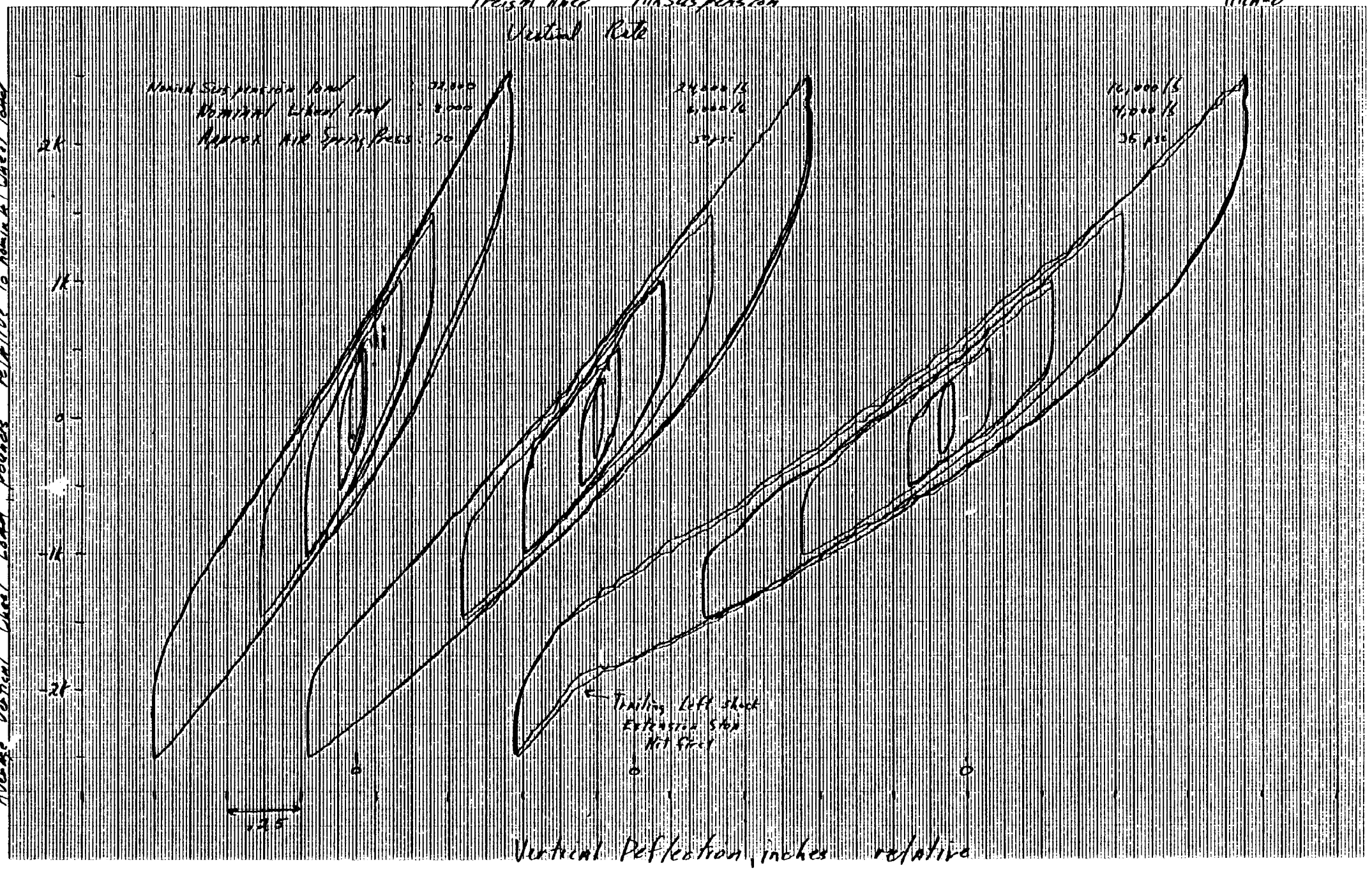
Inter Axle Load Transfer, Rear Brake Only, P.O

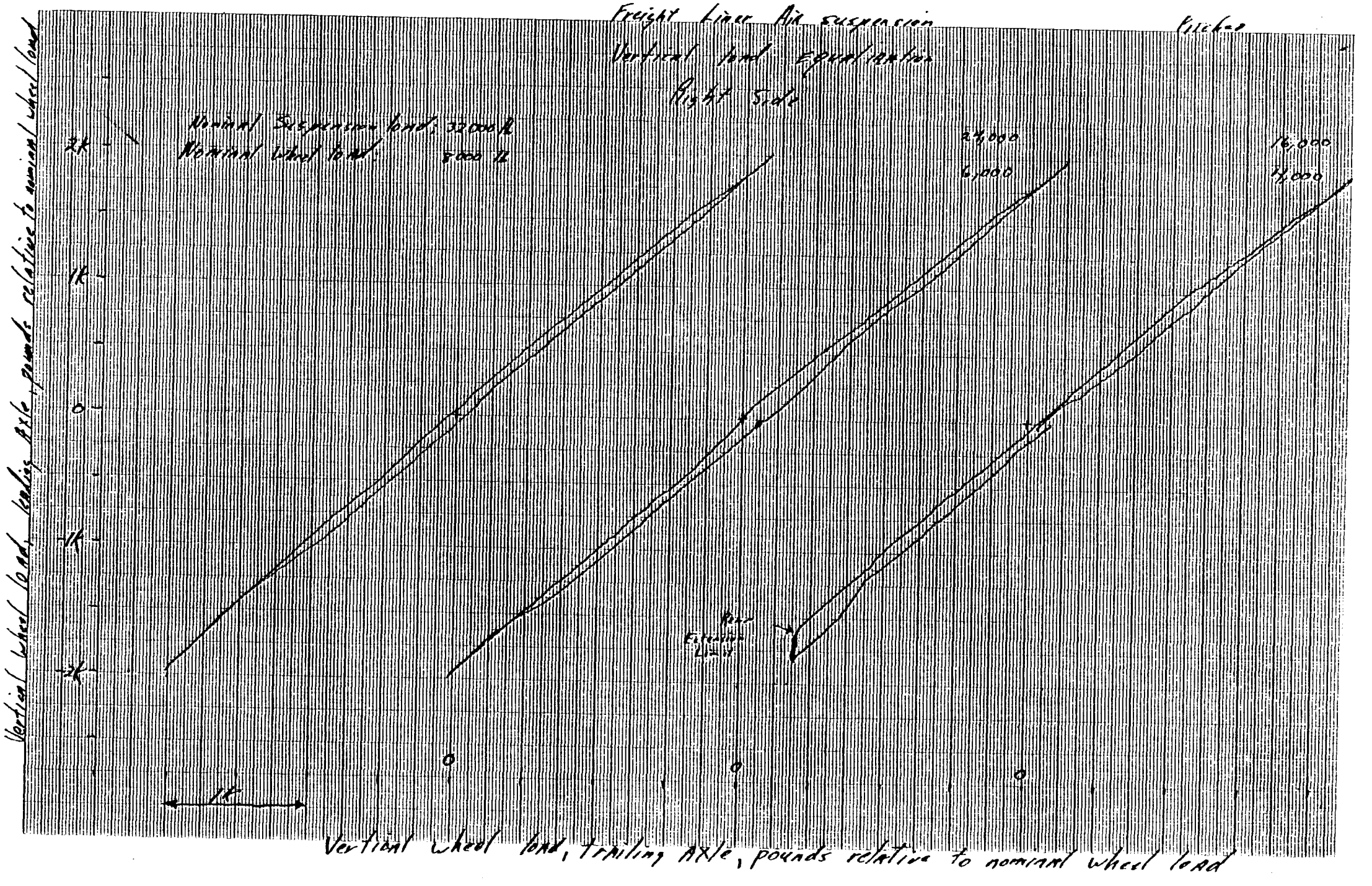


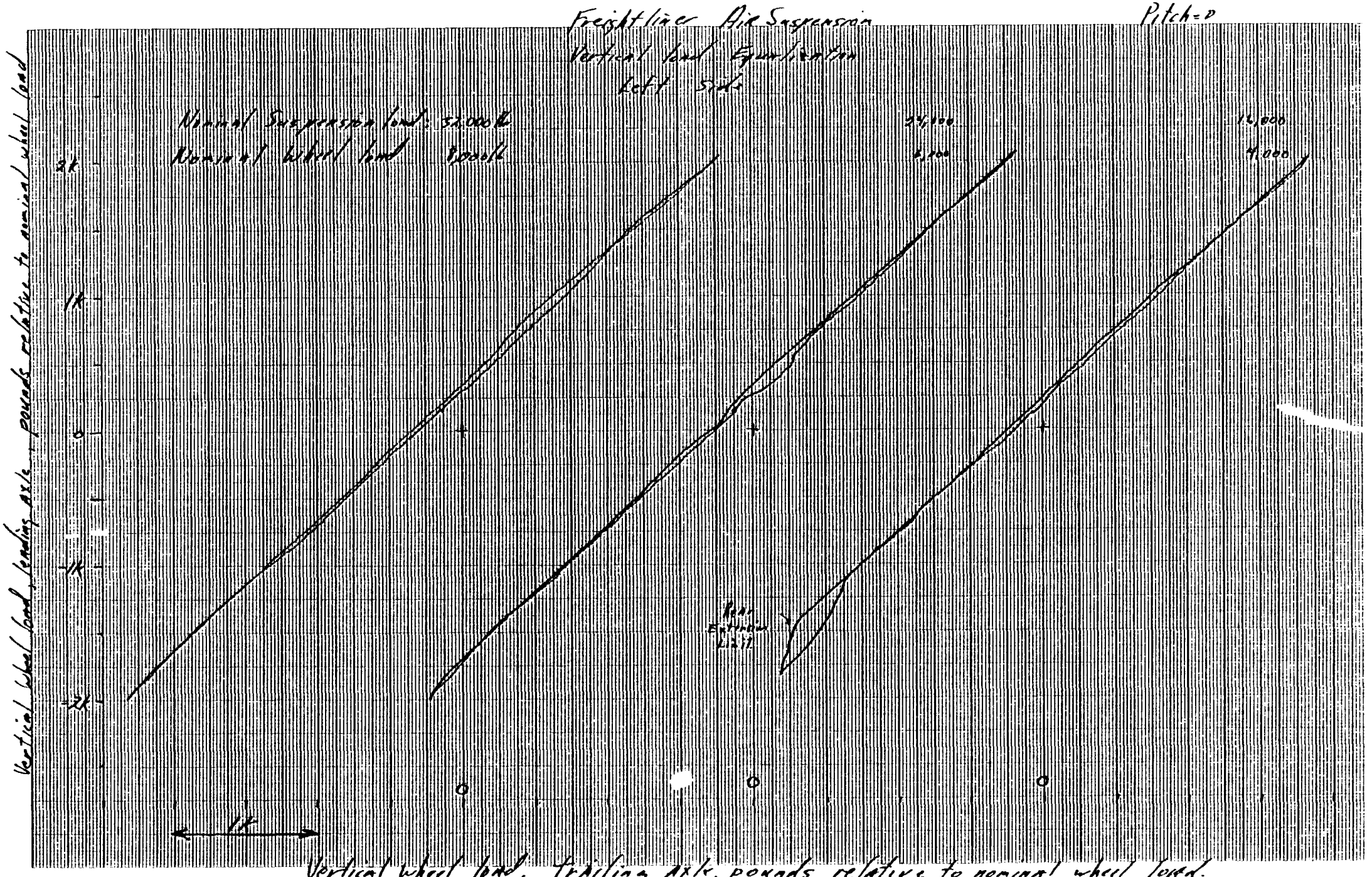
K+E 10 X 10 TO THE CENTIMETER 25 X 25 CM. KEUFFEL & ESSER CO. MADE IN U.S.A. 47 1512

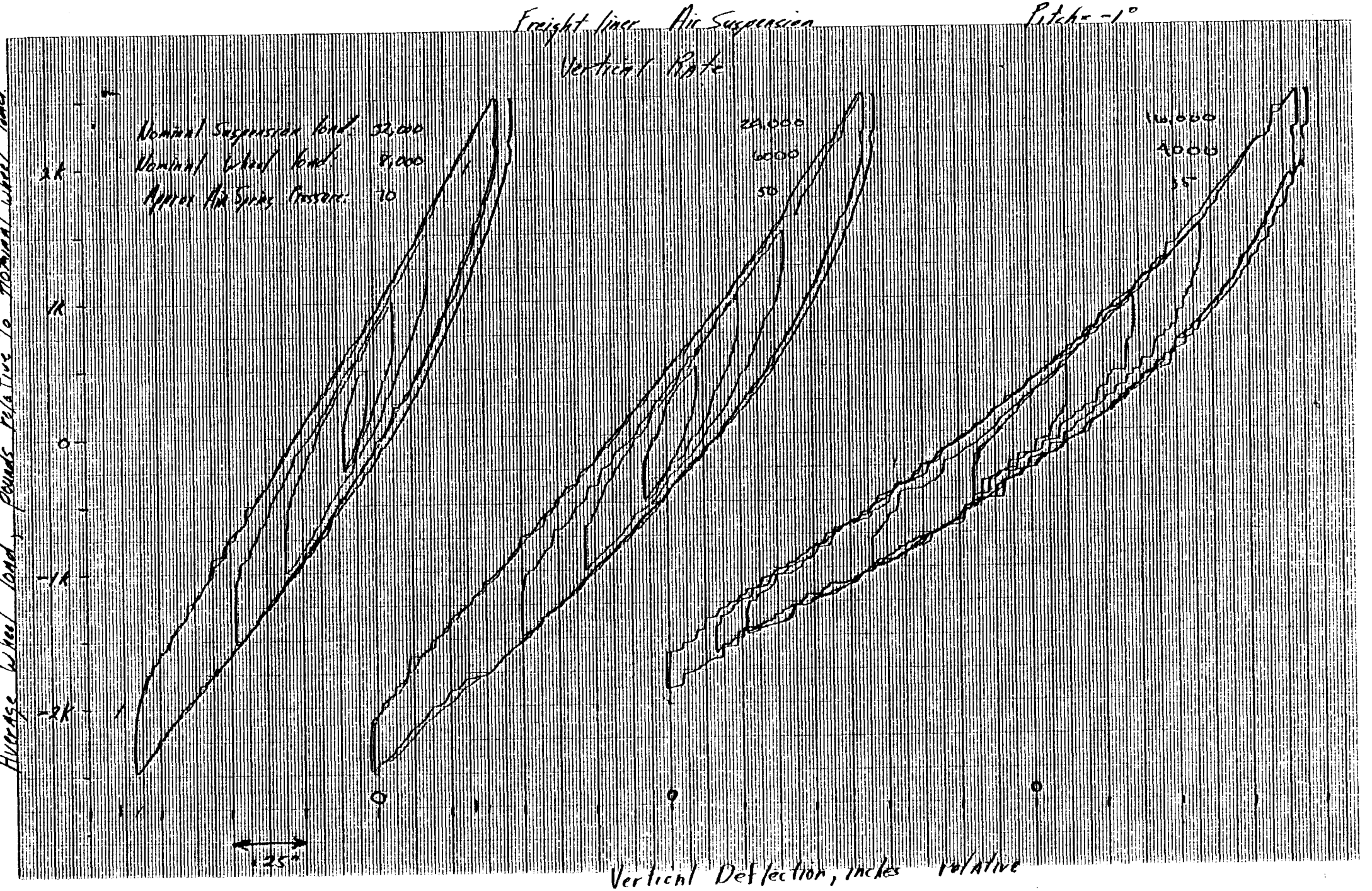
SUSPENSION: FREIGHTLINER AIR SUSPENSION

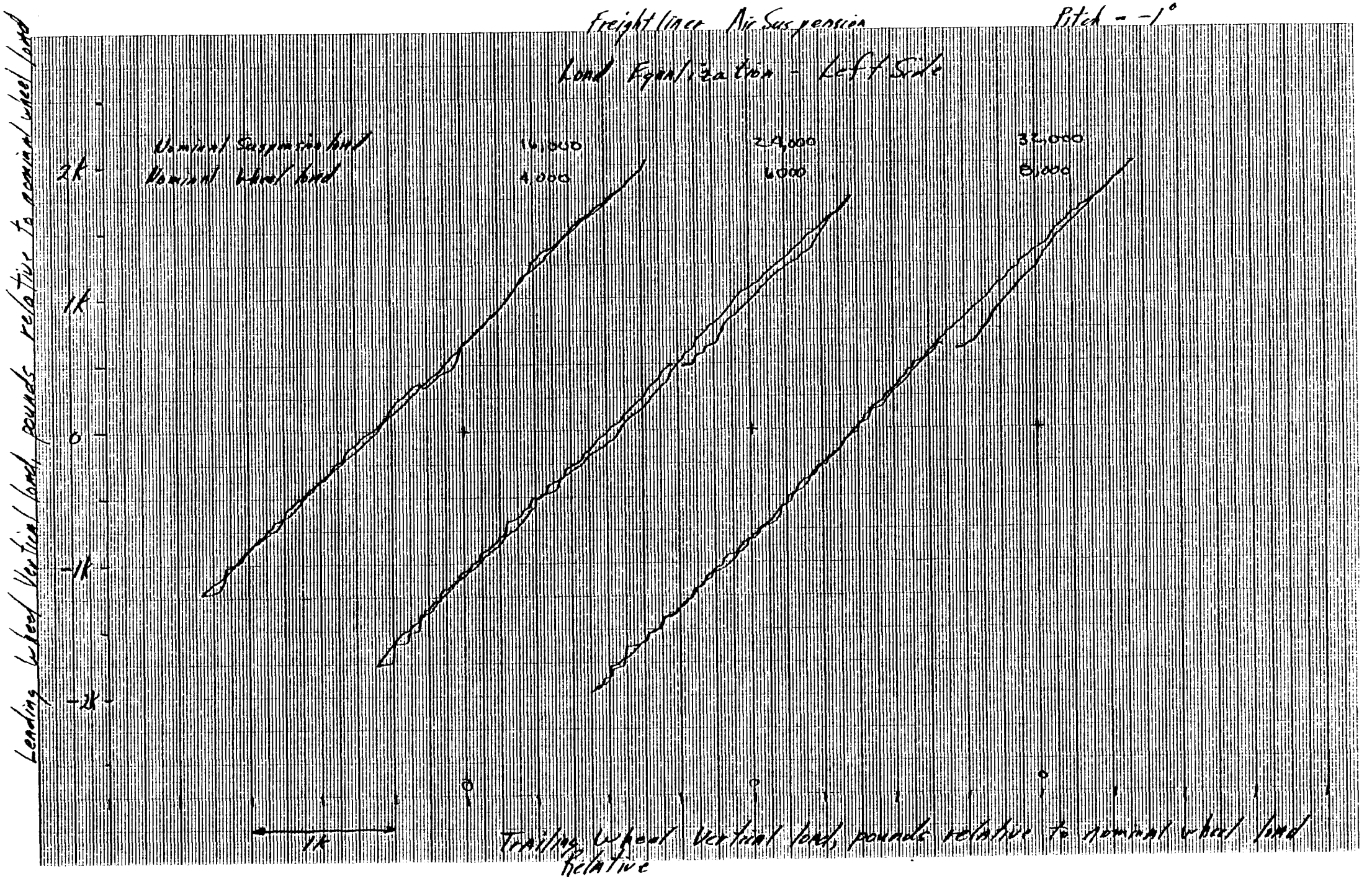
		Susp Load 32000	24000	16000
Vertical Rate (lb/in)		3500	2600	1700
Coulomb Friction (lb)		625	500	500
ROLL RATE (in-lb/deg)	F	105K	85K	80K
	R	95K	85K	85K
ROLL CENTER HT (in below top of frame)	F	←	NA	→
	R			
ROLL STEER (DEG / DEG)	F	.01	———	
	R	nil	———	
ALIGNING MOMENT COMPLIANCE STEER (deg/in lb)	F	———	4×10^{-6}	———
	R	———	4×10^{-6}	———
LATERAL FORCE COMPLIANCE (deg/lb)	F	———	4×10^{-6}	———
	R	———	3×10^{-6}	———
INTERAXLE LOAD TRANSFER (BUMP) (lb/lb)		———	nil	———

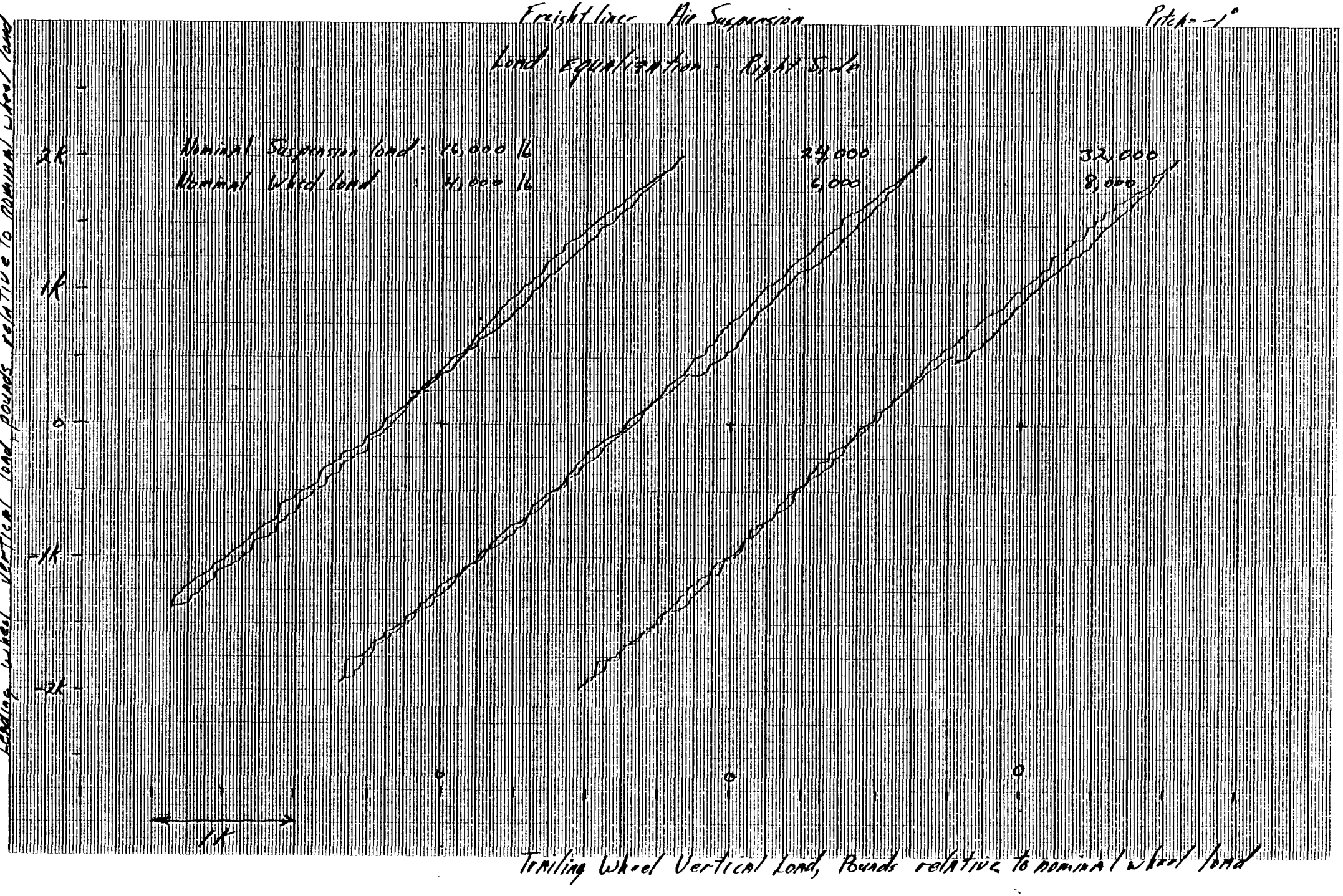

Freight Liner Air Suspension
Vertical Rate
Pitch-0
Nominal Suspension Load : 32,000
Nominal Wheel Load : 8,000
Approx Air Spring Press : 70
24,000 lb
6,000 lb
50 psi
16,000 lb
4,000 lb
35 psi
2k
1k
0
-1k
-2k
Average Vertical Wheel Load, pounds relative to nominal wheel load
Trailing Left Shock
Extension Stop
Hit First
0
0
0
.25
Vertical Deflection, inches relative

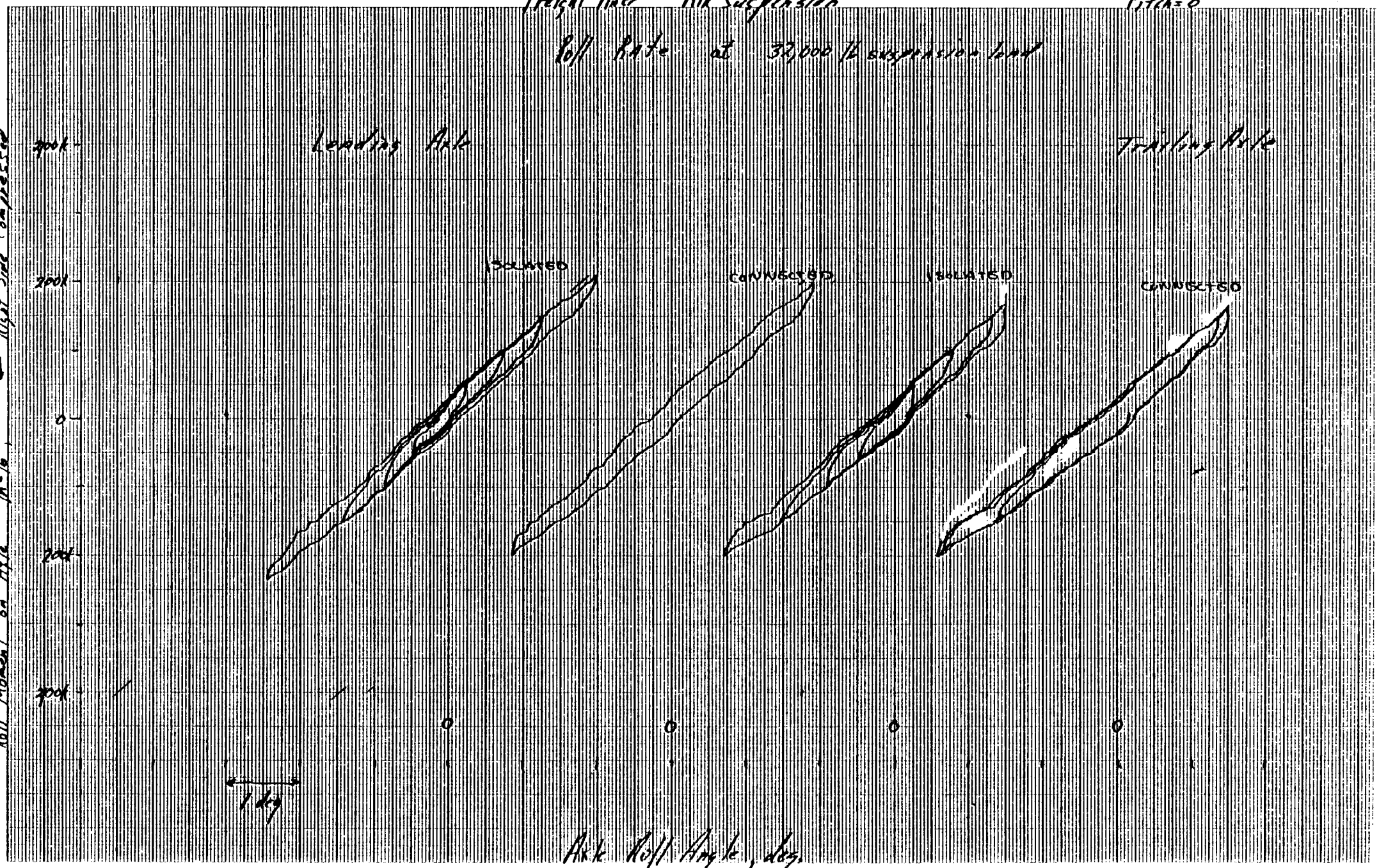

Freight Liner Air suspension
Vertical load Equalization
Right Side
Pitcher
Nominal Suspension load: 32000 lb
Nominal Wheel load: 8000 lb
24,000
6,000
16,000
4,000
2k
1k
0
-1k
-2k
Rear Extension Limit
0
0
0
1k
Vertical wheel load, leading Axle, pounds relative to nominal wheel load
Vertical wheel load, trailing Axle, pounds relative to nominal wheel load

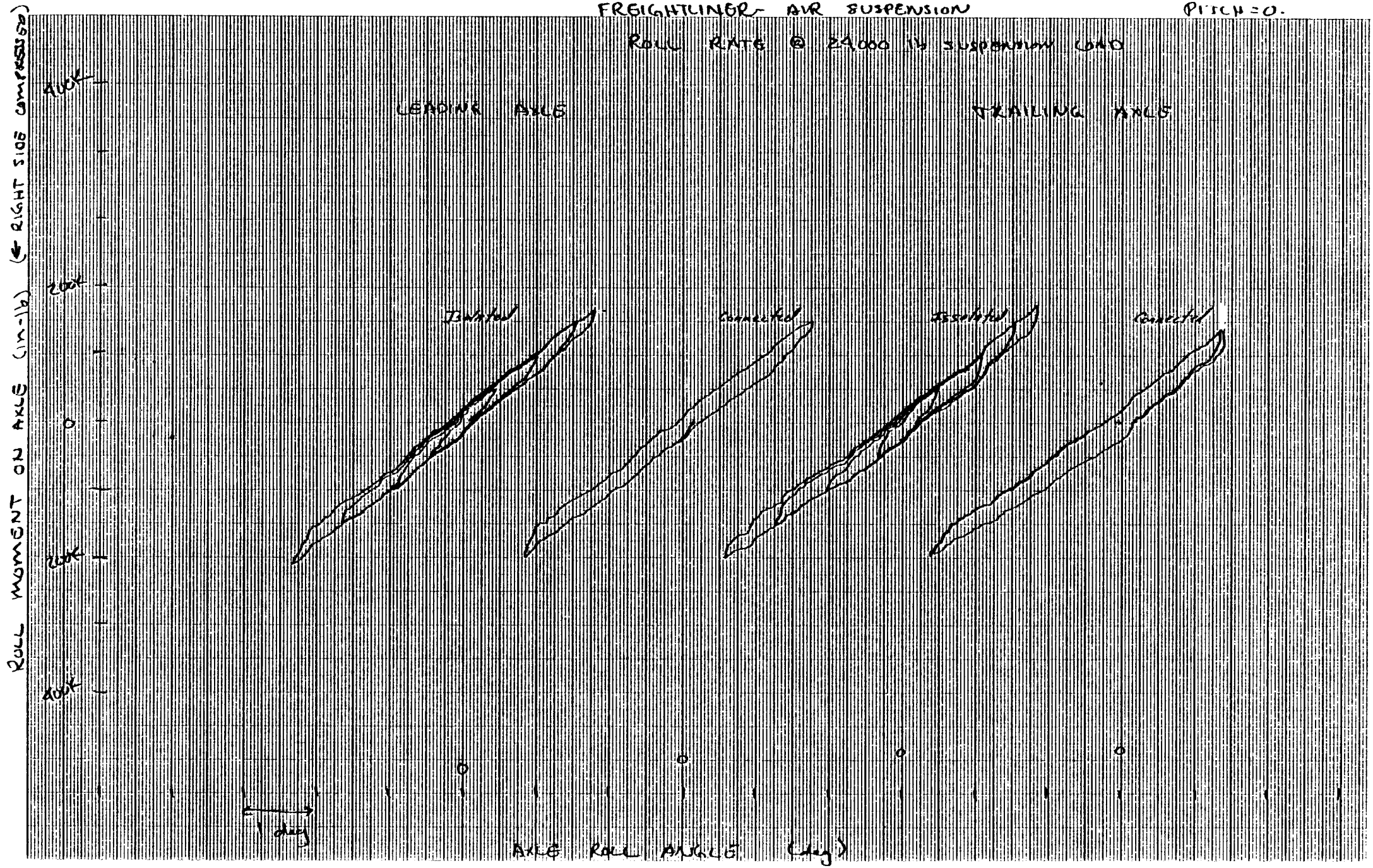

Freightliner Air Suspension
Vertical load Equalization
Left Side
Pitch=0
Nominal Suspension load: 32,000 lb
Nominal Wheel load 8,000 lb
24,000
16,000
6,000
4,000
2k
1k
0
-1k
-2k
Rear Extension Limit
1k
Vertical wheel load, leading axle, pounds relative to nominal wheel load
Vertical wheel load, trailing axle, pounds relative to nominal wheel load.

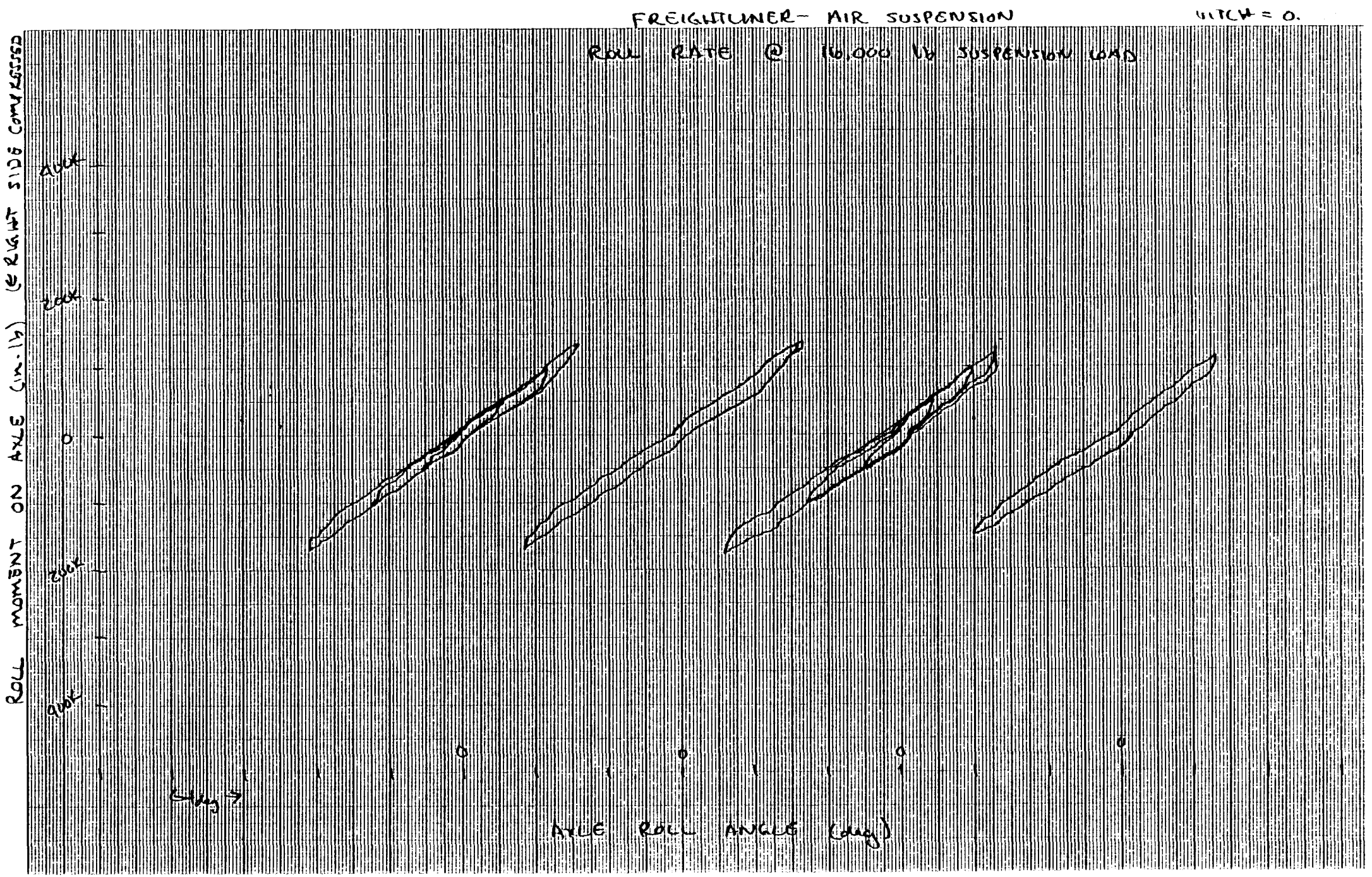

Freight liner Air Suspension
Vertical Rate
Pitch - 1°
Nominal Suspension load 32,000
Nominal Wheel load 8,000
Approx Air Spring Pressure 70
20,000
6000
50
100,000
40000
35
Average Wheel load - Pounds relative to nominal wheel load
2K
1K
0
-1K
-2K
1.25"
Vertical Deflection, inches relative

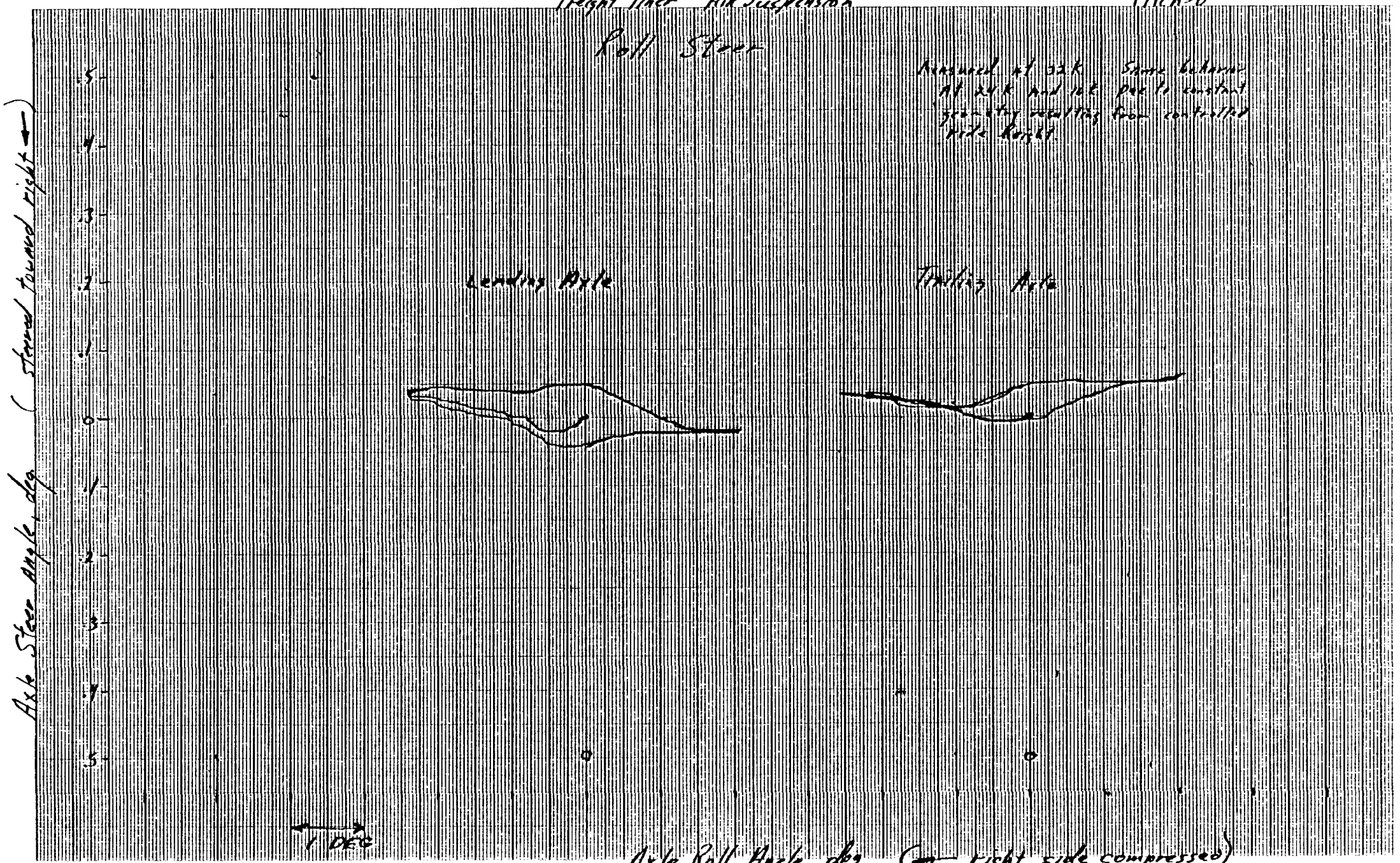

Freightliner Air Suspension
Pitch = -1°
Load Equalization - Left Side
Nominal Suspension load
Nominal Wheel load
16,000
4,000
24,000
6000
32,000
8,000
2k
1k
0
-1k
-2k
Leading Wheel Vertical load, pounds relative to nominal wheel load
1k
Trailing Wheel Vertical load, pounds relative to nominal wheel load
Relative

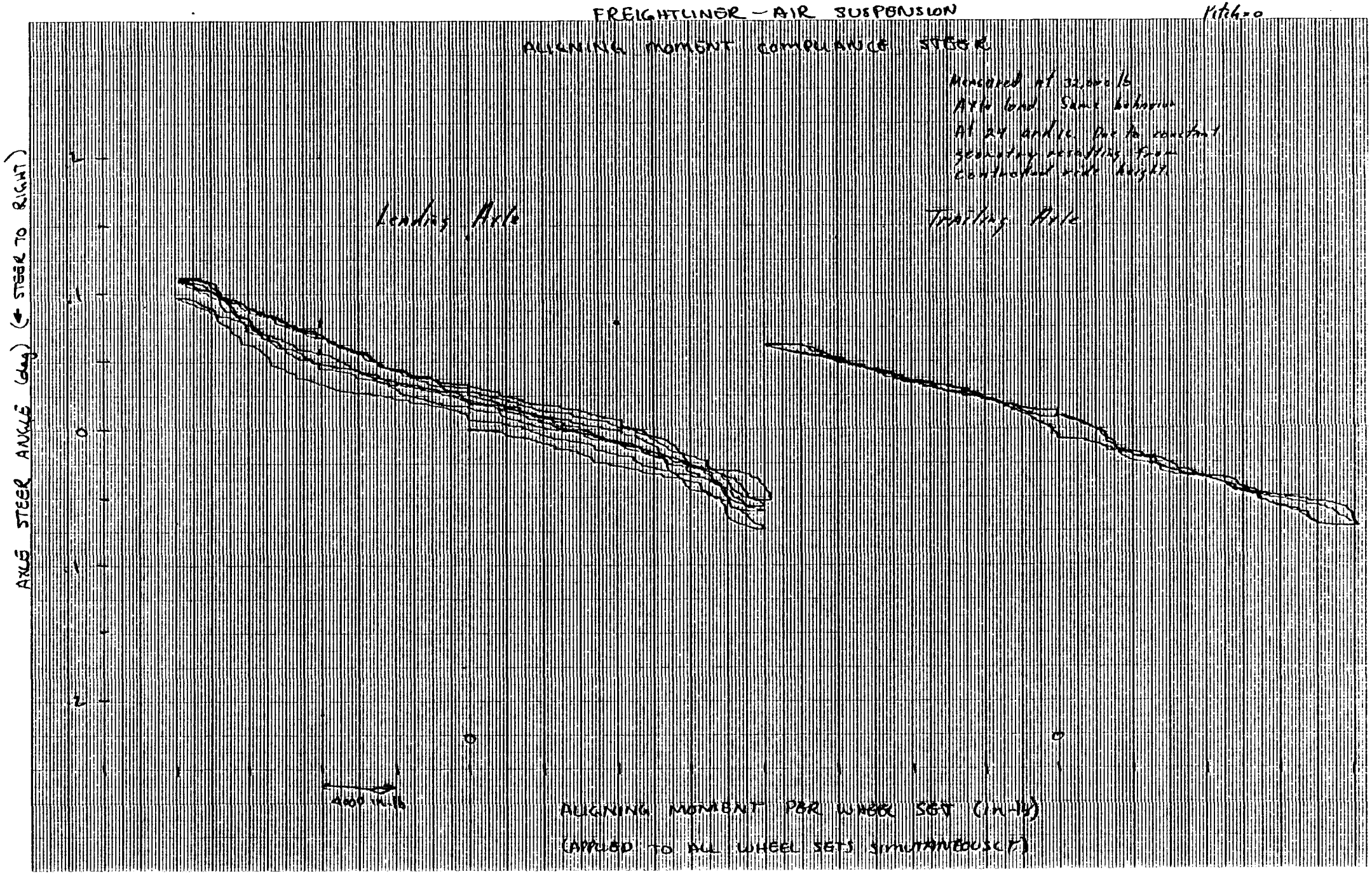

Freight Cars Air Suspension
Load Equalization: Right Side
Pitch = -1°
Nominal Suspension Load: 16,000 lb
Nominal Wheel Load: 4,000 lb
2k
1k
0
-1k
-2k
1k
16,000
4,000
24,000
6,000
32,000
8,000
Leading wheel vertical load, pounds relative to nominal wheel load
Trailing Wheel Vertical Load, Pounds relative to nominal wheel load

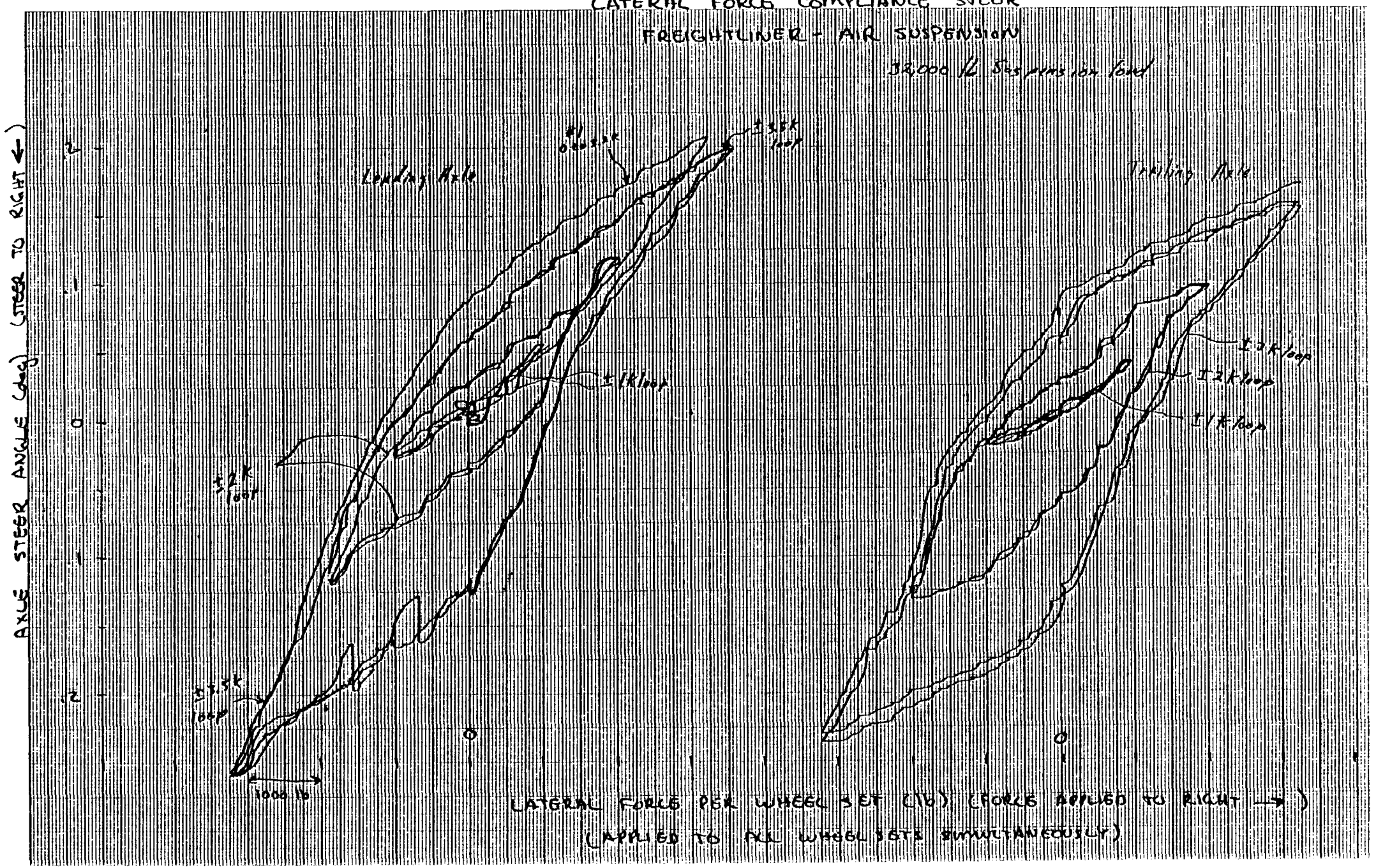

Freight liner Air Suspension
Roll Rate at 33,000 lb suspension load
Pitch=0
Leading Axle
Trailing Axle
ISOLATED
CONNECTED
ISOLATED
CONNECTED
200
0
200
200
0
0
0
1 deg
Roll Moment on Axle, in-lb, ← Right Side Compressed
Axle Roll Angle, deg.


FREIGHTLINER - AIR SUSPENSION
PITCH = 0.
ROLL RATE @ 24,000 lb SUSPENSION LOAD
LEADING AXLE
TRAILING AXLE
Isolated
Connected
Isolated
Connected
400K
200K
0
200K
400K
ROLL MOMENT ON AXLE (in-lb) (← RIGHT SIDE COMPRESSED)
0
0
0
0
1 deg
AXLE ROLL ANGLE (deg)


FREIGHTLINER- AIR SUSPENSION
PITCH = 0.
ROLL RATE @ 16,000 lb SUSPENSION LOAD
ROLL MOMENT ON AXLE (in-lb) (+ RIGHT SIDE COMPRESSED)
400K
200K
0
200K
400K
0
0
0
0
AXLE ROLL ANGLE (deg)


Freight liner Air Suspension
Pitch=0
Roll Steer
Measured at 32K Same behavior
At 24K and 16K Due to constant
geometry resulting from controlled
ride height.
Leading Axle
Trailing Axle
Axle Steer Angle, deg (steered toward right ⟵)
.5
.4
.3
.2
.1
0
.1
.2
.3
.4
.5
1 DEG
Axle Roll Angle deg (⟵ right side compressed)


FREIGHTLINER – AIR SUSPENSION
Pitch=0
ALIGNING MOMENT COMPLIANCE STEER
Measured at 32,000 lb
Axle load. Same behavior
At 24 and 16. Due to constant
geometry resulting from
controlled ride height.
Leading Axle
Trailing Axle
AXLE STEER ANGLE (deg) (← STEER TO RIGHT)
.2
.1
0
.1
.2
0
0
4000 in-lb
ALIGNING MOMENT PER WHEEL SET (in-lb)
(APPLIED TO ALL WHEEL SETS SIMULTANEOUSLY)


LATERAL FORCE COMPLIANCE STEER
FREIGHTLINER - AIR SUSPENSION
32,000 lb Suspension load
AXLE STEER ANGLE (deg) (STEER TO RIGHT ←)
.2
.1
0
.1
.2
Leading Axle
Trailing Axle
±1k loop
±2k loop
±3.5k loop
±3k loop
±2k loop
±1k loop
1000 lb
0
0
LATERAL FORCE PER WHEEL SET (lb) (FORCE APPLIED TO RIGHT →)
(APPLIED TO ALL WHEEL SETS SIMULTANEOUSLY)

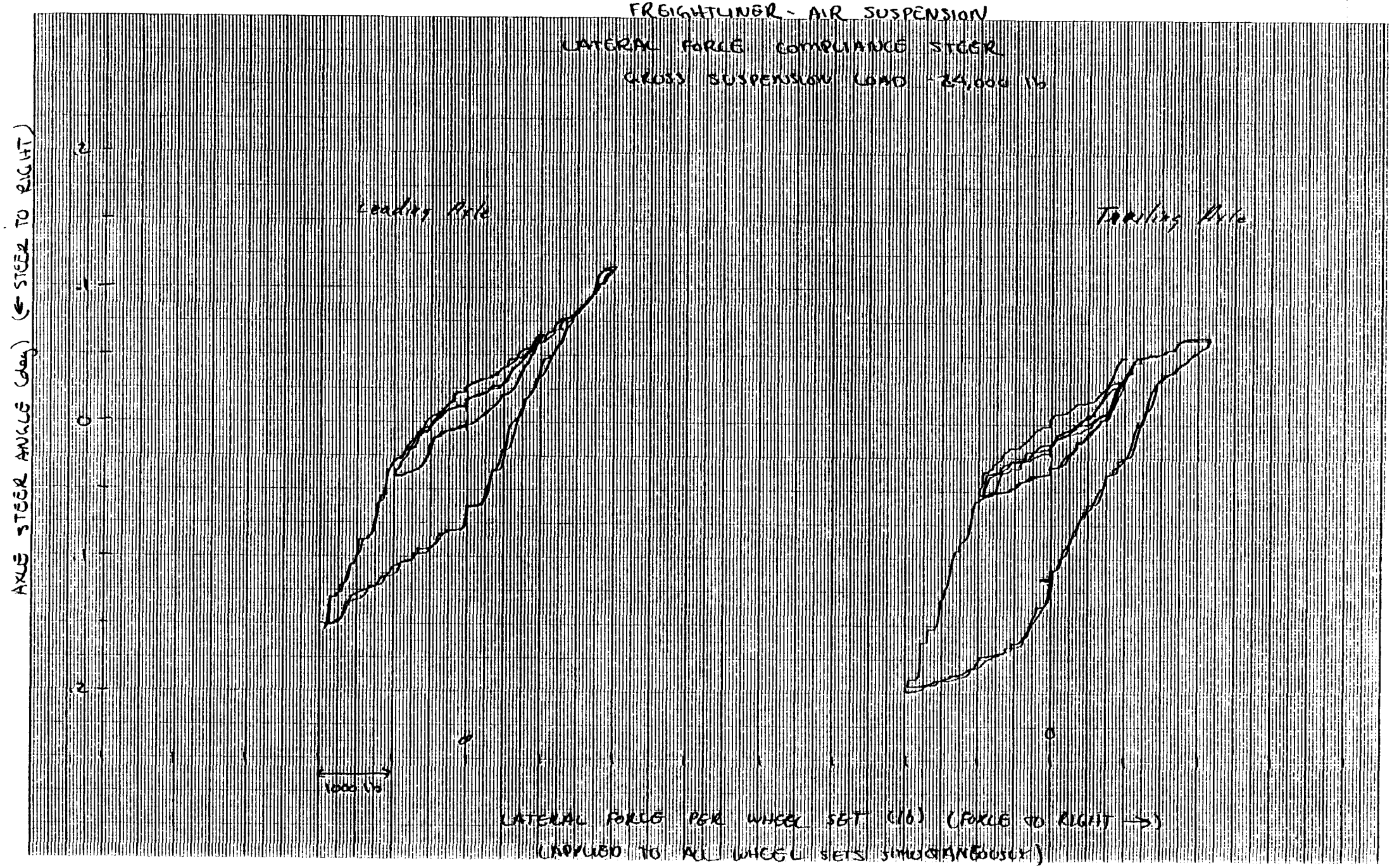
FREIGHTLINER - AIR SUSPENSION

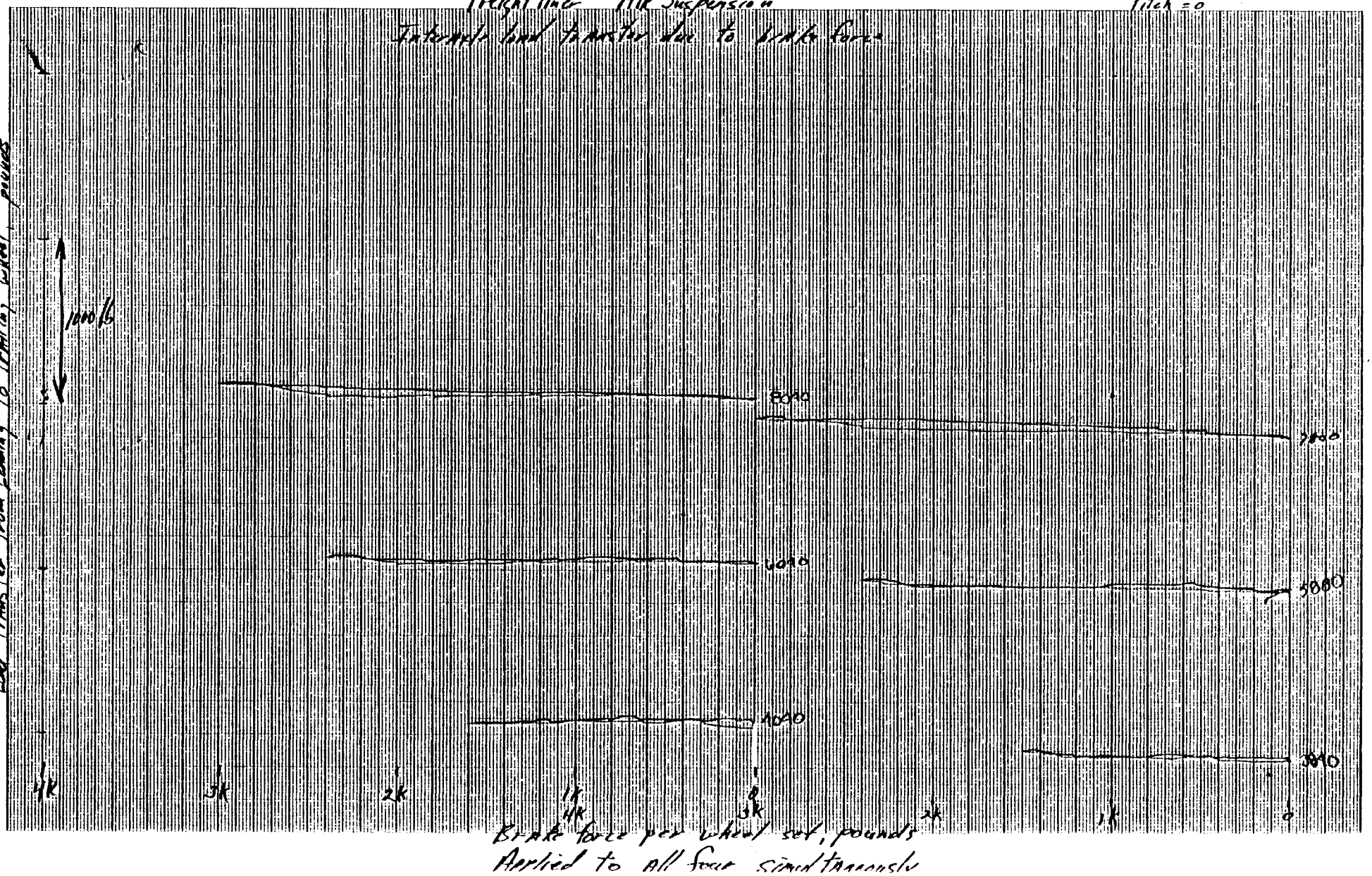
LATERAL FORCE COMPLIANCE STEER

LOAD 1% SUSPENSION LOAD

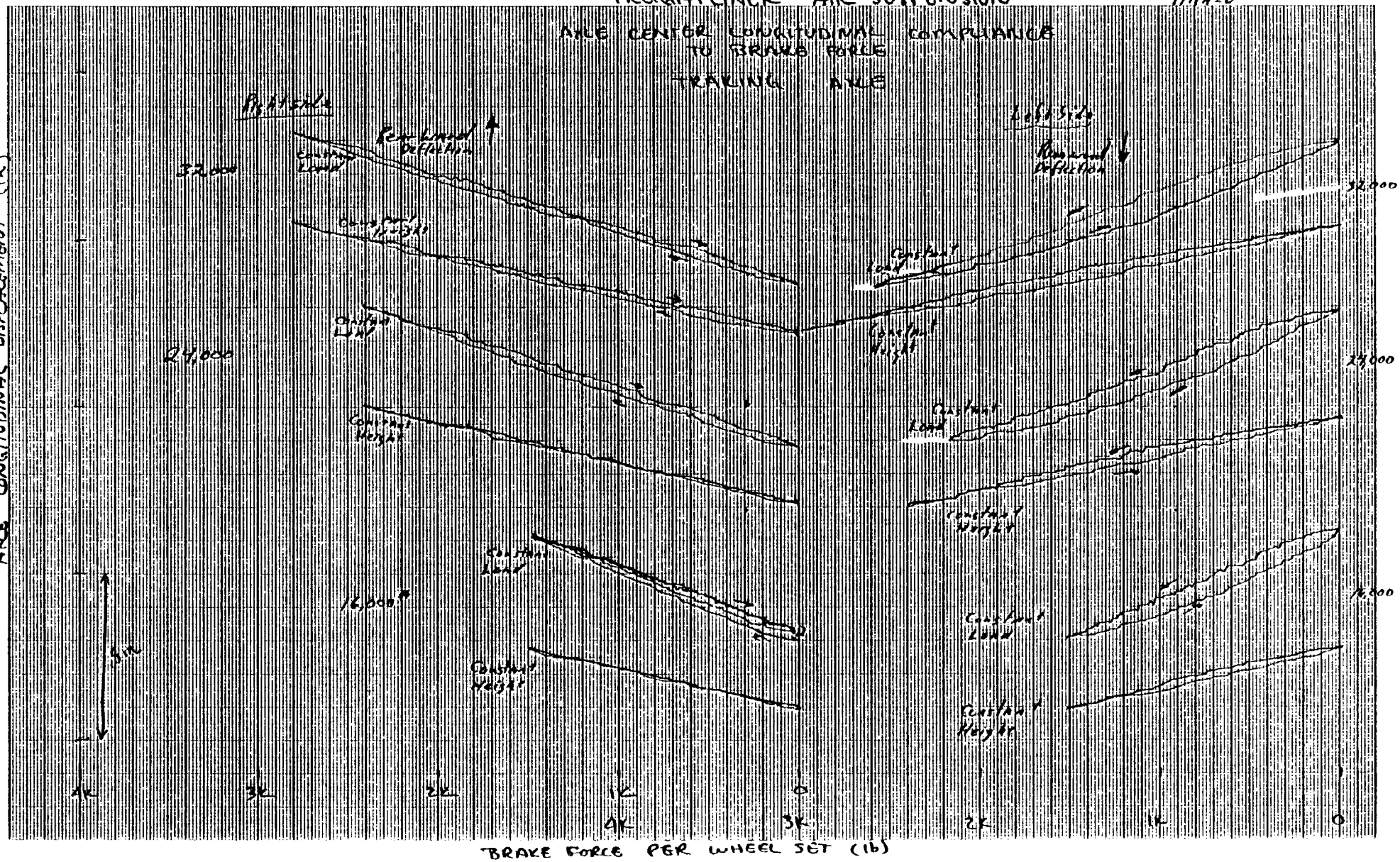
LATERAL FORCE PER WHEEL SET (lbf) (FORCE APPLIED TO RIGHT →)

(APPLIED TO ALL WHEEL SETS SIMULTANEOUSLY)


FREIGHTLINER - AIR SUSPENSION
LATERAL FORCE COMPLIANCE STEER
GROSS SUSPENSION LOAD - 34,000 lb
AXLE STEER ANGLE (deg) (← STEER TO RIGHT)
2
1
0
-1
-2
Leading Axle
Trailing Axle
1000 lb
LATERAL FORCE PER WHEEL SET (lb) (FORCE TO RIGHT →)
(APPLIED TO ALL WHEEL SETS SIMULTANEOUSLY)

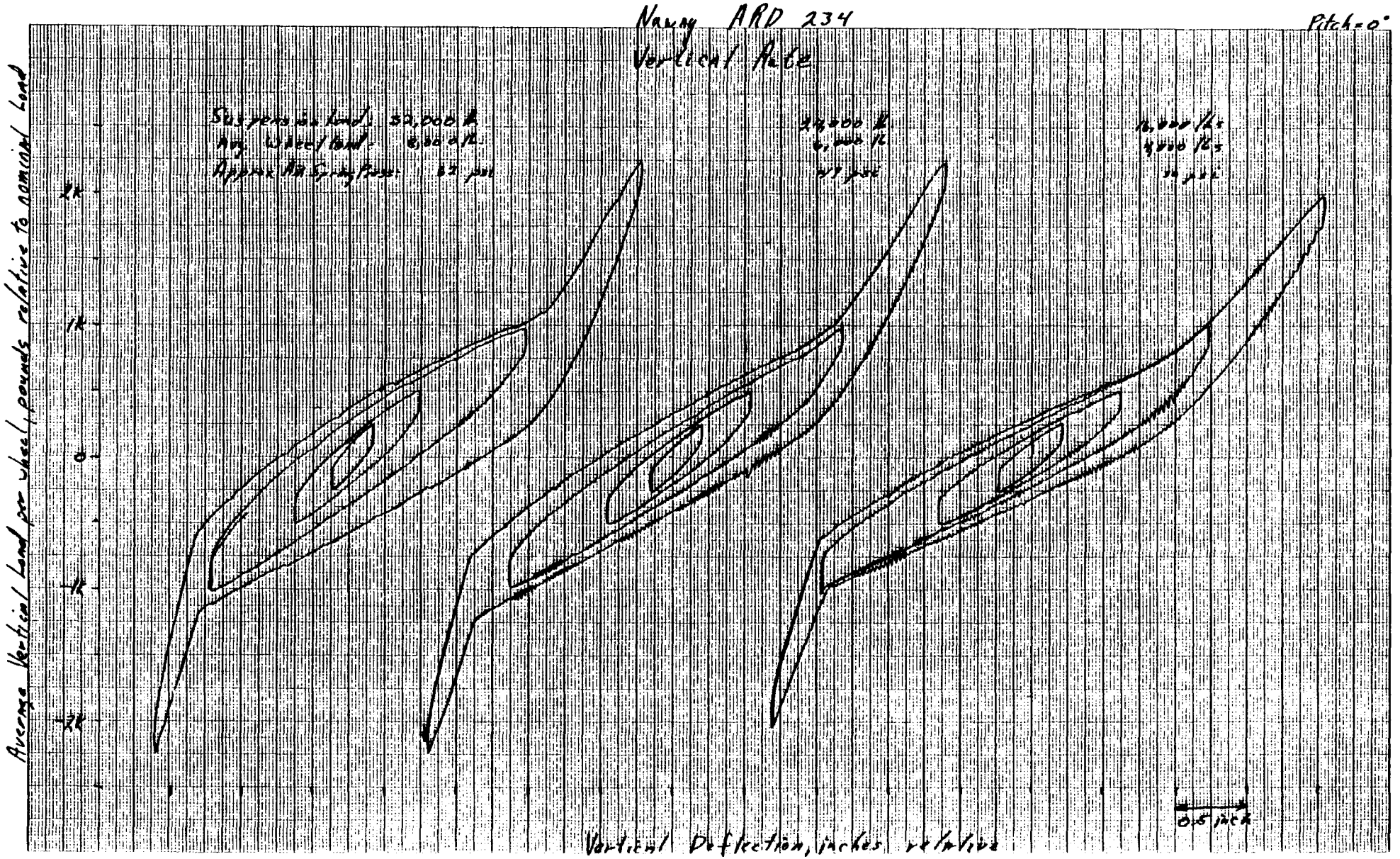

Freightliner Air Suspension
Pitch = 0
Intermediate load transfer due to brake force
Load Transfer from Leading to Trailing wheel, pounds
1000 lb
8000
7000
6000
5000
4000
3000
4K
3K
2K
1K
0
Brake force per wheel set, pounds
Applied to all four simultaneously

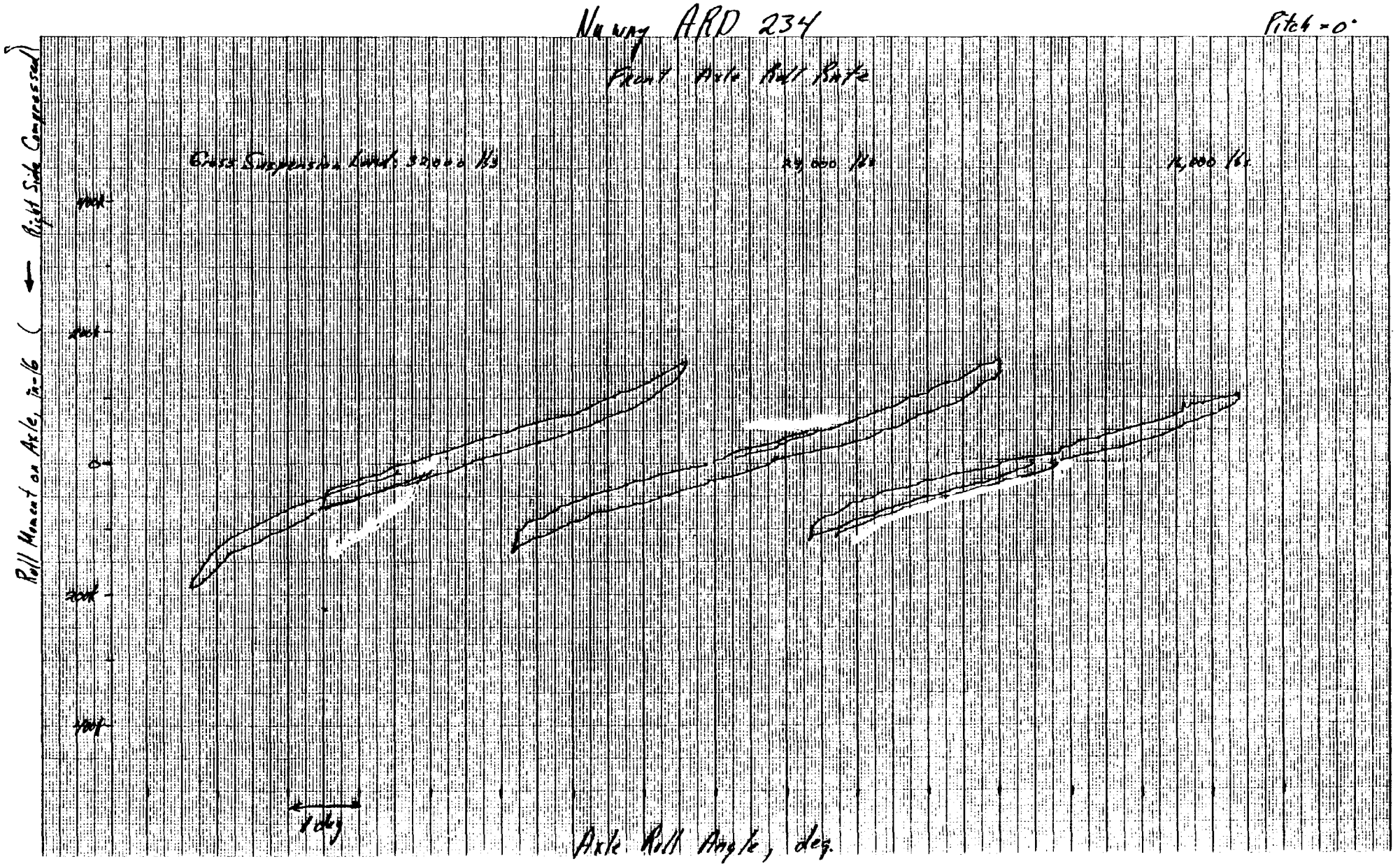
K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1510


FREIGHTLINER - AIR SUSPENSION
AXLE CENTER LONGITUDINAL COMPLIANCE TO BRAKE FORCE
TRAILING AXLE
AXLE LONGITUDINAL DISPLACEMENT (in)
BRAKE FORCE PER WHEEL SET (lb)
32,000
24,000
16,000
0
4K
3K
2K
1K
Constant Load
Constant Height

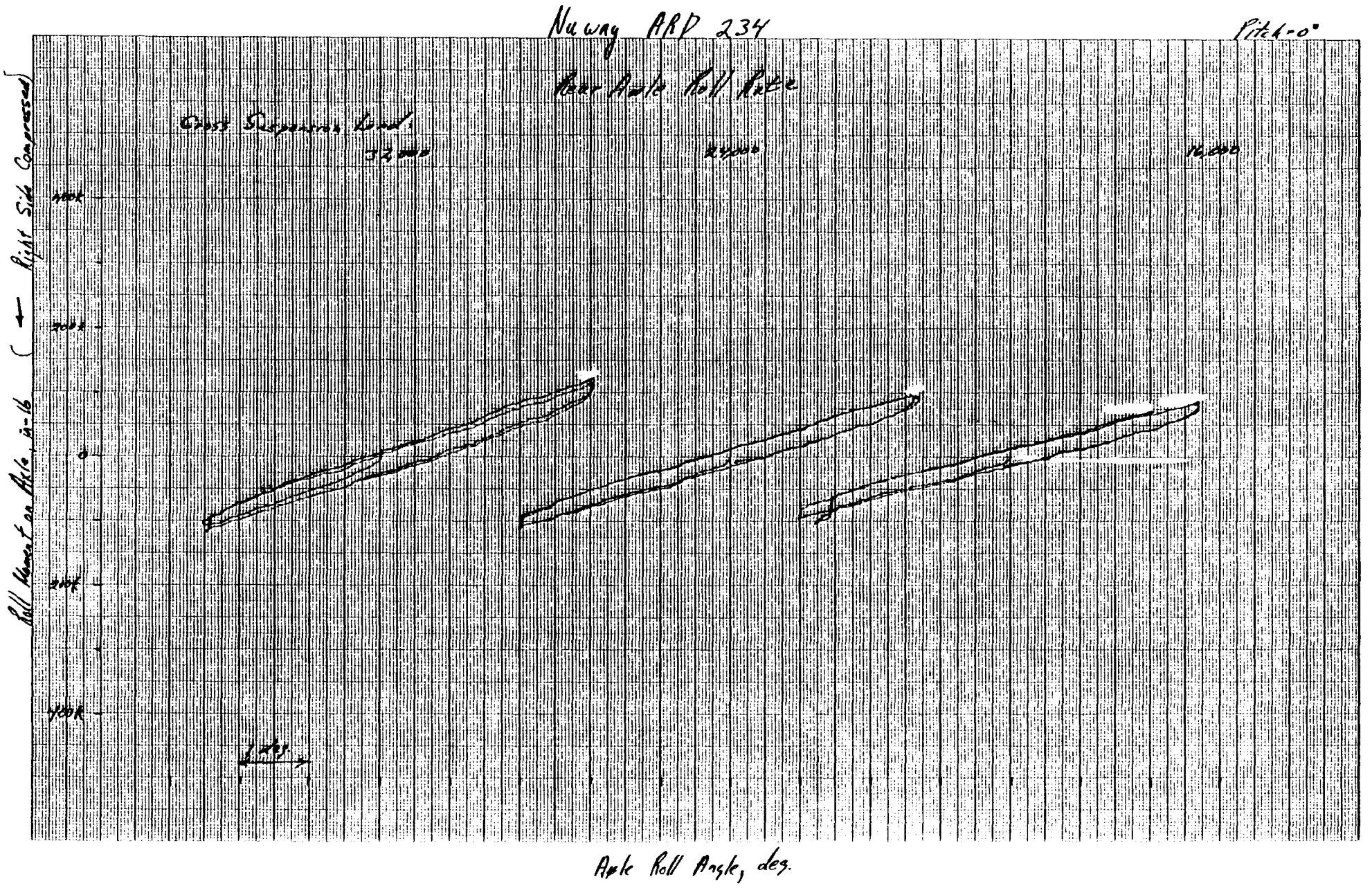
Suspension: NEWAY ARD 234

		Susp Load 32000	24000	16000
Vertical Rate (lb/in)		675	625	500
Coulomb Friction (lb)		475	375	300
ROLL RATE (in-lb/deg)	F	36K	33K	25K
	R	35K	32K	26K
ROLL CENTER HT (in below top of frame)	F	←	8.7	→
	R		9.1	
ROLL STEER (DEG / DEG)	F	—	.23	—
	R	—	.22	—
ALIGNING MOMENT COMPLIANCE STEER (deg/in lb)	F	—	5.5×10^{-6}	—
	R	—	6.5×10^{-6}	—
LATERAL FORCE COMPLIANCE (deg/lb)	F	—	1×10^{-6}	—
	R	—	1.5×10^{-6}	—
INTERAXLE LOAD TRANSFER (BYMOM) (lb/lb)		—	n:1	—


Naway ARD 234
Vertical Rate
Pitch = 0°
Suspension Load: 32,000 lb
Avg. Wheel Load: 8,000 lb
Approx Air Spring Press: 62 psi
24,000 lb
6,000 lb
47 psi
16,000 lbs
4,000 lbs
30 psi
2k
1k
0
-1k
-2k
Average Vertical Load per wheel, pounds relative to nominal Load
0.5 inch
Vertical Deflection, inches relative



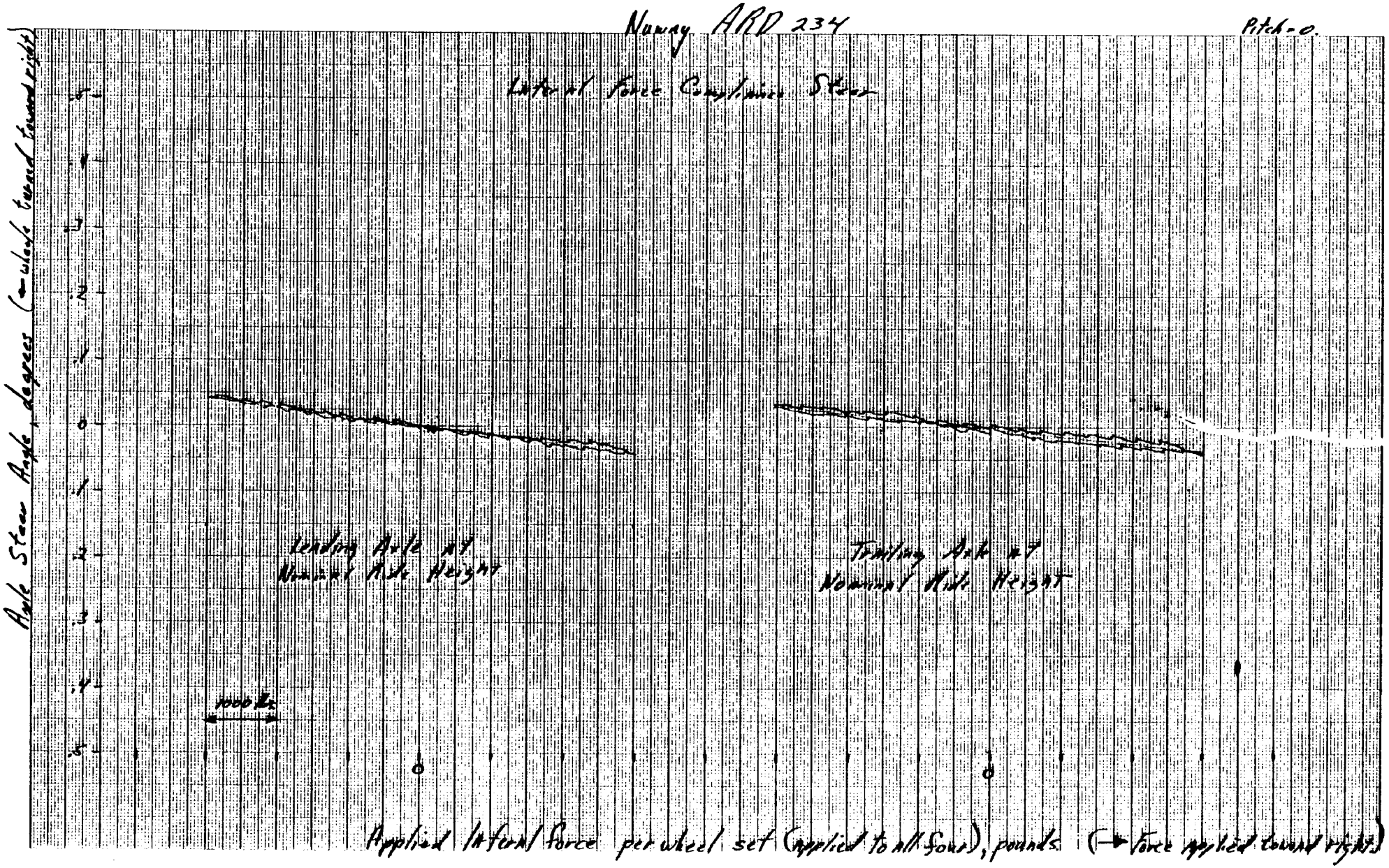
K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM. KEUFFEL & ESSER CO. MADE IN U.S.A. 47 1512



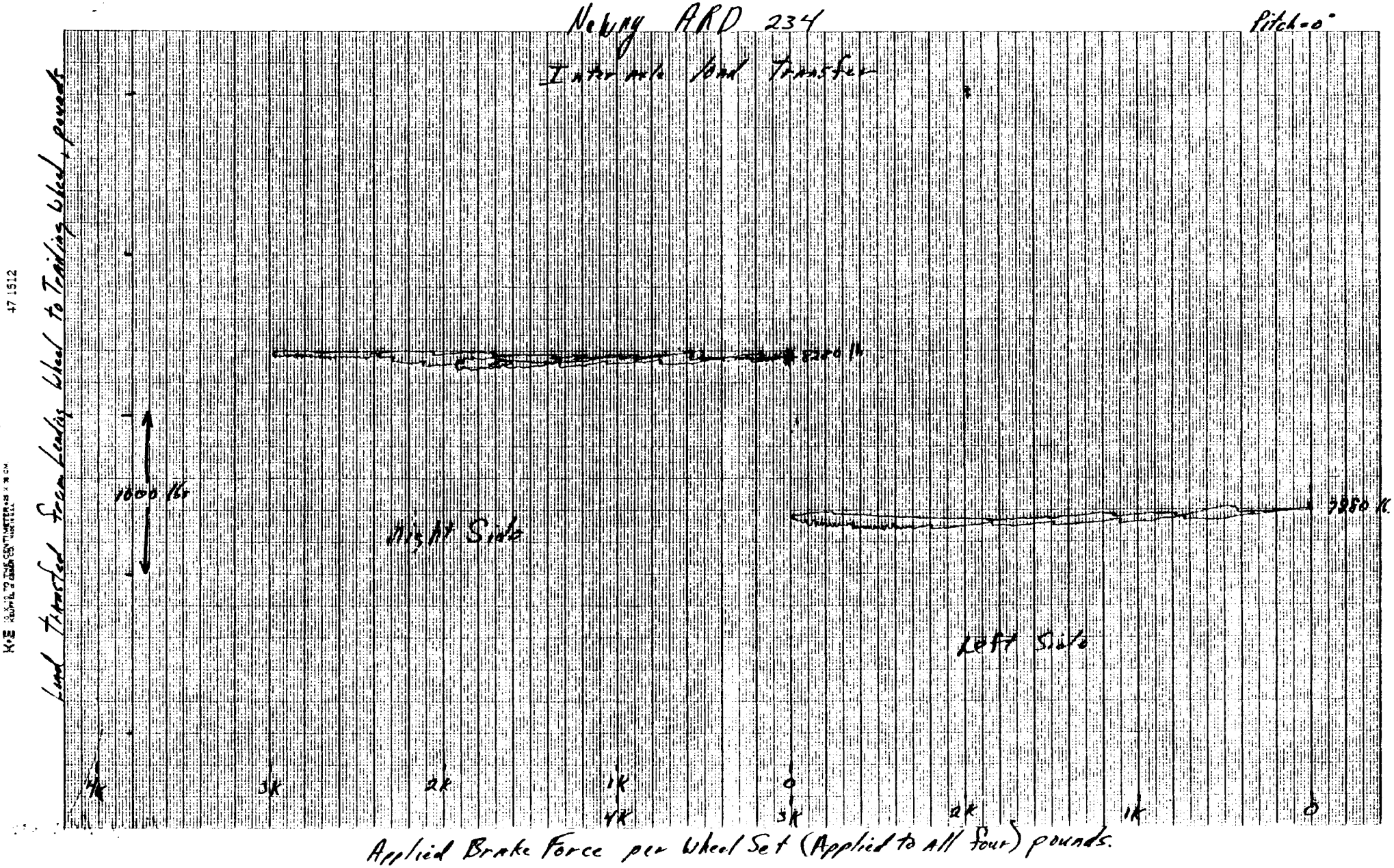
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM. KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512

Aileron Angle, degrees (— Wheels turned toward right)
-5°
-4°
-3°
-2°
-1°
0
1°
2°
3°
4°
5°
Aileron Angle, degrees
Left 8.2°
Right 7.3°
Average 7.75

Navy ARD 234
Hydraulic Manual Compliance Steer
Hydraulic Manual Steer Wheel Set (Applied to Steer Wheel Set)
Hydraulic Manual Steer Wheel Set
Hydraulic Manual Steer Wheel Set
Hydraulic Manual Steer Wheel Set

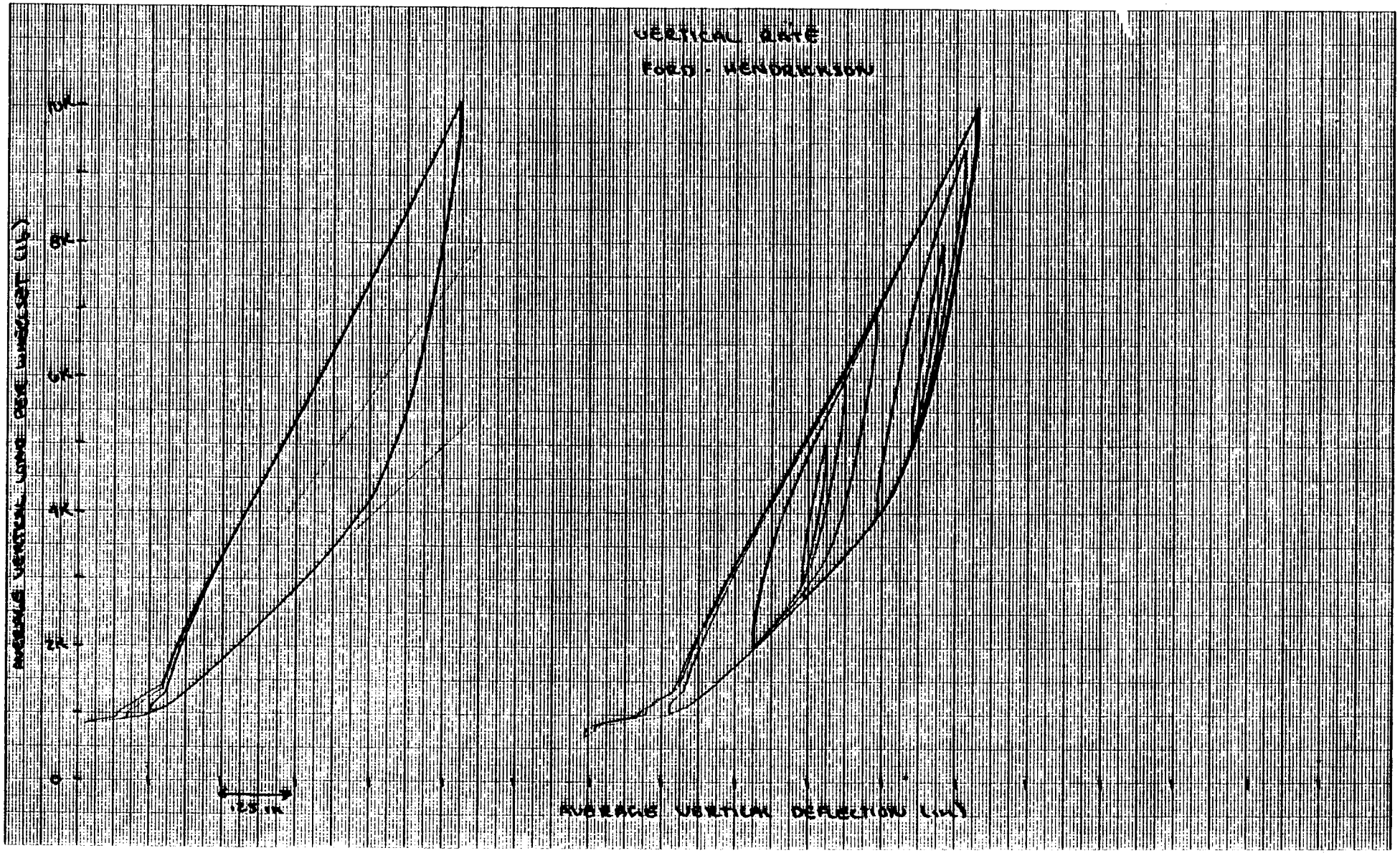


K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM KEUFFEL & ESSER CO. MADE IN U.S.A. 47 1512

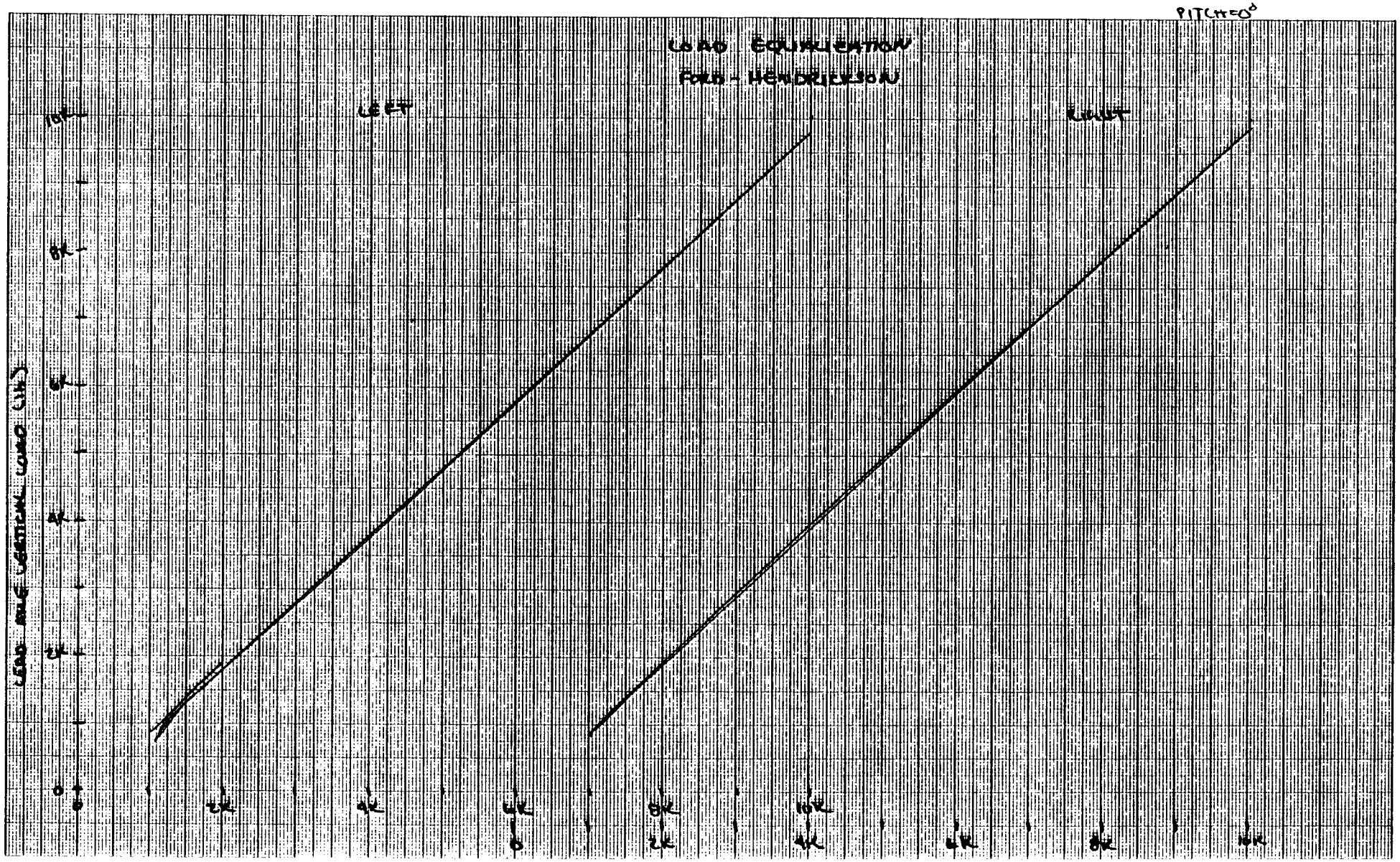

Nehrig ARD 234
Pitch-0°
Inertia Load Transfer
Load Transfer from Loaded Wheel to Trailing Wheel, pounds
1000 lbs
Zero lb
9250 lb.
Right Side
Left Side
4K
3K
2K
1K
0
4K
3K
2K
1K
0
Applied Brake Force per Wheel Set (Applied to all four) pounds.

Suspension: Hendrickson Walking Beam - Steel Spring

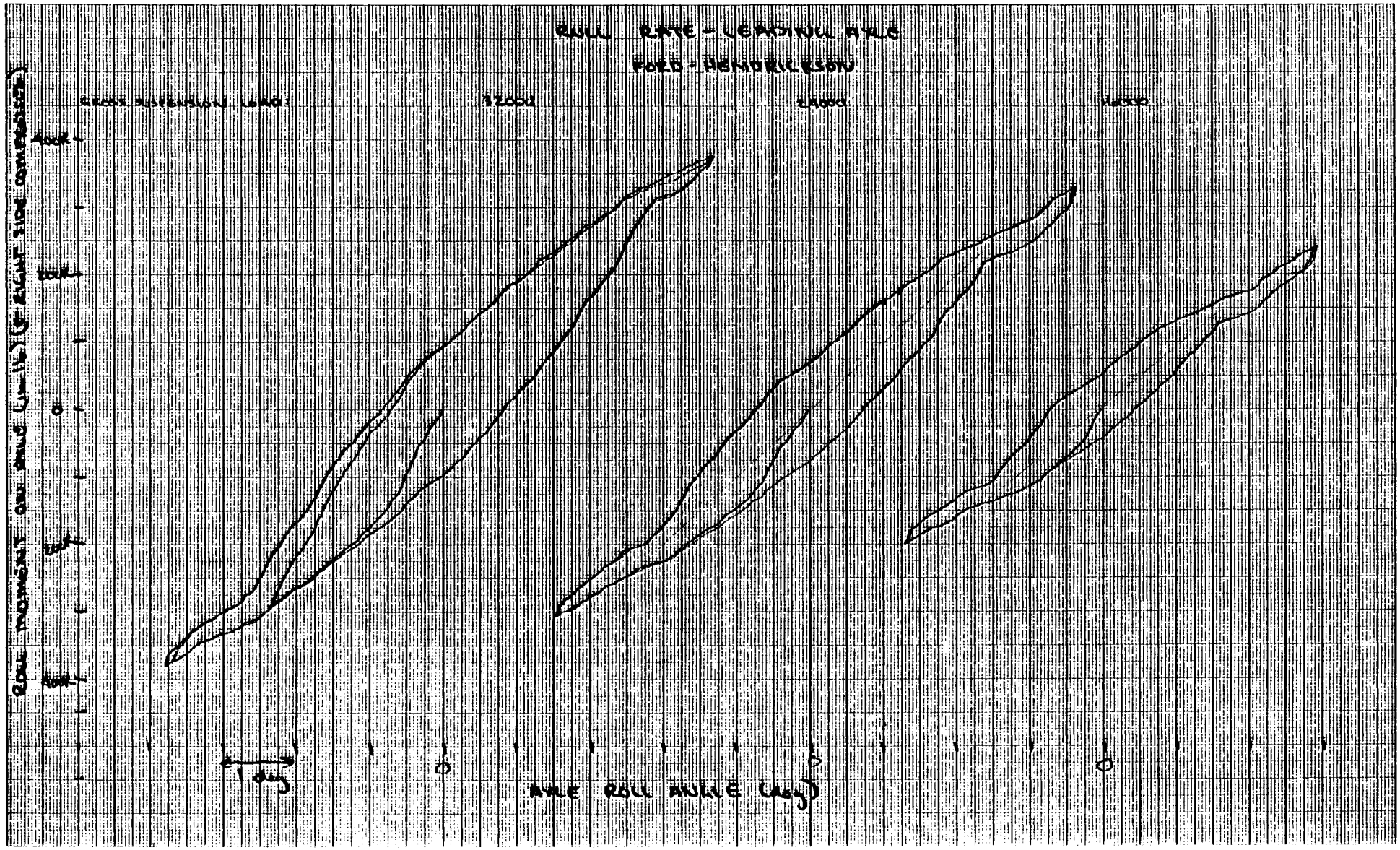
		Susp Load (lb) 32000	24000	16000
Vertical Rate (lb/in)		6280	6280	6280
Coulomb Friction		2500	1850	1150
ROLL RATE (in-lb/deg)	F	115K	100K	85K
	R	110K	95K	85K
ROLL CENTER HT (in below top of frame)	F	17.3	15.8	15.8
	R	17.8	17.4	16.7
ROLL STEER (DEG / DEG)	F	.16	.23	.29
	R	.19	.26	.26
ALIGNING MOMENT COMPLIANCE STEER (deg/in lb)	F	7×10^{-6}	6×10^{-6}	6×10^{-6}
	R	1×10^{-5}	1×10^{-5}	1×10^{-5}
LATERAL FORCE COMPLIANCE (deg/lb)	F	nil		
	R			
INTERAXLE LOAD TRANSFER (BRAKING) (lb/lb)		nil for 0 - -2° pitch		



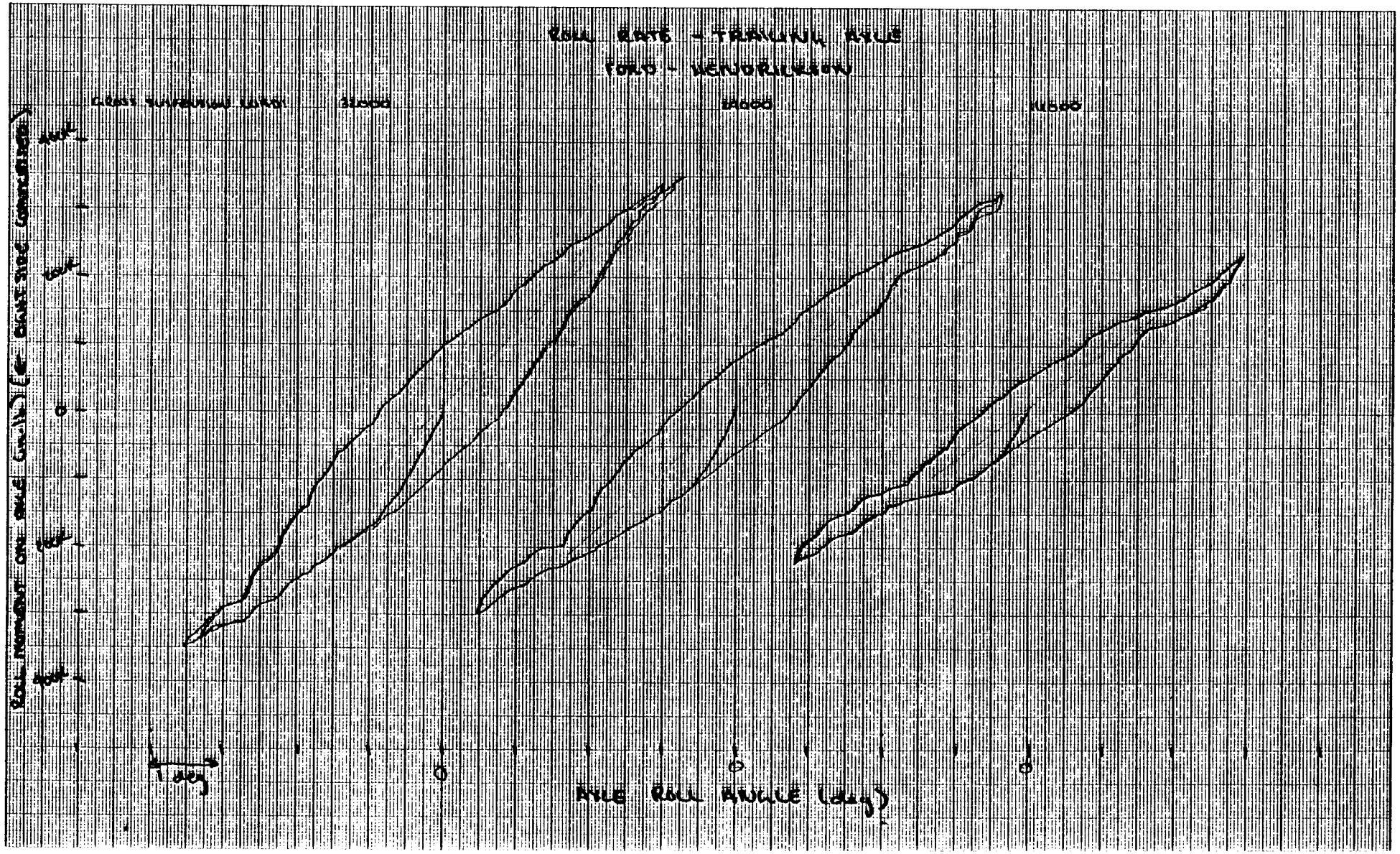
K+E 10 X 10 TO THE CENTIMETER 25 X 35 CM. KEUFFEL & ESSER CO. MADE IN U.S.A. 47 1512



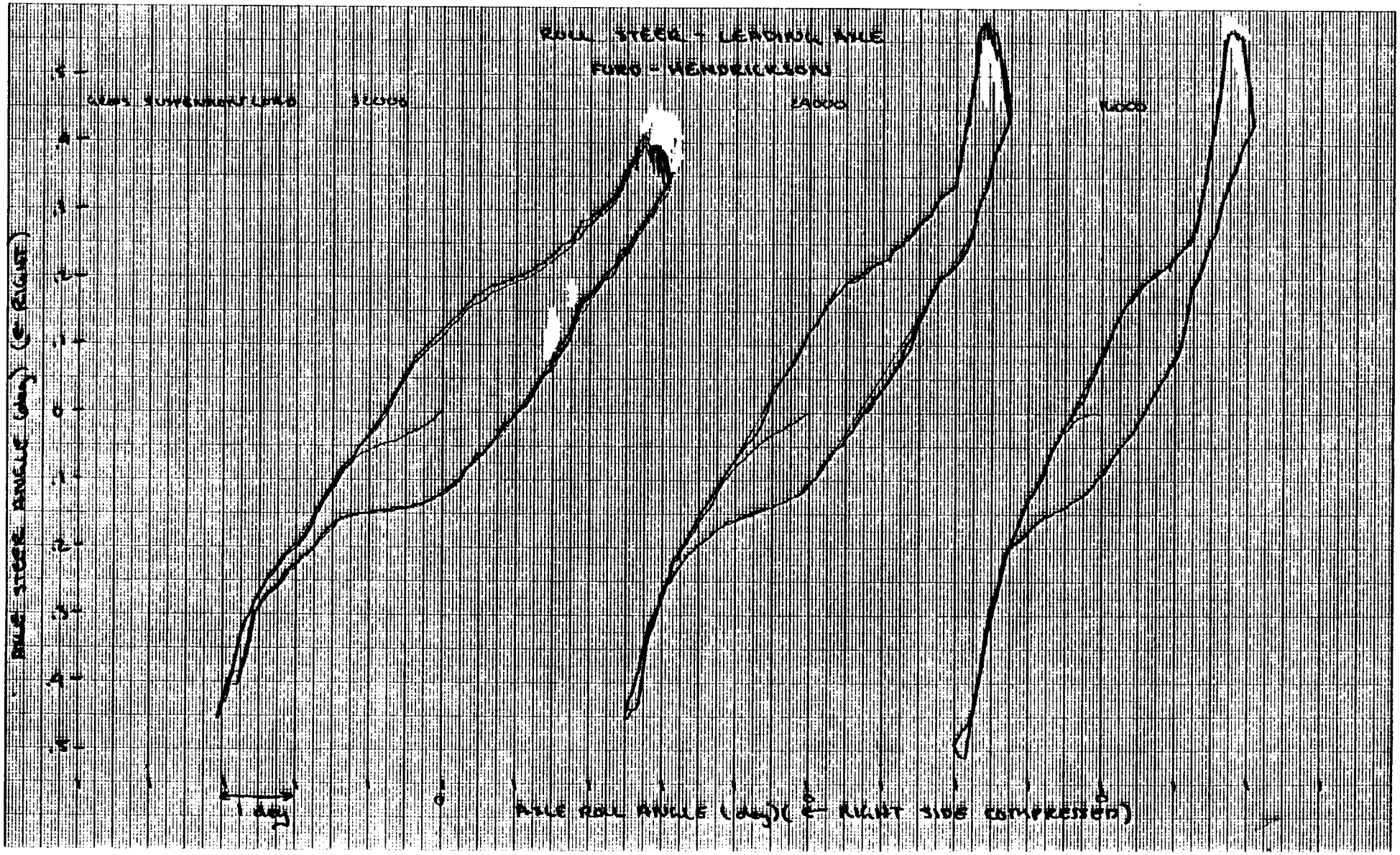
K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512



K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512

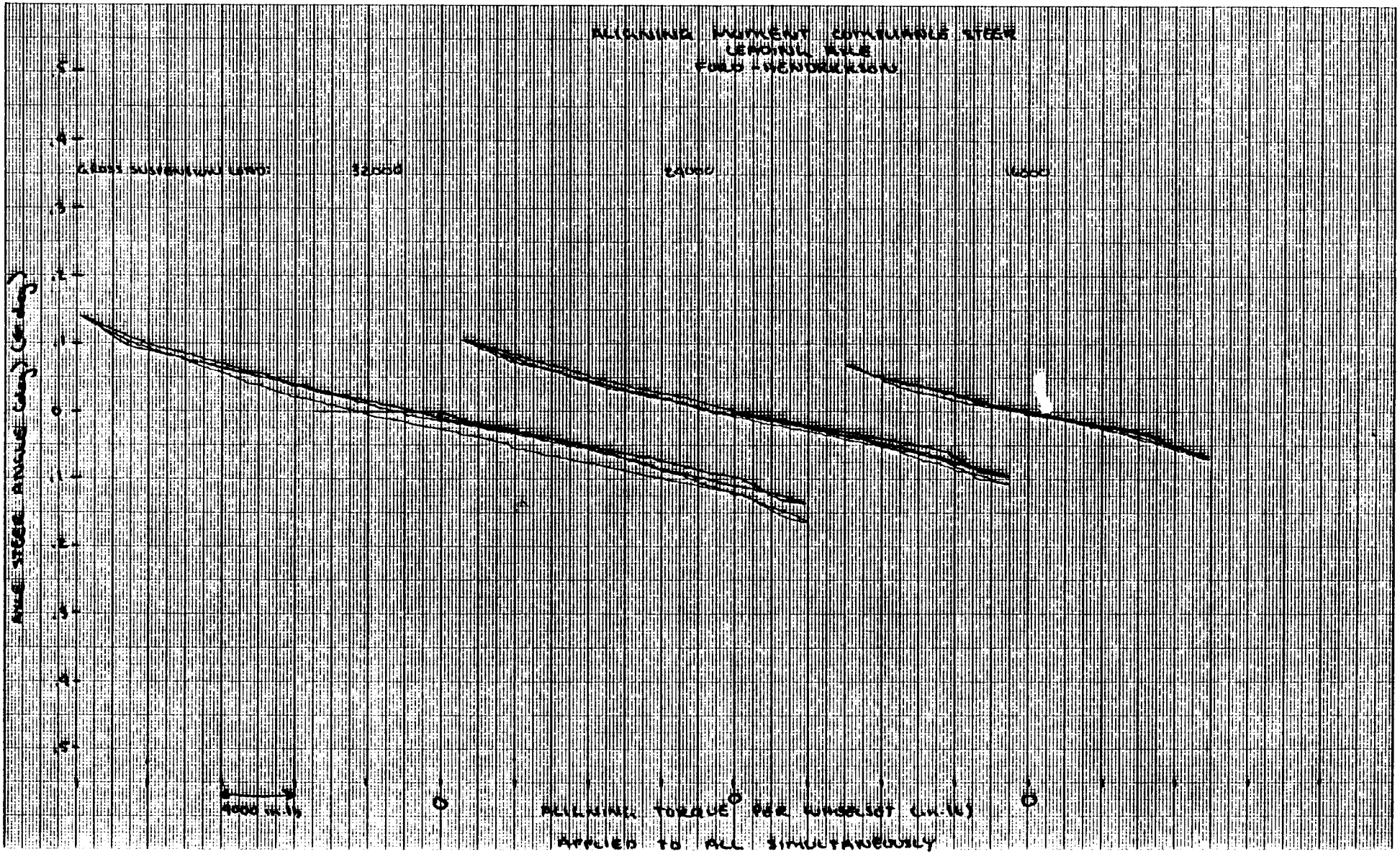


K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM
47 1512



K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
47 1512

BALL STEEL - TRAILING BALL
FORD - HENDRICKSON
1966
1965
GROSS ALTERNATE LOAD
AXLE STEEL PNEUMATIC (duals) (2 TIRES)
BALL STEEL PNEUMATIC (duals) (4 TIRES SIDE BY SIDE)



K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512

ALUMINUM MOMENT COEFFICIENT
PLOTTED VERSUS ANGLE OF ATTACK
FOR A TAPERED WING
WITH ROUNDED TIPS
AND SWEPTBACK LEADING EDGE
ALUMINUM MOMENT
ADJUSTED TO FULL SIMULTANEOUS
Stable
Unstable
Stable
Unstable
Stable
Unstable

Average stress - modulus (σ/ε) (pounds per square inch)
Longitudinal strain in inches per inch
Longitudinal strain per inch in terms of 1/5
Longitudinal strain per inch in terms of 1/10
Longitudinal strain per inch in terms of 1/20
Longitudinal strain per inch in terms of 1/40
Longitudinal strain per inch in terms of 1/80
Longitudinal strain per inch in terms of 1/160
Longitudinal strain per inch in terms of 1/320
Longitudinal strain per inch in terms of 1/640
Longitudinal strain per inch in terms of 1/1280
Longitudinal strain per inch in terms of 1/2560
Longitudinal strain per inch in terms of 1/5120
Longitudinal strain per inch in terms of 1/10240
Longitudinal strain per inch in terms of 1/20480
Longitudinal strain per inch in terms of 1/40960
Longitudinal strain per inch in terms of 1/81920
Longitudinal strain per inch in terms of 1/163840
Longitudinal strain per inch in terms of 1/327680
Longitudinal strain per inch in terms of 1/655360
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Longitudinal strain per inch in terms of 1/2621440
Longitudinal strain per inch in terms of 1/5242880
Longitudinal strain per inch in terms of 1/10485760
Longitudinal strain per inch in terms of 1/20971520
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Longitudinal strain per inch in terms of 1/687194767360
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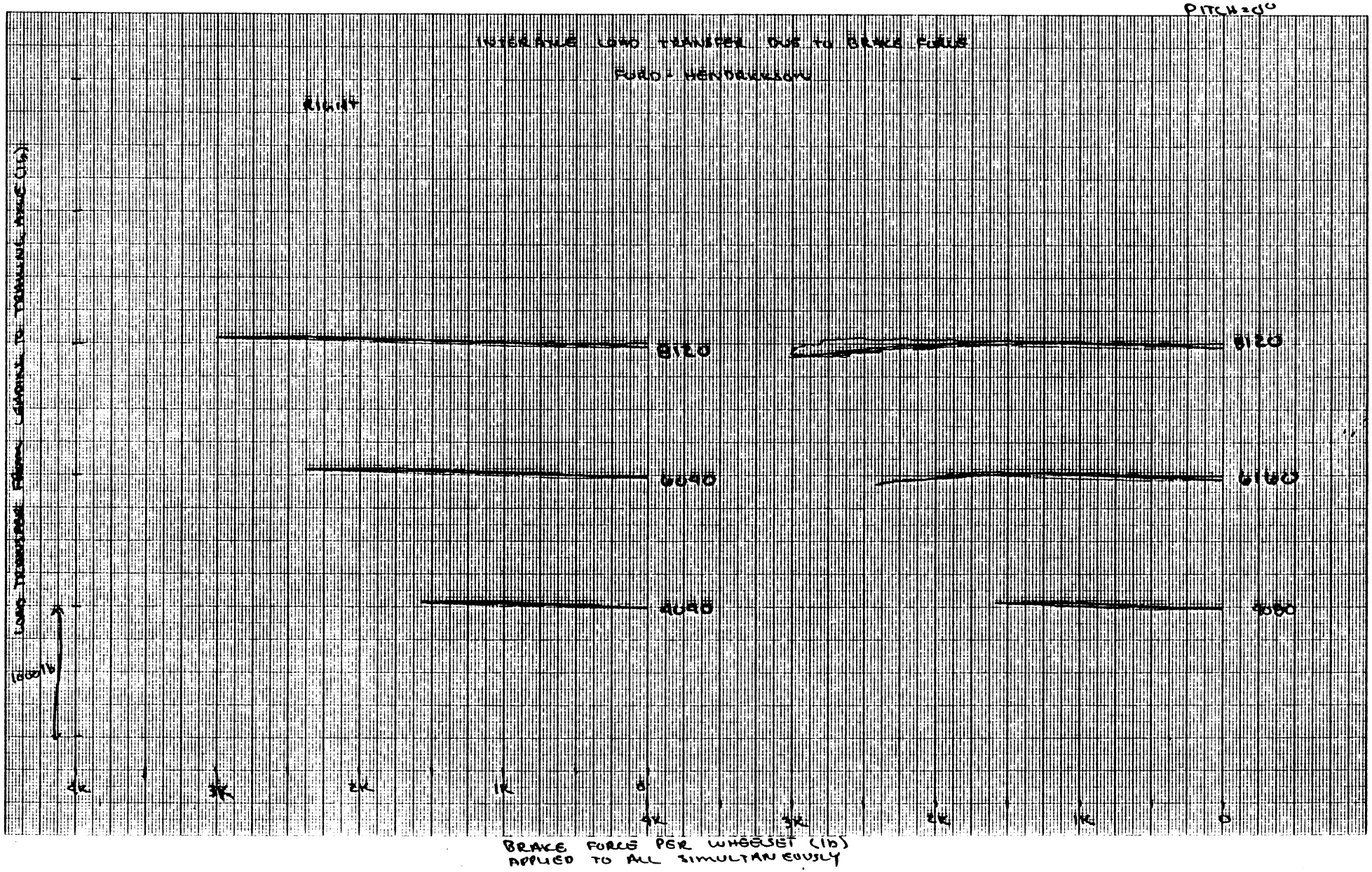
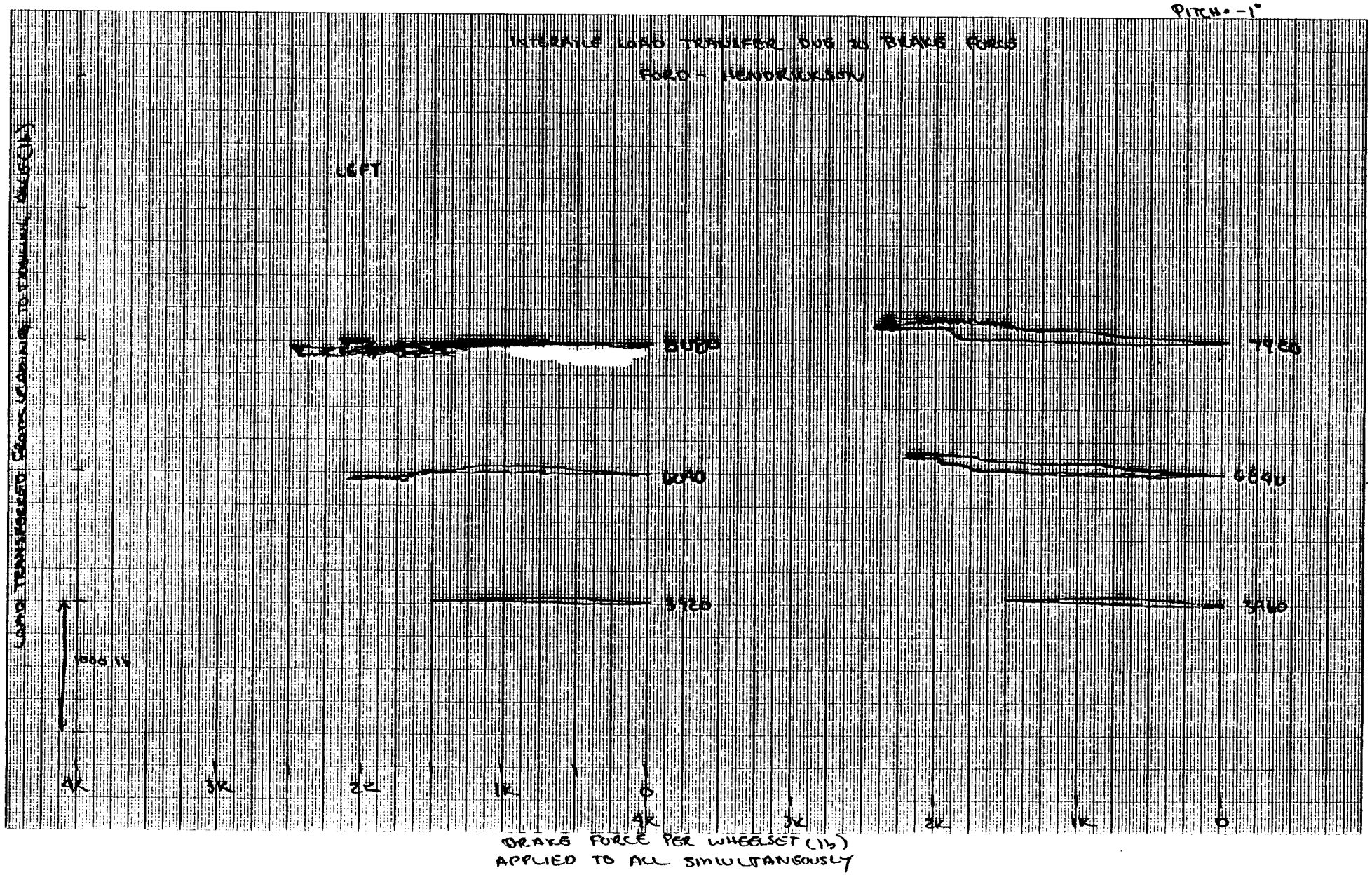
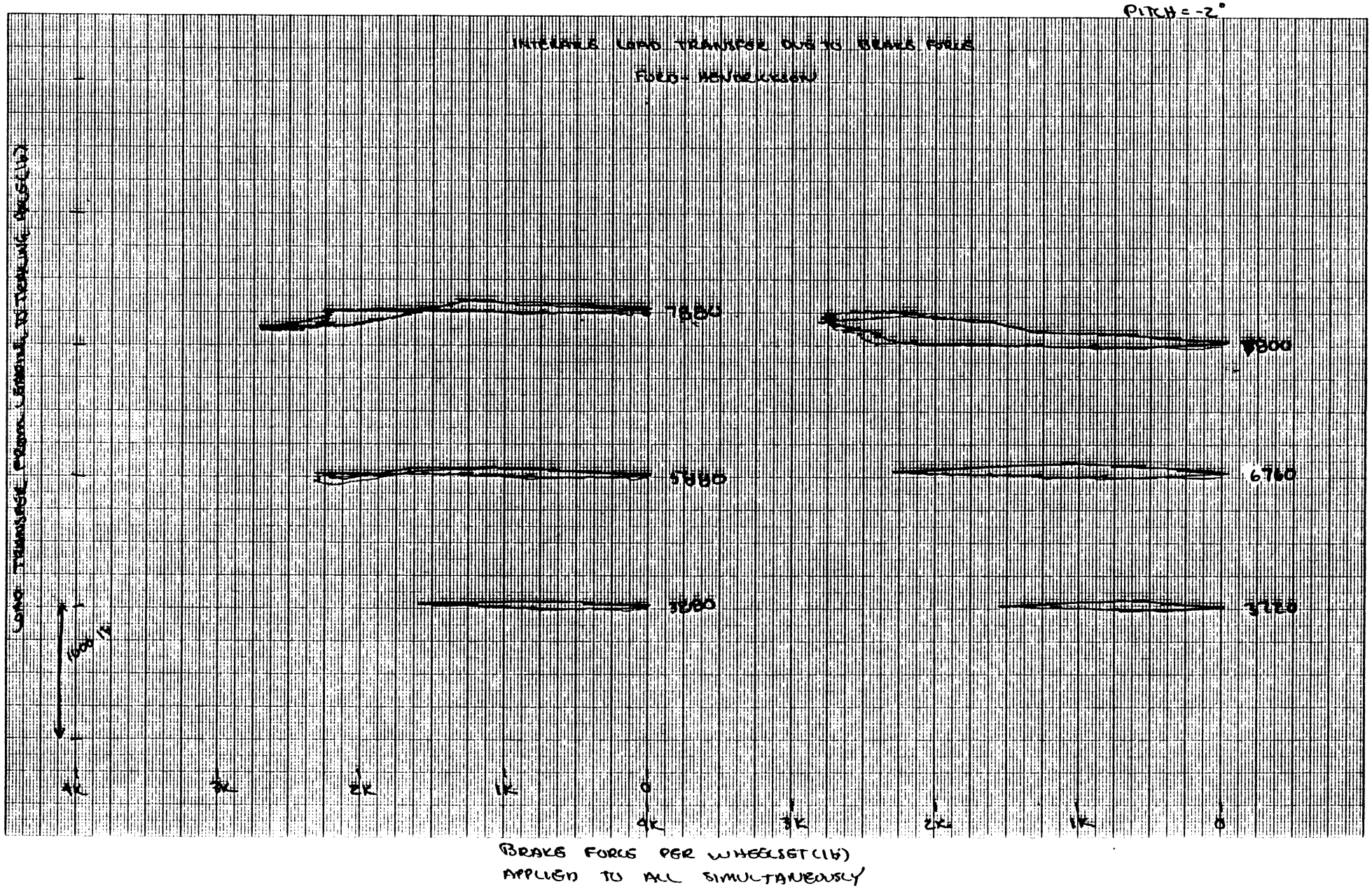
UNIAXIAL FAILURE ENVELOPES FOR
FRACTURING FLUIDS
AND MEDIUM STRENGTH ROCK
UNIAXIAL FAILURE PER UNDERWOOD (1977)
APPLIED TO ALL STIMULATIONS
Figure 12
Shale stress ratios (σ3/σ1)
Keuffel & Esser Co. Made in U.S.A.



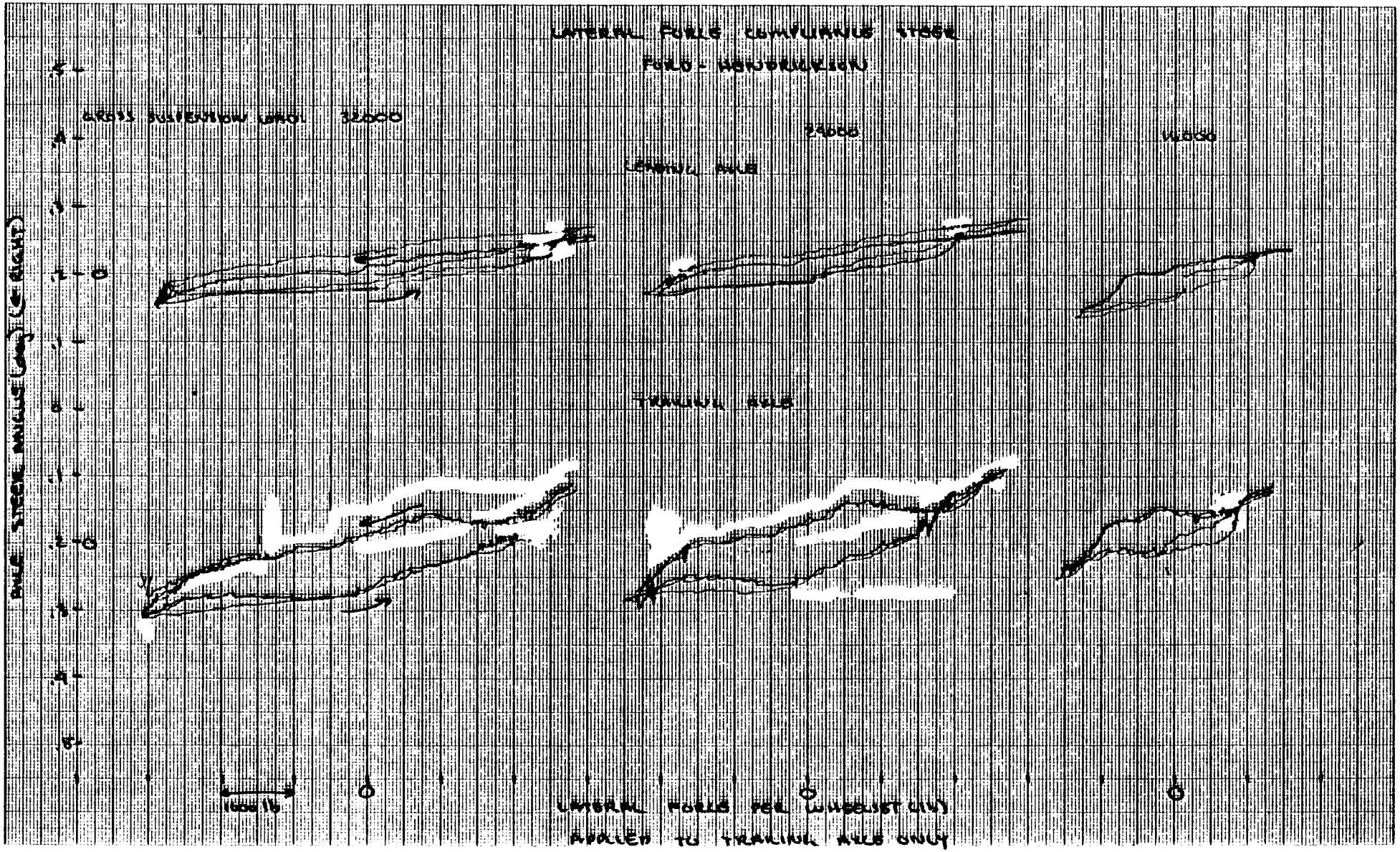
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512



K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512



K•E 10 X 10 TO THE CENTIMETER • 25 X 38 CM KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512



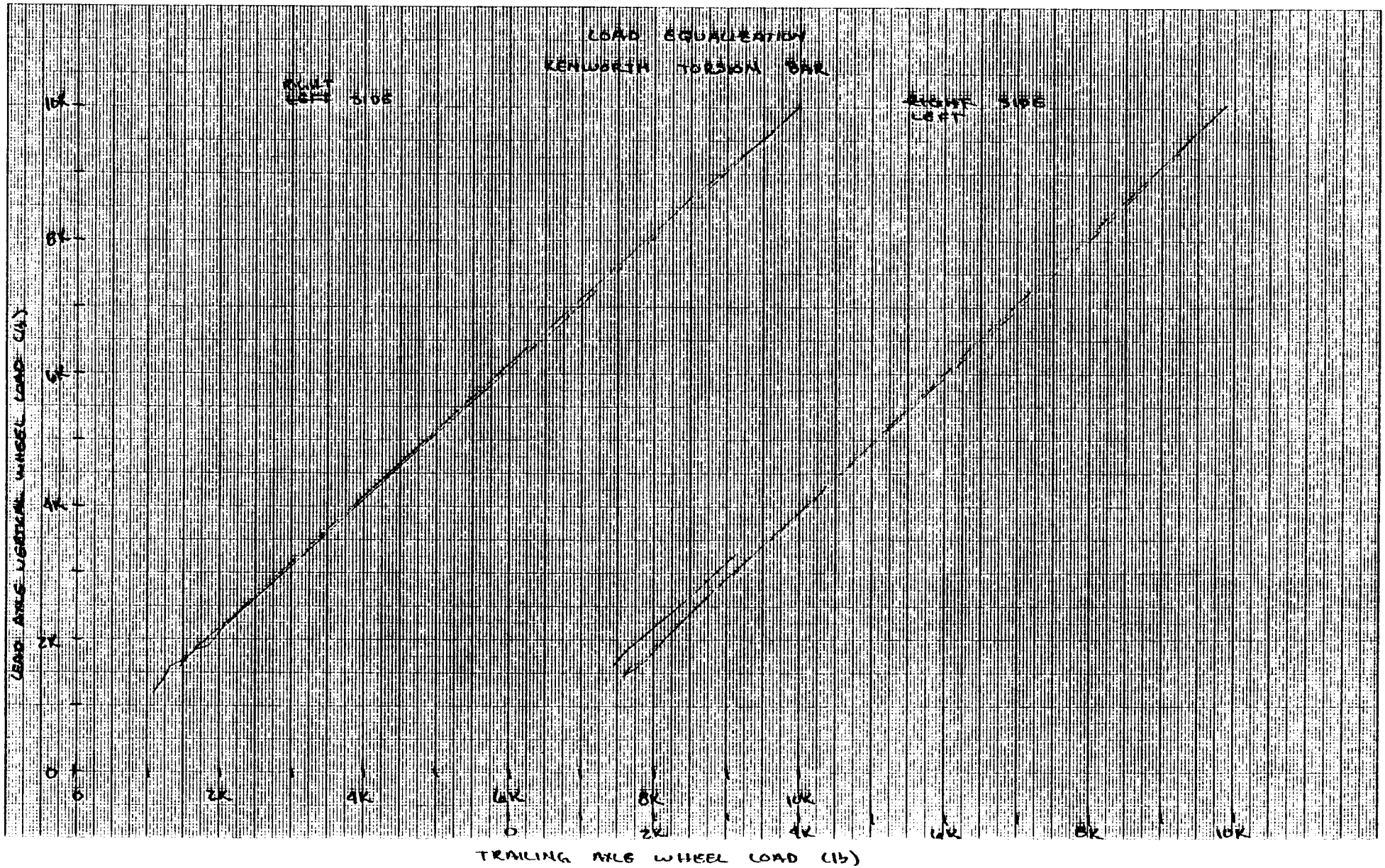
K+E 10 X 10 TO THE CENTIMETER 25 X 18 CM KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512

K&E 10 X 10 TO THE CENTIMETER
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512

Suspension: KENWORTH TORSION BAR

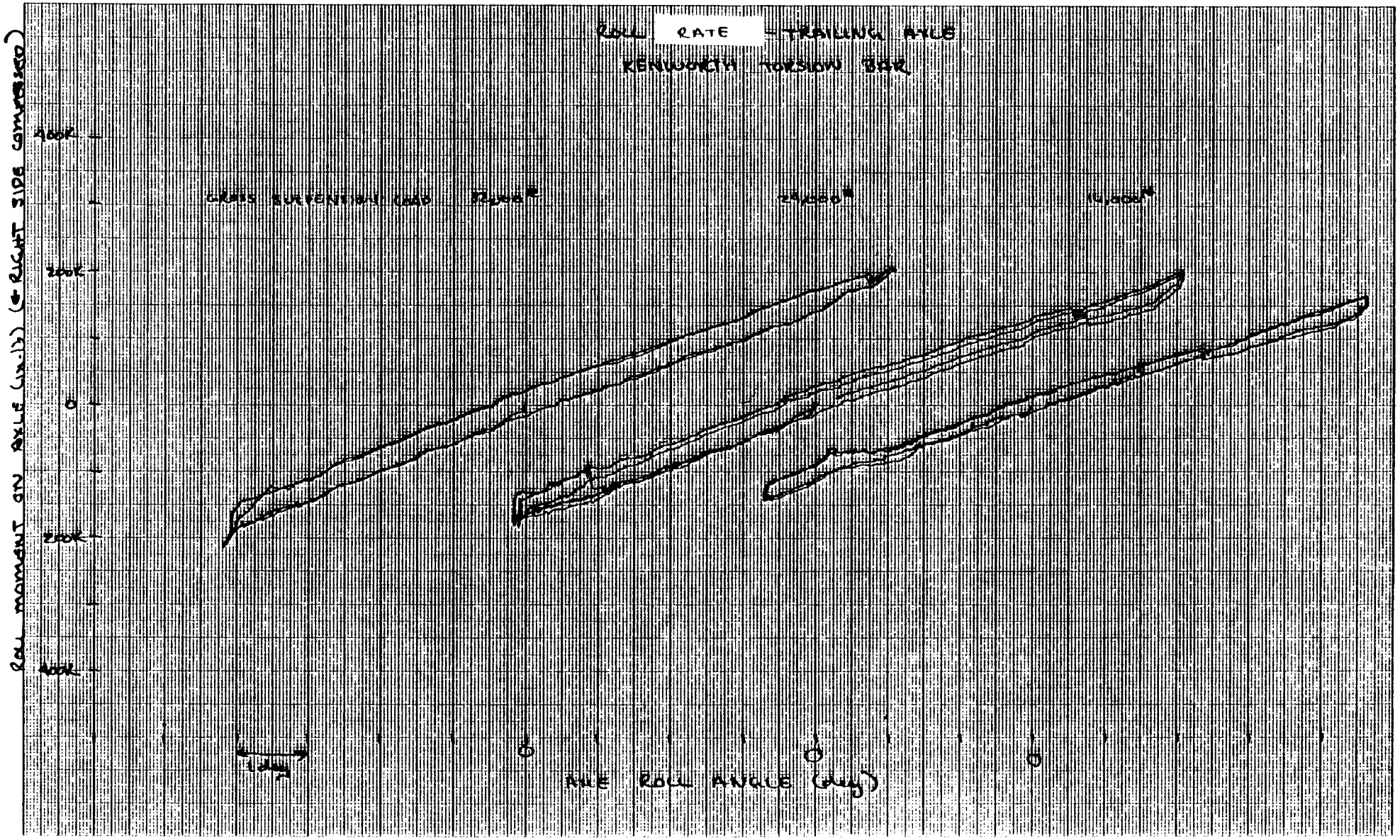
		Susp Load 32000	24000	16000
Vertical Rate (lb/in)		5000	4400	4800
Coulomb Friction		500	400	250
ROLL RATE	F	80K	75K	65K
(in.lb/deg)	R	45K	35K	35K
ROLL CENTER HT	F	13.4	13.0	NA
(in below top of frame)	R	15.5	15.9	16.5
ROLL STEER	F	———	nil	———
(DEG / DEG)	R	- .015	- .01	- .02
ALIGNING MOMENT COMPLIANCE STEER	F	5×10^{-6}	5.2×10^{-6}	5.2×10^{-6}
(deg/in lb)	R	7.5×10^{-6}	6×10^{-6}	7×10^{-6}
LATERAL FORCE COMPLIANCE	F	———	nil	———
(deg/lb)	R	(lateral lash is substantial)		
INTERAXLE LOAD TRANSFER (BRAKE)				
(lb/lb)			NA.	

VERTICAL RATE
KENWORTH TORSION BAR
VERTICAL LOAD PER WHEELSET (lb)
10K
8K
6K
4K
2K
0
AVERAGE VERTICAL WHEEL DEFLECTION (in)
.25 in.



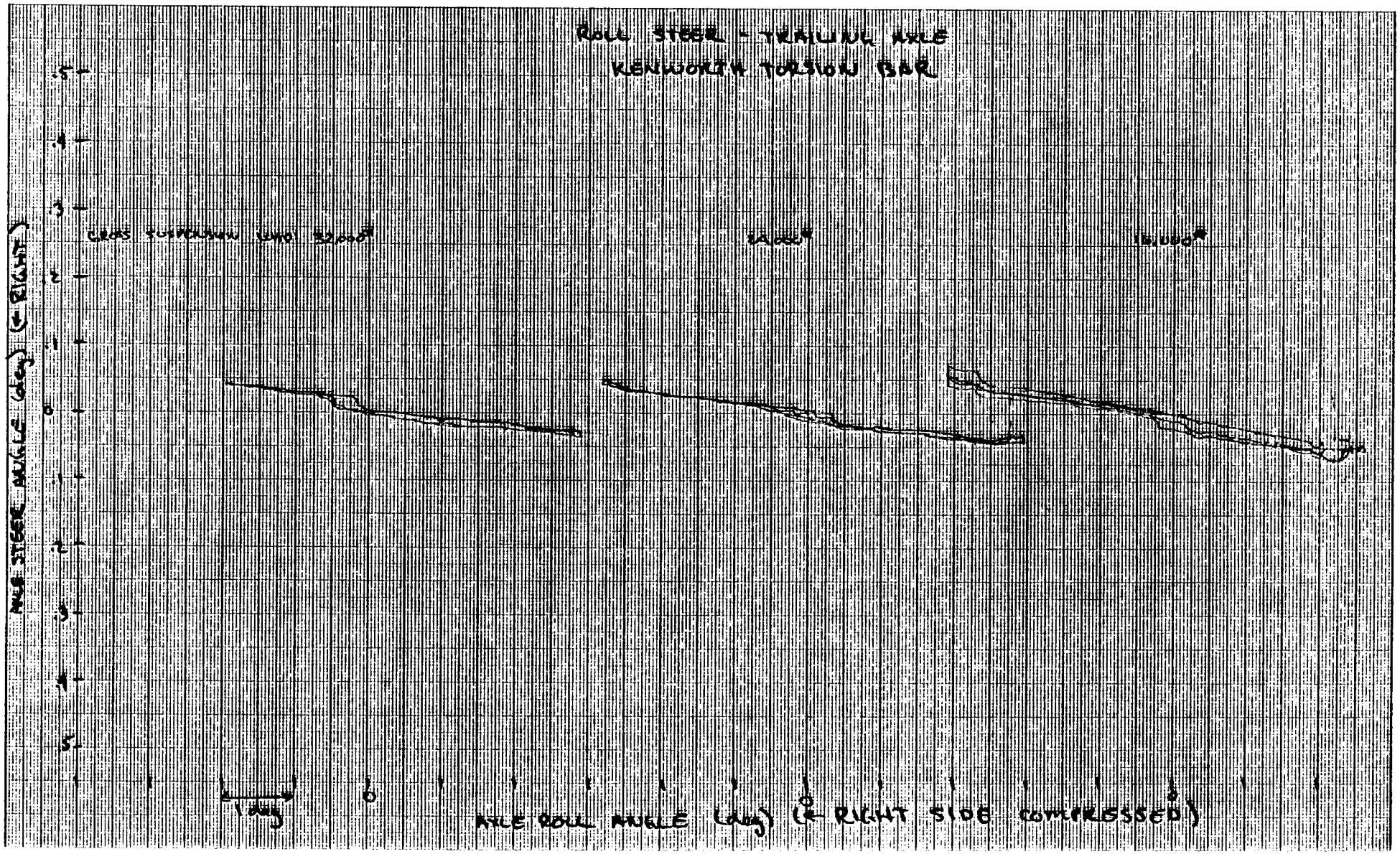
K+E 10 X 10 TO THE CENTIMETER 47 1510

ROLL MOMENT ON AXLE (in.-lb) (at right side connection)
-4000
-2000
0
2000
4000
Roll angle (deg)
6
0
-6
Roll angle
Right side upward
Left side upward

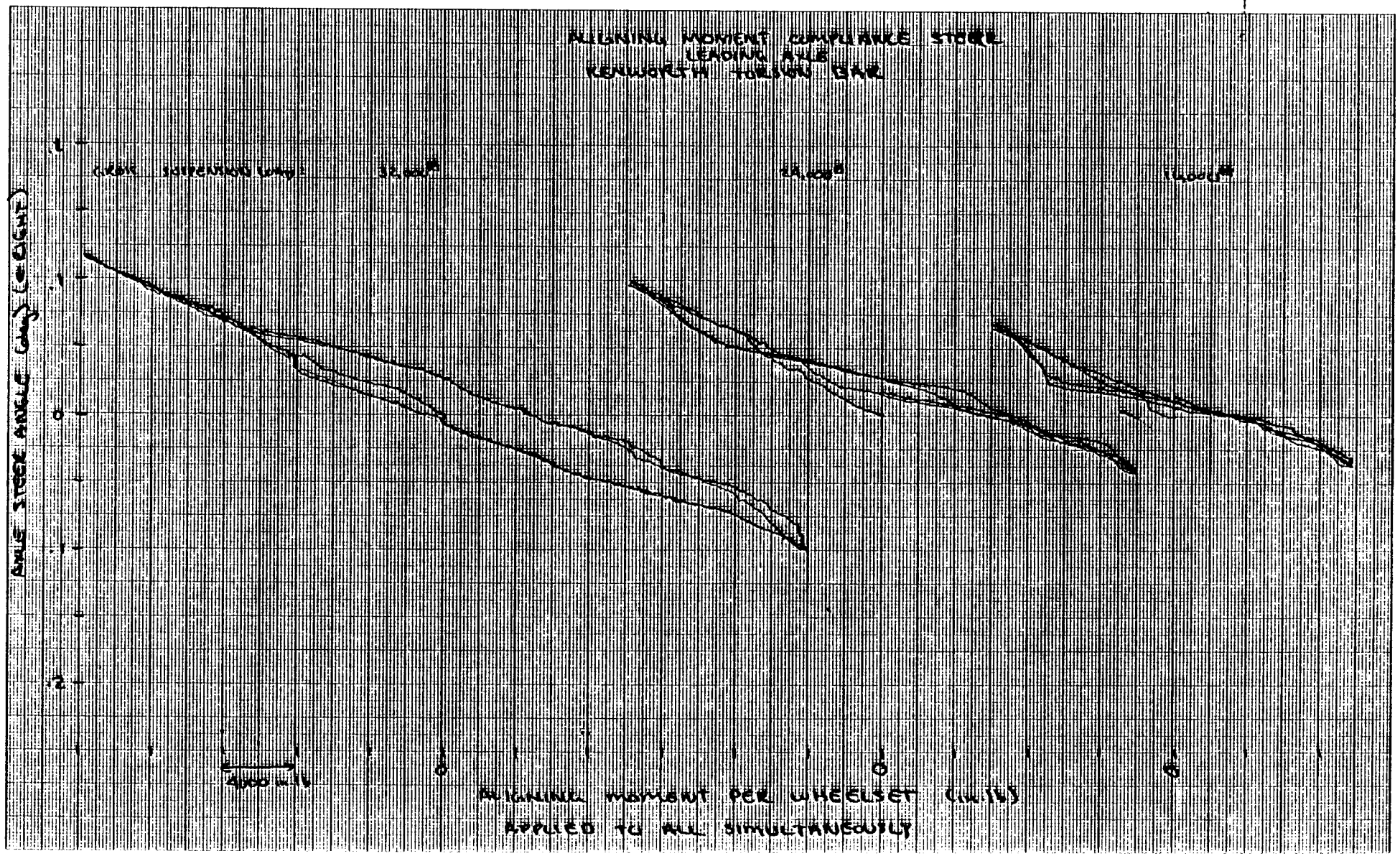


K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1510

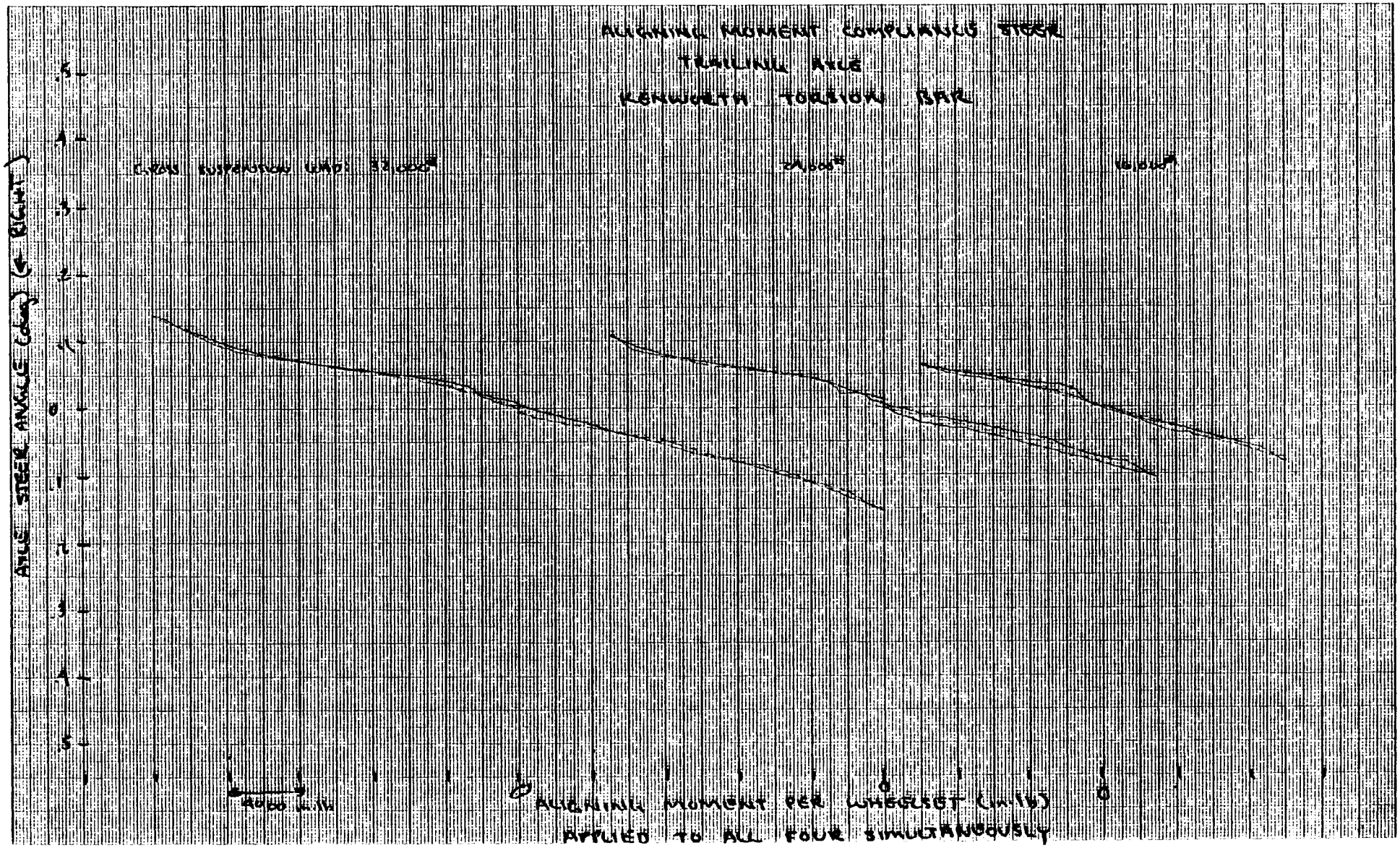
ROUND STEEL LEADING EDGE
NEUTRON TORQUE BAR
Fuse Support Points
Fuse Support Points
Fuse Support Points



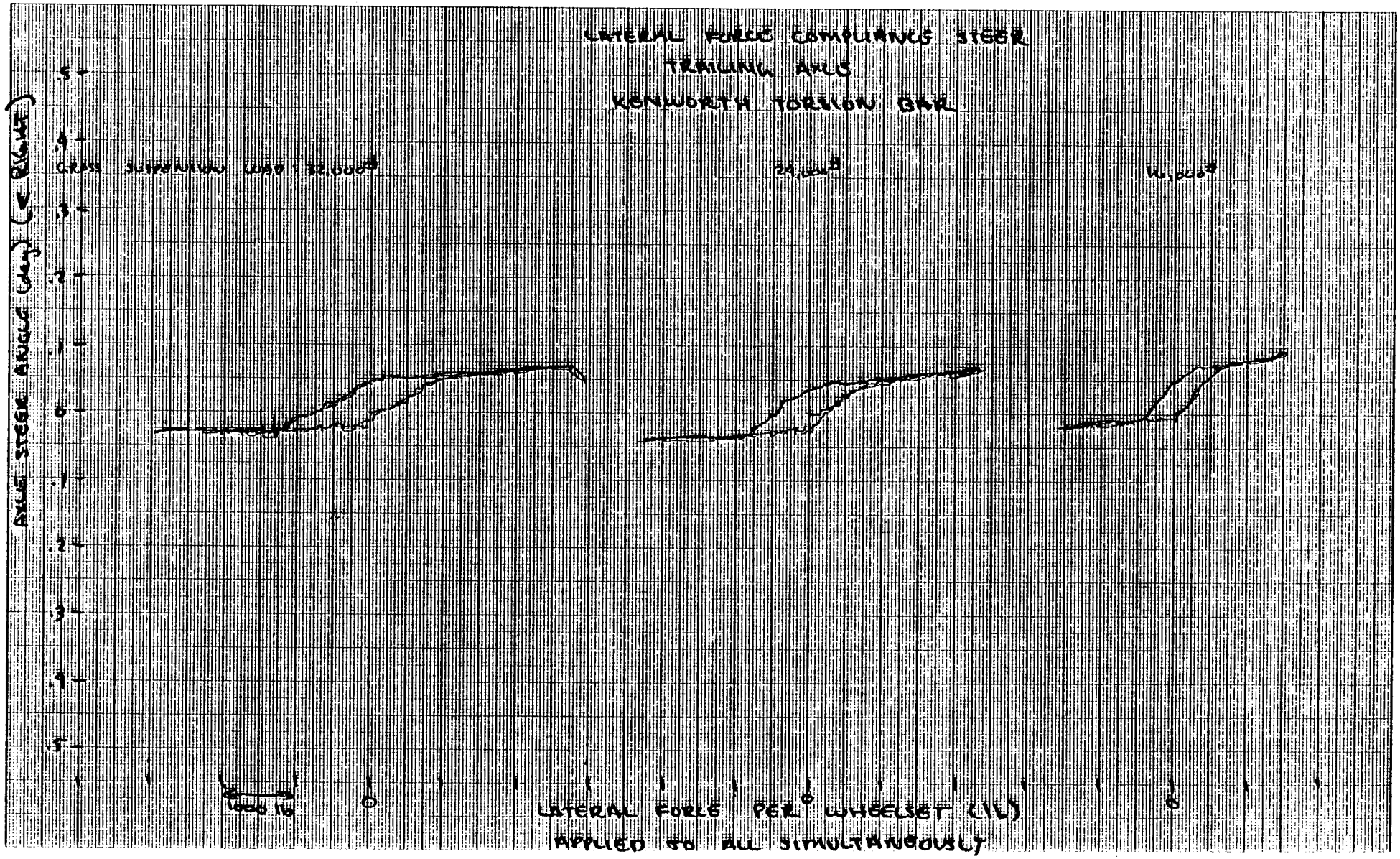
K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1510



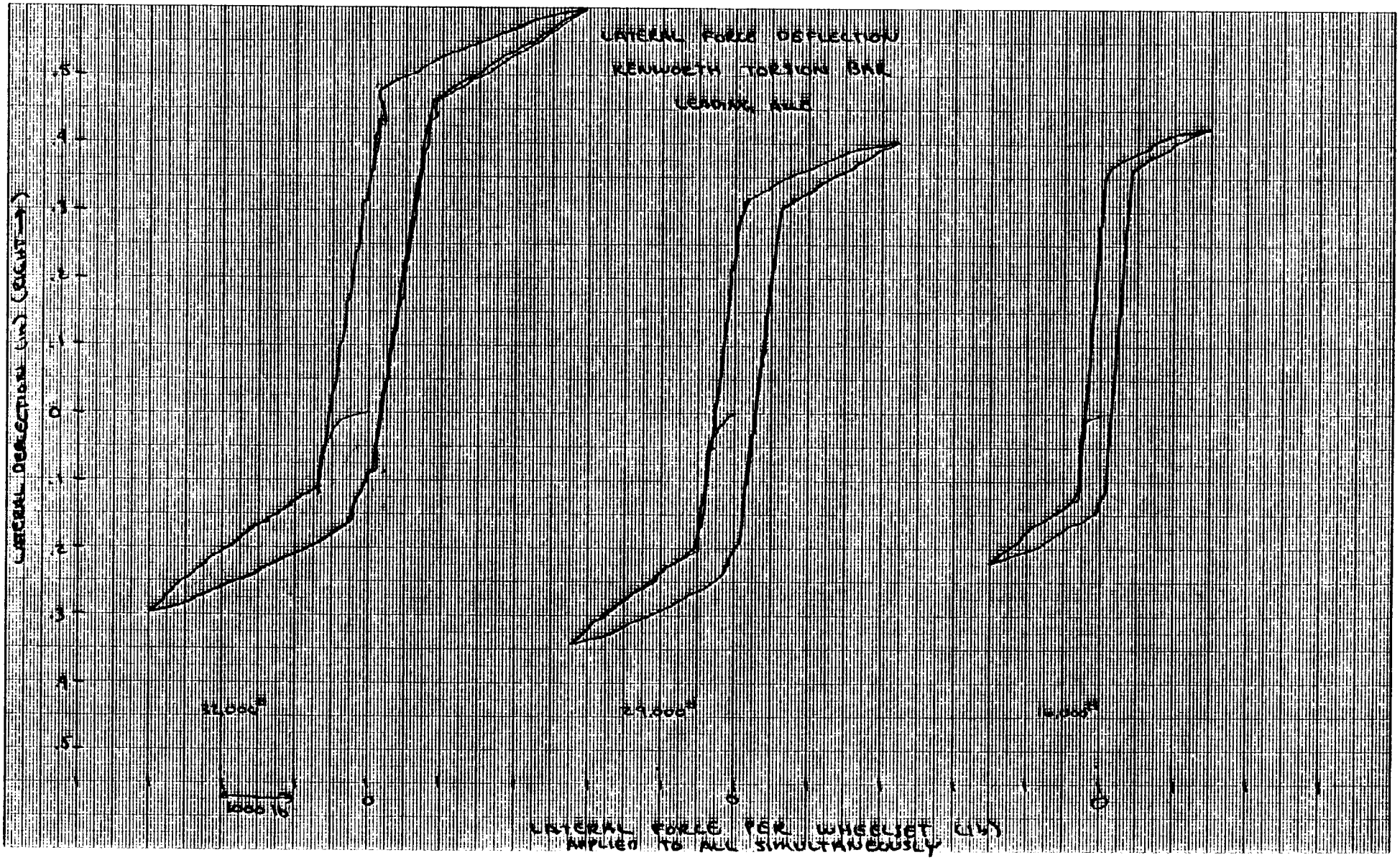
47 1510
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.



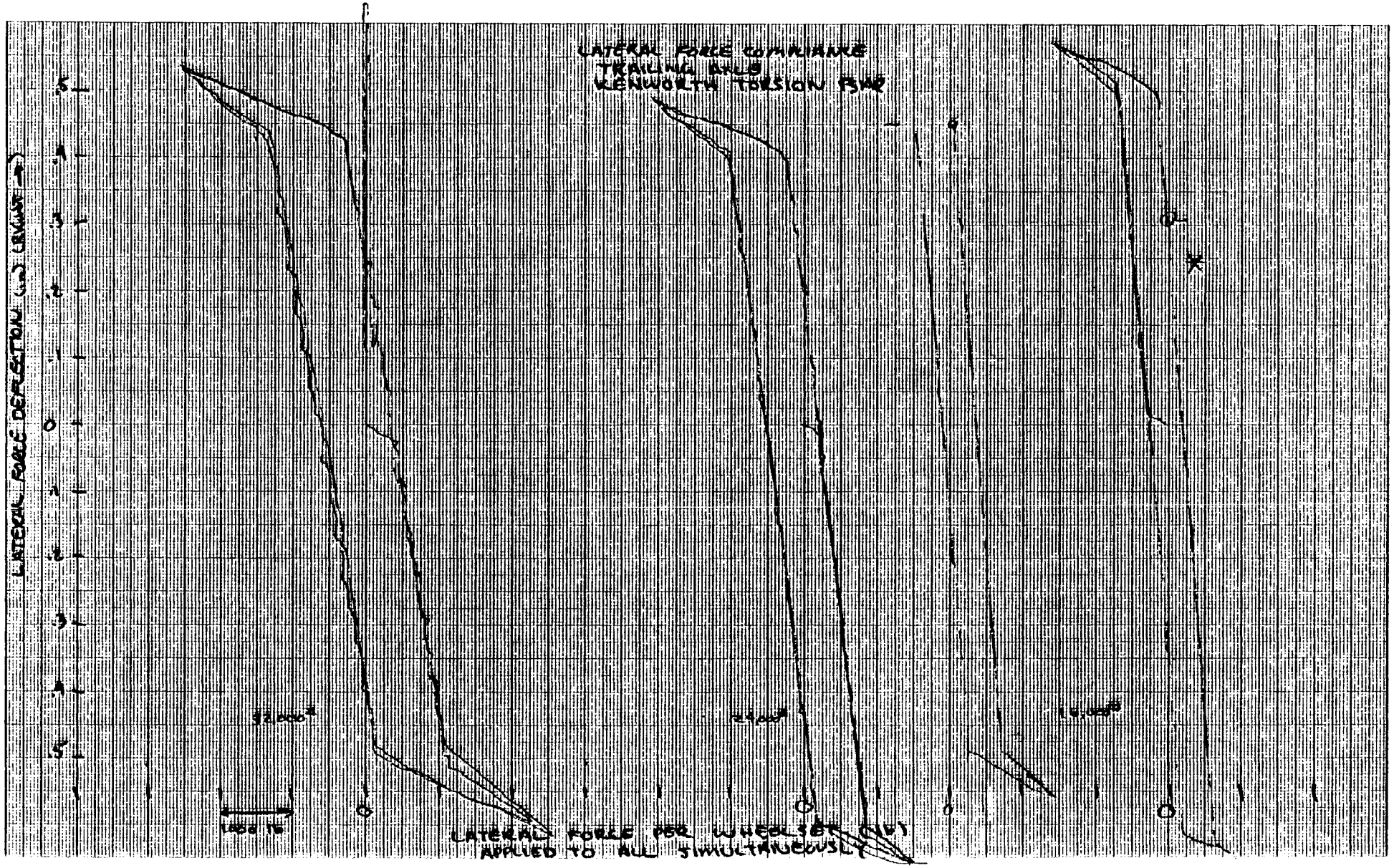
K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1510



K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM. 47 1510



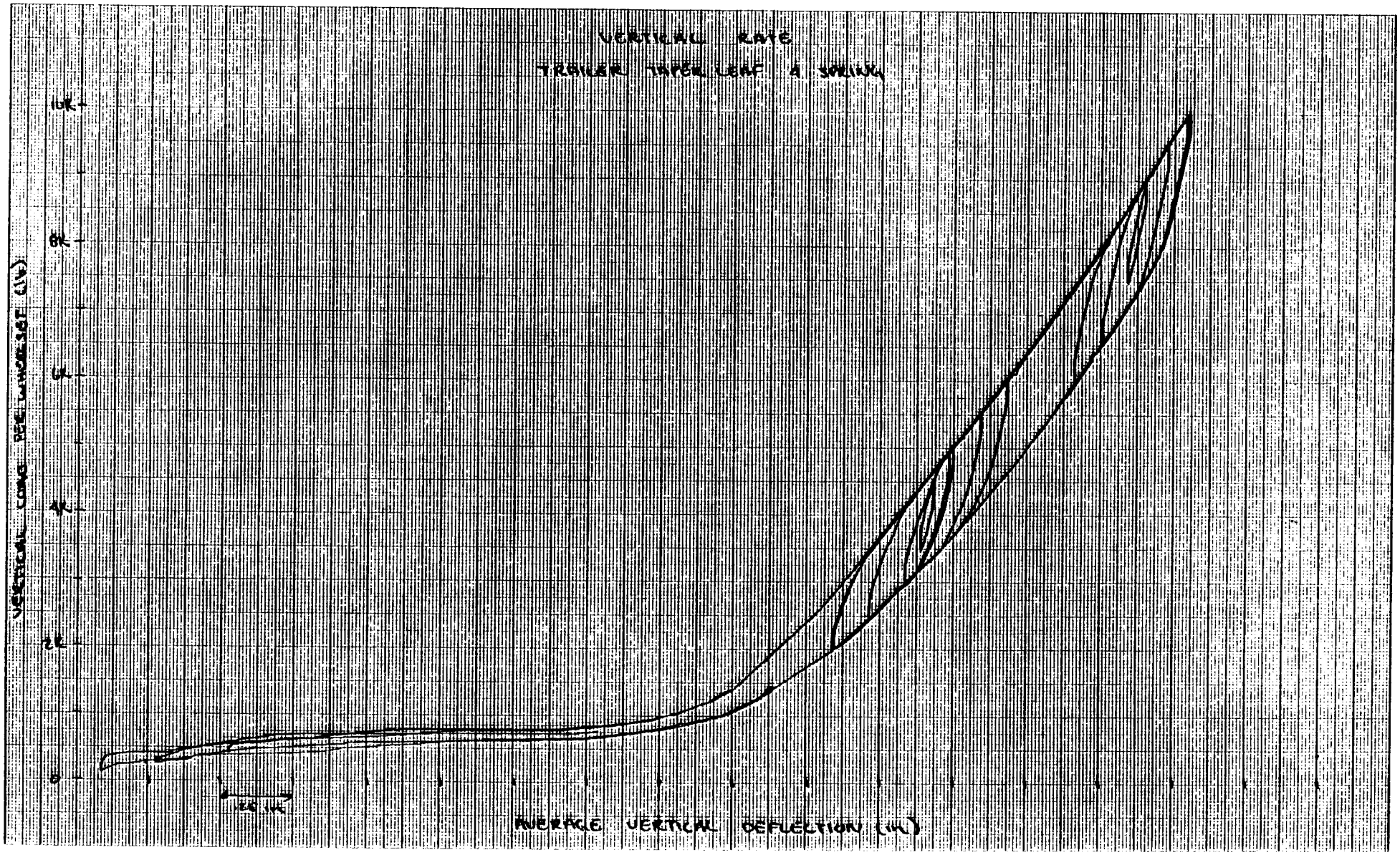
K+E 10 X 10 TO THE CENTIMETER 46 X 38 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1510



K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1510

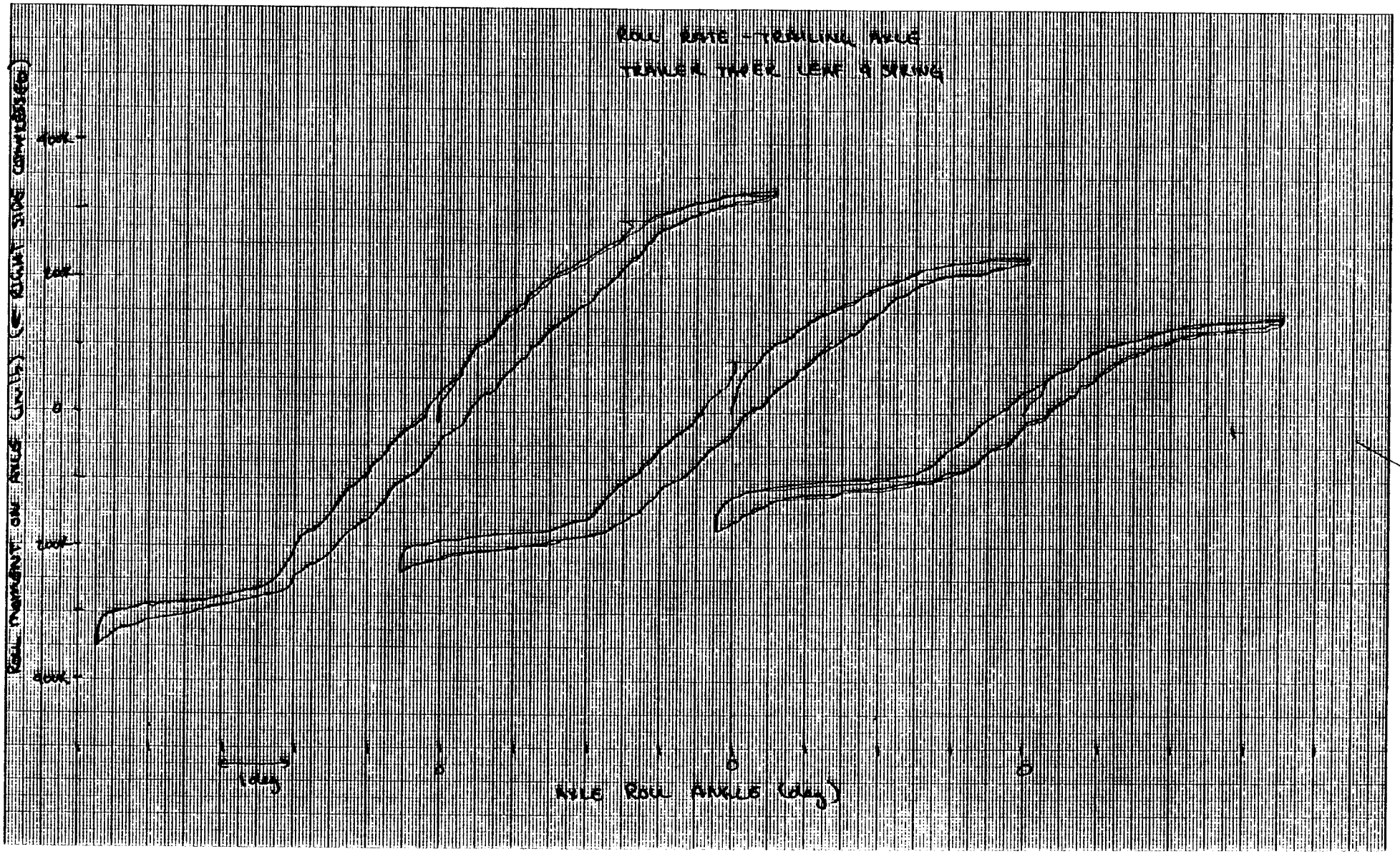
Suspension: Taper Leaf 4 Spring - Hutchens Trailer

		32000	Susp Load 24000	16000
VERTICAL RATE (lb/in)		6200	5800	5400
Coulomb Friction (lb)		750	700	550
ROLL RATE (in-lb/deg)	F	110K	100K	80K
	R	120K	97K	75K
ROLL CENTER HT (in below top of frame)	F	15.2	15.8	16.3
	R	15.9	15.6	14.7
ROLL STEER (DEG / DEG)	F		NA	
	R			
ALIGNING MOMENT COMPLIANCE STEER (deg/in lb)	F		NA	
	R			
LATERAL FORCE COMPLIANCE (deg/lb)	F		NA	
	R			
INTERAXLE LOAD TRANSFER (BRAKING) (lb/lb)			NA	



K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1510

ROLL RATE - TERRAIN AVOIDANCE
TORQUE - THREE LEAF SPRING
ROLL MOMENT ON MUSCLE (in-lb)
(+ RIGHT SIDE COMPRESSED)
ROLL ANGLE (deg)

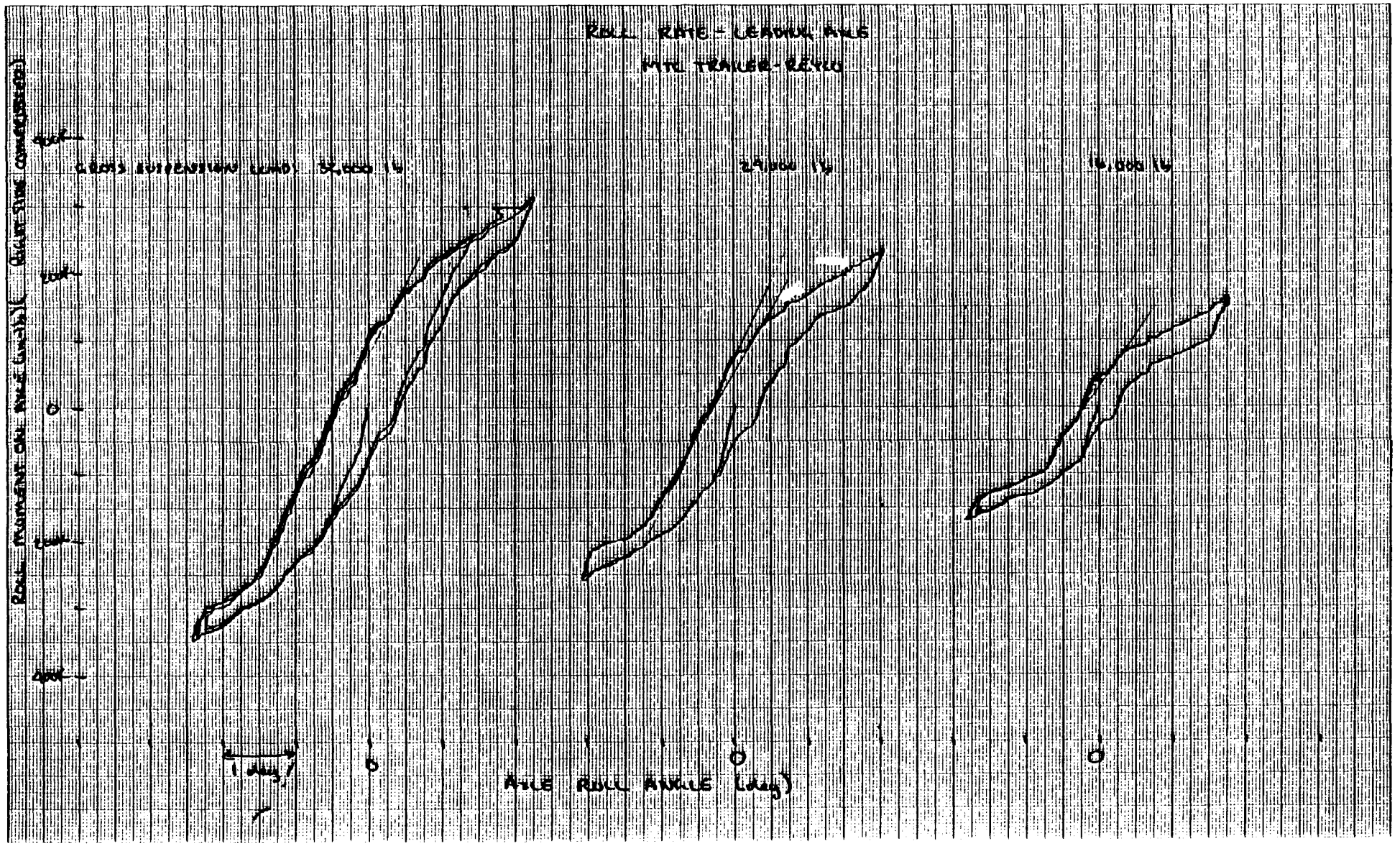


K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1510

Suspension: Reyco 4 Spring - King Trailer

		Susp Load 32000	24000	16000
Vertical Rate (lb/in)		11,800	10,800	10000
Coulomb Friction (lb)		1400	1250	850
ROLL RATE (in-lb/deg)	F	200K	180K	150K
	R	250K	200K	165K
ROLL CENTER HT (in below top of frame)	F	NA		
	R			
ROLL STEER (DEG / DEG)	F	.21	.23	.23
	R	.23	.23	.23
ALIGNING MOMENT COMPLIANCE STEER (deg/in lb)	F	3×10^{-6}	2.7×10^{-6}	3.5×10^{-6}
	R	5.5×10^{-6}	6×10^{-6}	6.5×10^{-6}
LATERAL FORCE COMPLIANCE (deg/lb)	F	nil		
	R			
INTERAXLE LOAD TRANSFER (BY MASS) (lb/lb)		NA		

VERTICAL RATE
MTU TRAVELLED
AVERAGE VERTICAL DEFLECTION (MM)
VERTICAL LOAD PER WHEEL (LB)



K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512

Ankle Dorsiflexion Moment, One Stride (ft-lb) (Plane Side Connected)

STEER LEADING ANGLE
WITH POWER REVD
2.5 DEG
1.5 DEG
ROLL ANGLE (DEG) (+ RIGHT SIDE DOWNWARD)
TIME

Roll angle (deg) (+ right - 10° compression)
Aileron deflection (deg) (+ right - 10° compression)

Price Stock Index (log) (Current)
Adjusted Monthly Consumption Yield
Long Treasury Rate
Adjusted Monthly Consumption Yield
Long Treasury Rate
Adjusted Monthly Consumption Yield
Long Treasury Rate

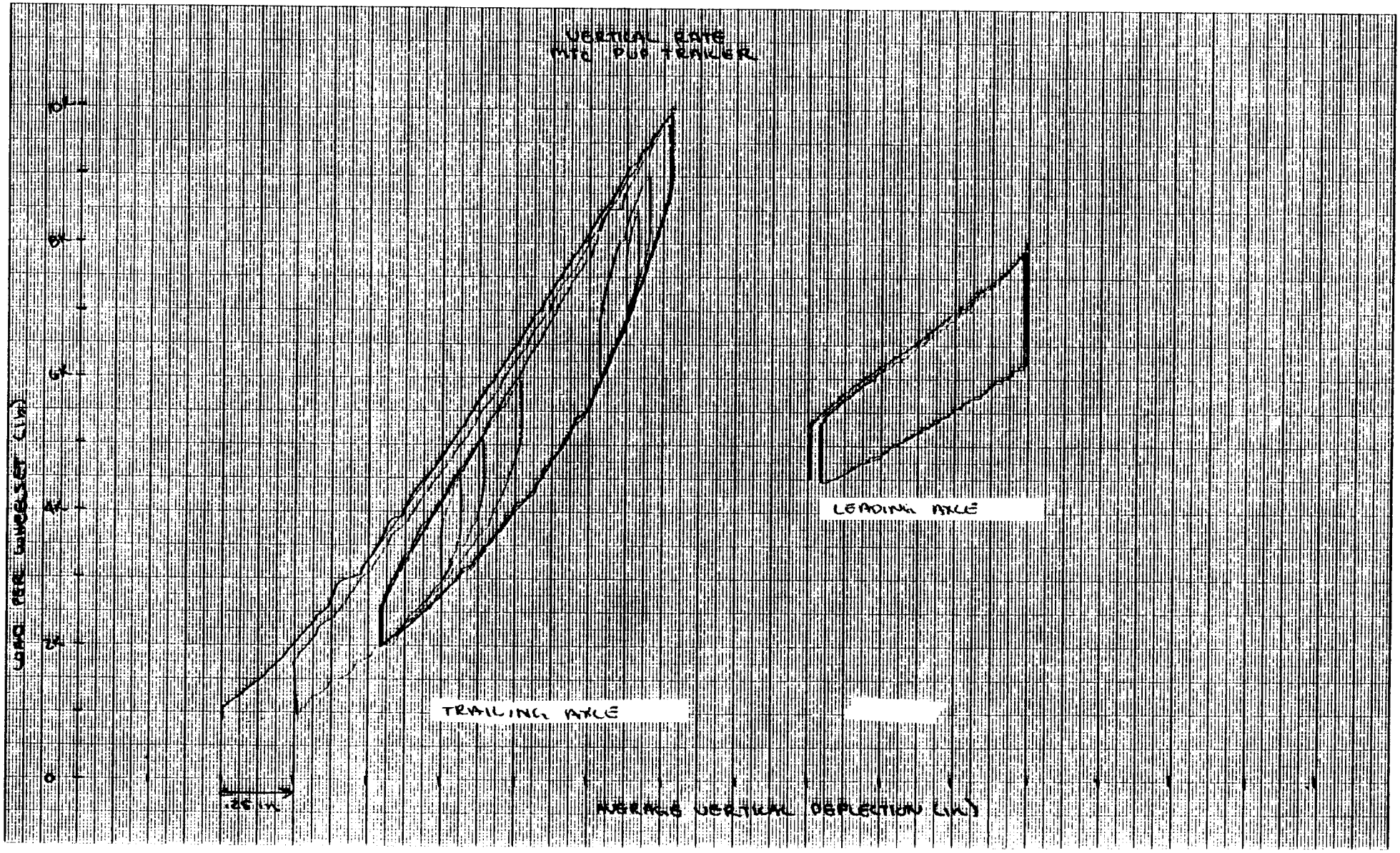
Plate Stress, ksi (MPa)
Outer plate
Inner plate
Bolt
Bolt
Plate
Bolt
Bolt
Plate
Bolt
Bolt

Lateral Force per Unit Weight (lb/lb)
Applied to All Simultaneously
Lateral Force per Unit Weight (lb/lb) Applied to Roof Only
Lateral Force per Unit Weight (lb/lb) Applied to Floor Only
Lateral Force per Unit Weight (lb/lb) Applied to Floor Only
Lateral Force per Unit Weight (lb/lb) Applied to Roof Only
Lateral Force per Unit Weight (lb/lb) Applied to All Simultaneously

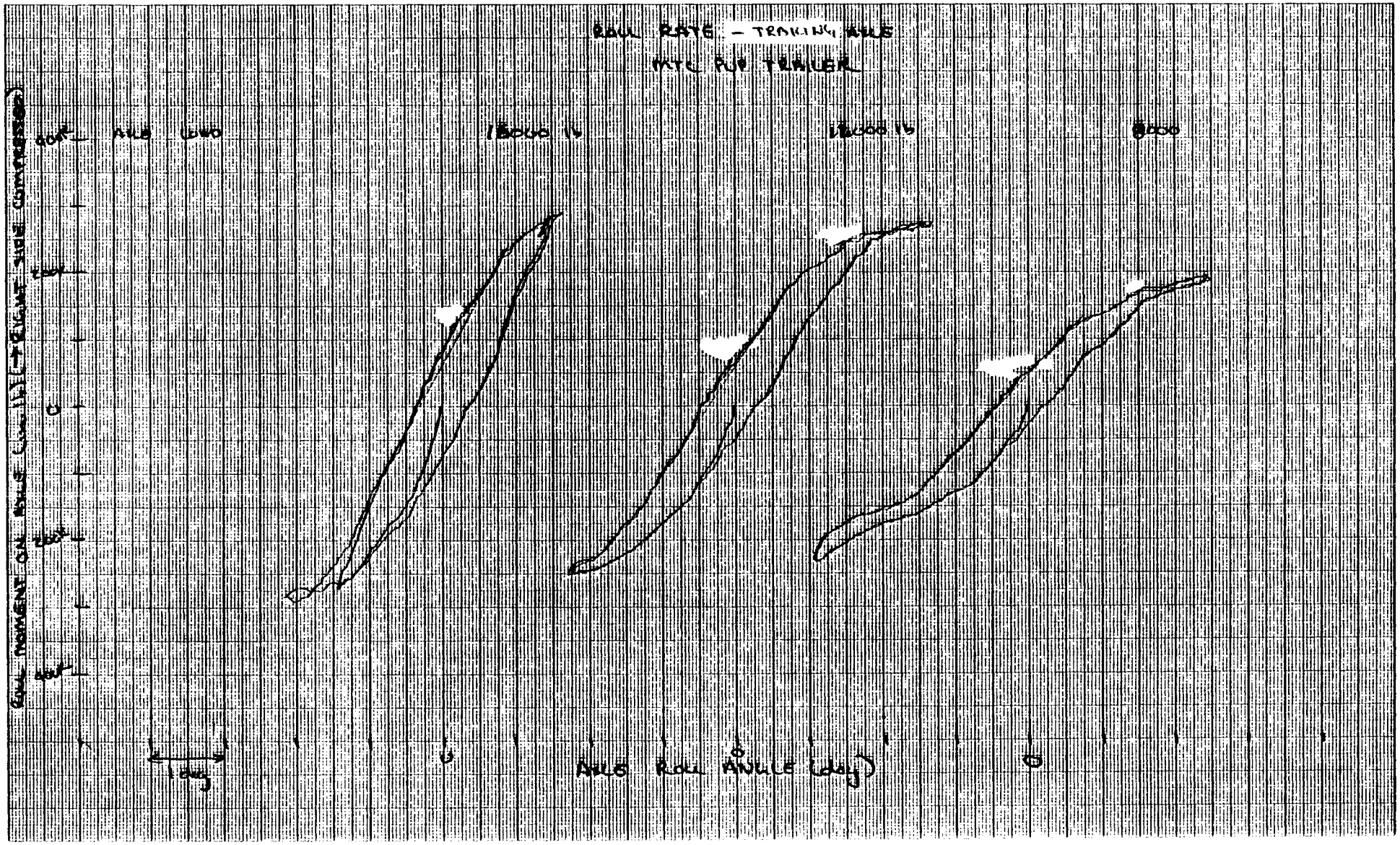
LATERAL FORCE CURVATURE STEEZ
TRAINING RULE
NOT TRAINED
CROSS WARMING UNIT 52000 LV
24 DEG. LV
UNIT No
LATERAL FORCE PER UNBEVEL UNIT (LB FORCE TO RAISE)
APPLIED TO ALL SIMULTANEOUSLY
INCH TO

Suspension: Reyco Single - King Trailer

		Susp Load 16000	12000	8000
Vertical Rate (lb/in)		6800	6600	6000
Coulomb Friction (lb)		1250	1200	825
ROLL RATE (in-lb/deg)	F	200K	160K	120
	R			
ROLL CENTER HT (in below top of frame)	F		NA	
	R			
ROLL STEER (DEG / DEG)	F	-.24	-.25	-.26
	R			
ALIGNING MOMENT COMPLIANCE STEER (deg/in lb)	F	8×10^{-6}	1×10^{-5}	1×10^{-5}
	R			
LATERAL FORCE COMPLIANCE (deg/lb)	F	6×10^{-5}	8×10^{-5}	1.2×10^{-4}
	R			
INTERAXLE LOAD TRANSFER (BY AXLE) (lb/lb)				

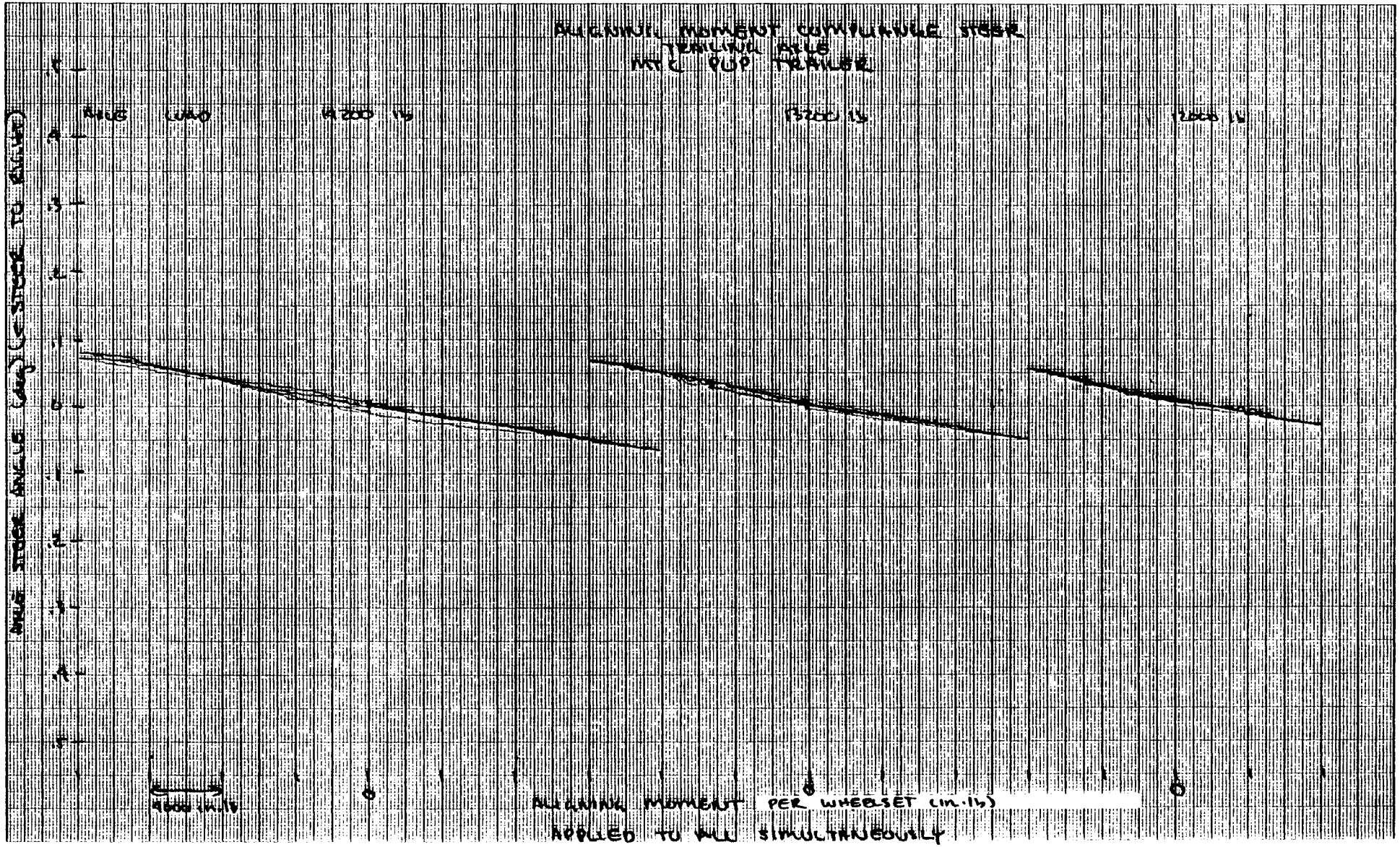


K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512

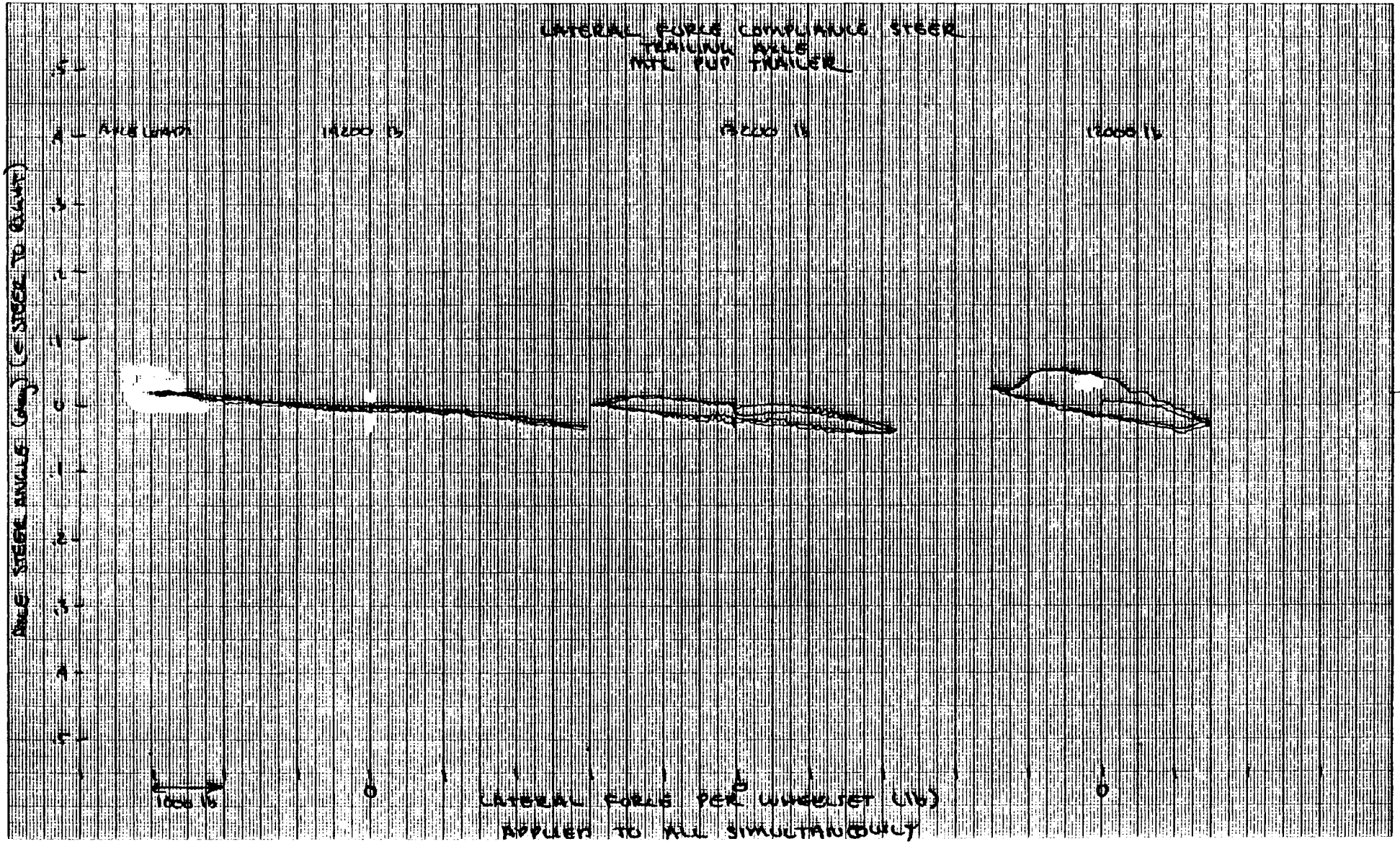


K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM. KEUFFEL & ESSER CO. MADE IN U.S.A. 47 1512

ROLL STEER / TRAILER ANGLE
WRT J-KNIFE TRAILER
STEER ANGLE (deg) (+ STEER TO RIGHT)
ANG ROLL ANGLE (deg) (+ RIGHT SIDE DOWN)
Test 1
Test 2
Test 3
Test 4
Test 5
Test 6
Test 7
Test 8
Test 9
Test 10
Test 11
Test 12
Test 13
Test 14
Test 15
Test 16
Test 17
Test 18
Test 19
Test 20
Test



K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
47 1512

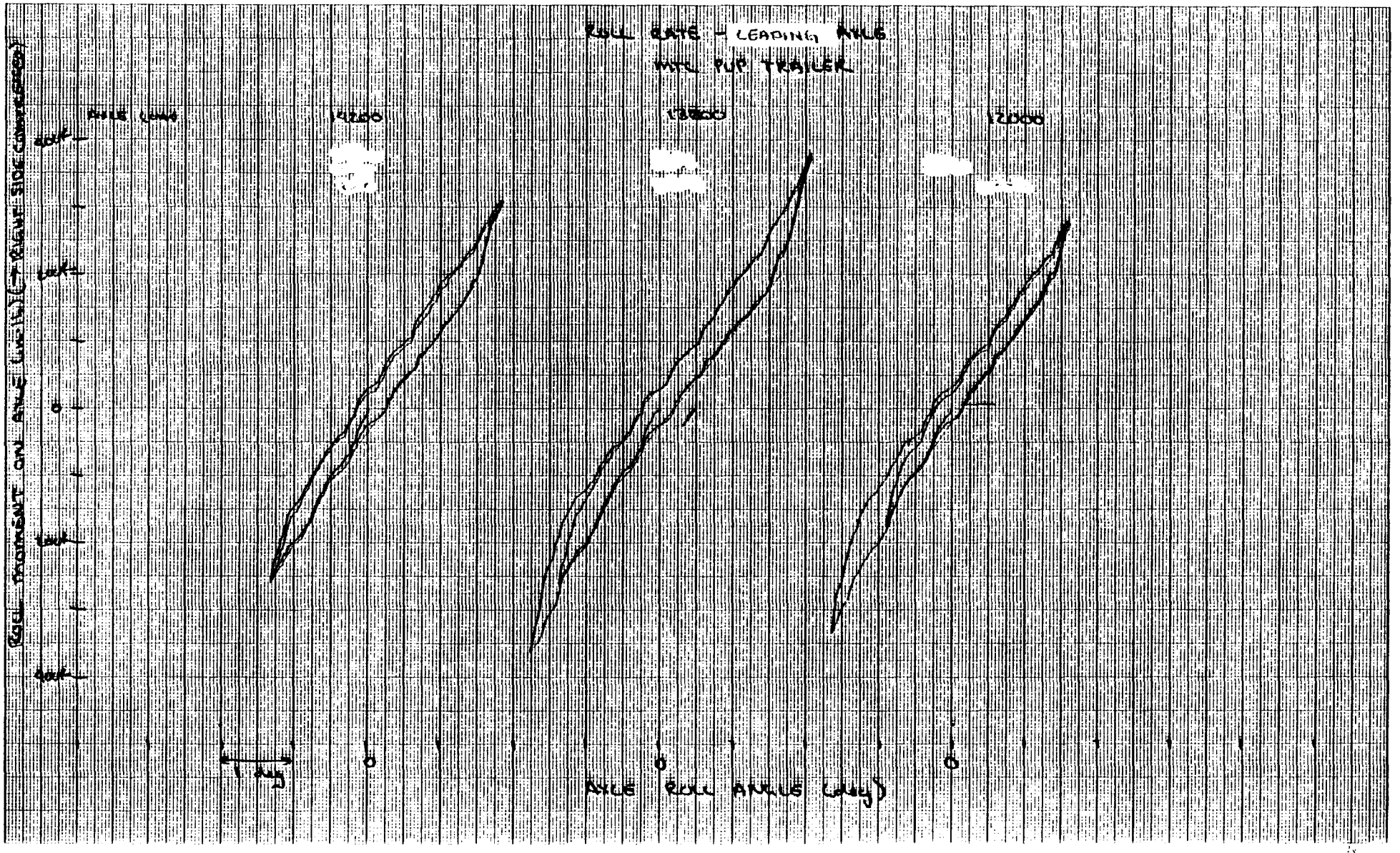


K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512

Suspension: Air Lift - King Trailer

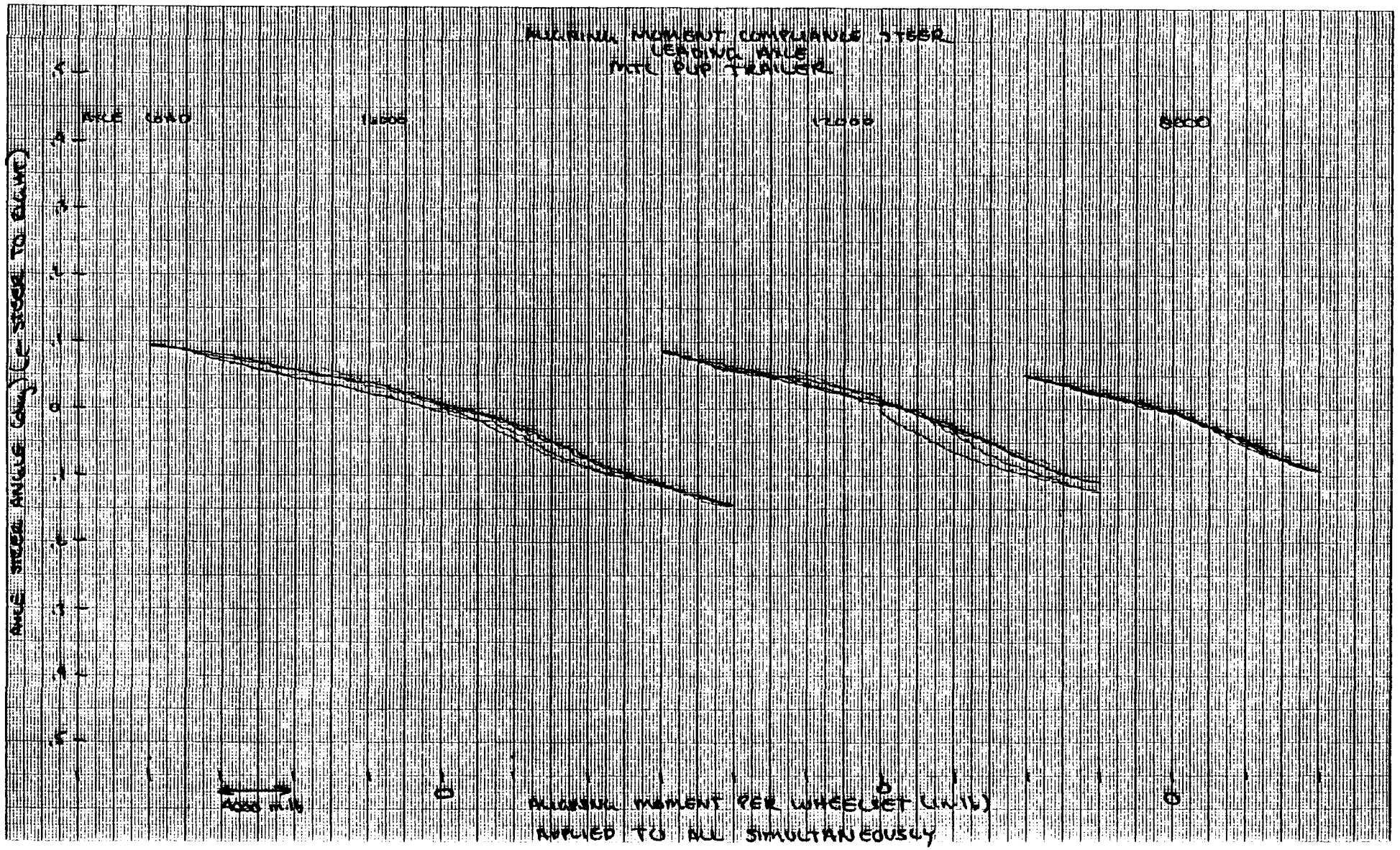
		Susp Load 14,200	13,200	12,000
Vertical Rate (lb/in)		3400		
ROLL RATE (in.lb/deg)	F	150K	135K	130K
	R			
ROLL CENTER HT (in below top of frame)	F	N/A		
	R			
ROLL STEER (DEG / DEG)	F	.02	.02	.02
	R			
ALIGNING MOMENT COMPLIANCE STEER (deg/in lb)	F	4×10^{-6}	5×10^{-6}	5×10^{-6}
	R			
LATERAL FORCE COMPLIANCE (deg/lb)	F	8×10^{-5}	1×10^{-4}	2.5×10^{-4}
	R			

INTERAXLE LOAD TRANSFER (BRAKING)
(lb/lb)

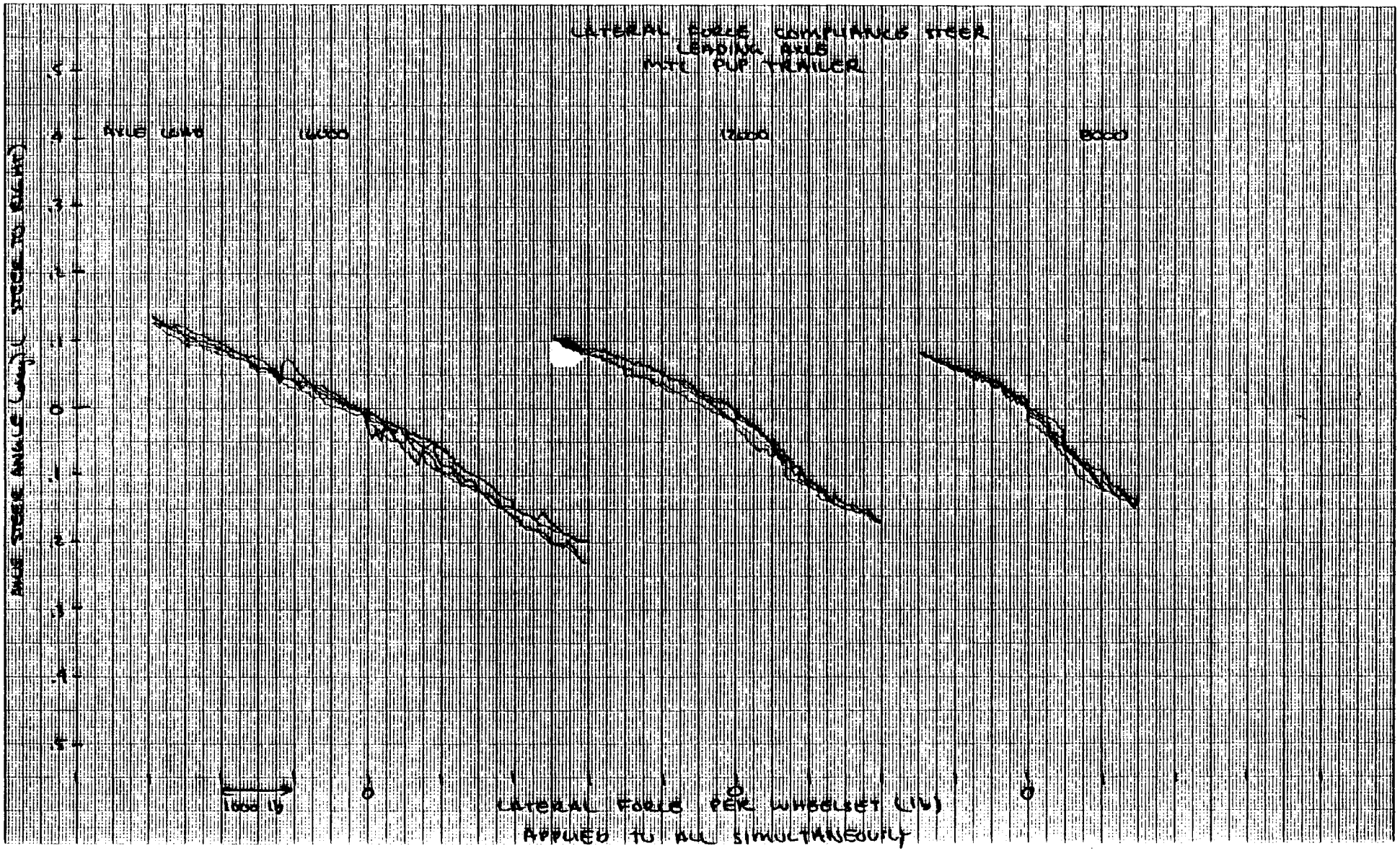


K+E 10 X 10 TO THE CENTIMETER 25 X 35 CM KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512

ROLL STEER - LEADING AXLE
INTO PUP TRAILER
(LOADED)
ROLL ANGLE (φ) RIGHT SIDE CONVEX (+)
LEFT
STEER ANGLE (δ) (+ STEER TO RIGHT)
-4°
-3°
-2°
-1°
0
1°
2°
3°
4°
AXLE
UNLOADED
LOADED



K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512



K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512

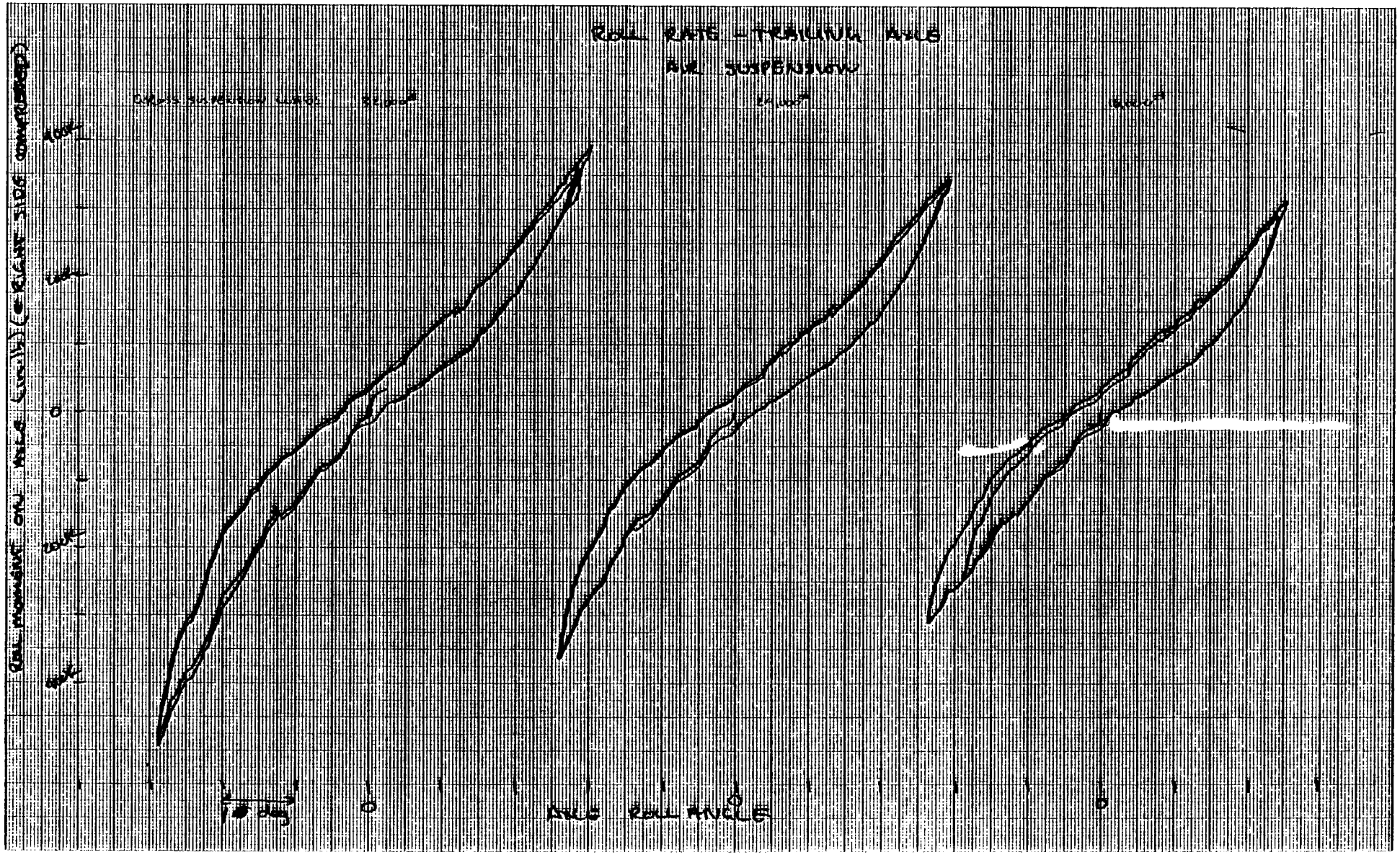
Suspension: Neway Air Suspension - Trailer

		Susp Load 32000	29000	16000
Vertical Rate (lb/in)		1900	1400	1000
Coulomb Friction (lb)		400	425	400
Roll Rate (in-lb/deg)	F	80K	75K	65K
	R	95K	75K	70K
Roll Center Ht (in below top of frame)	F		24.1	
	R		25.0	
Roll Steer (deg/deg)	F		NA	
	R			
Aligning Moment Compliance Steer (deg/in-lb)	F		NA	
	R			
Lateral Force Compliance (deg/lb)	F		NA	
	R			
Interaxle Load Transfer (Braking) (lb/lb)			NA	

KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1510

Fig. 7

K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1510



K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1510

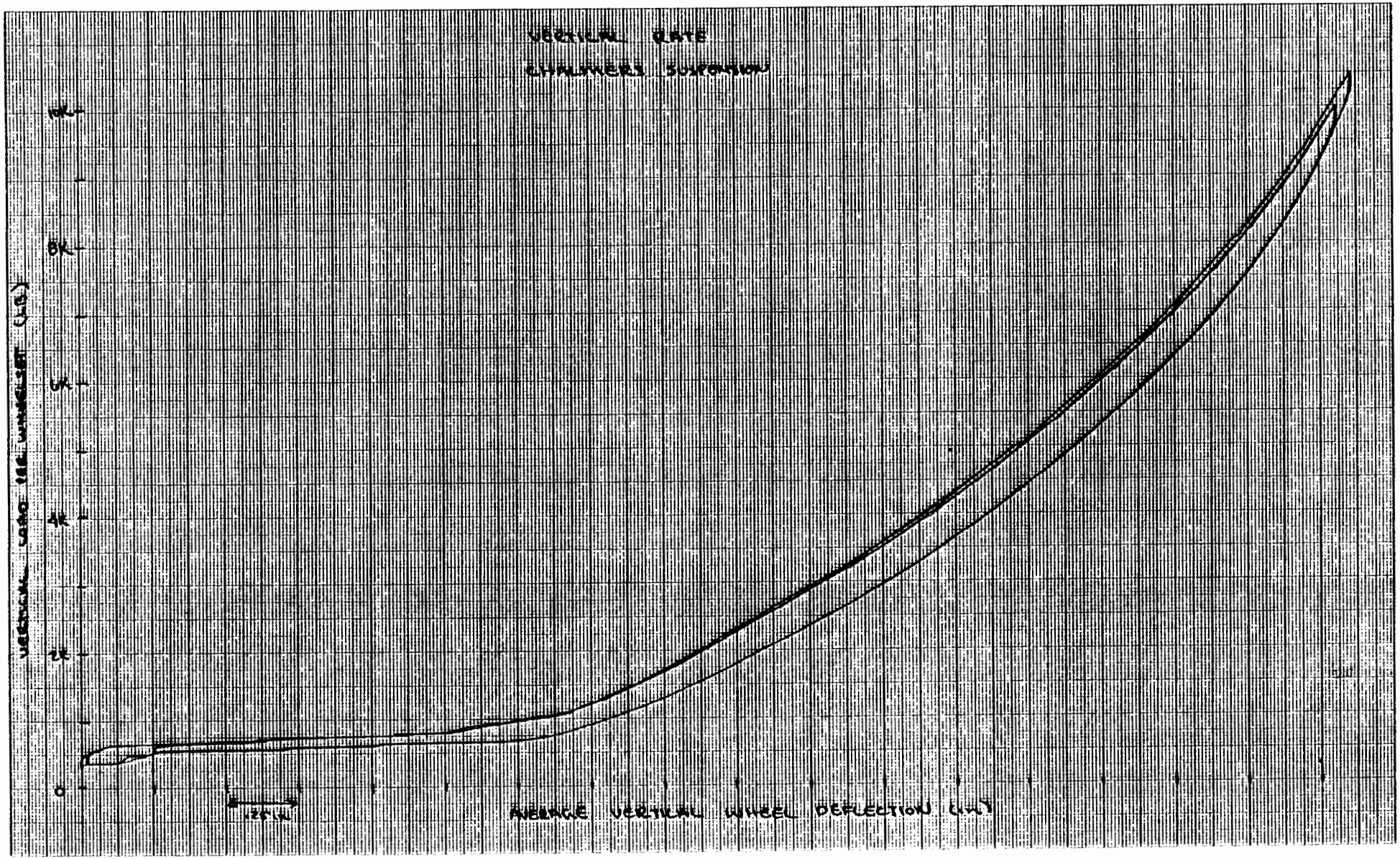
Suspension: Chalmers Rubber Block Walking Beam

		Susp Load 32000	24000	16000
Vertical Rate (lb/in)		5200	3800	3000
Coulomb Friction (lb)		375	325	300
Roll Rate (in lb/deg)	F	92K	67K	52K
	R	90K	65K	47K
Roll Center Ht (in below top of frame)	F	19.9	16.1	16.4
	R	15.4	15.9	16.5
Roll Steer (deg / deg)	F			
	R			

Aligning Moment Compliance Steer F
(deg / in lb) R

Lateral Force Compliance F
(deg / lb) R

Interaxle Load Transfer (Braking)
(lb / lb)



K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1510

ROLL RATE TRANSIENT
CURVED FLIGHT
ROLL RATE (DEG/SEC)
TIME (SEC)

ROCKET MOMENT ON WING (LIVE-LB) (+ ELEVATOR DOWN)
AILE RON ANGLE (DEG)

Suspension:

		Susp Load 20000	15000	10000
Vertical Rate (lb/in)		8000	8000	8000
ROLL RATE (in-lb/deg)	F	105K	87.5K	60K
	R			
ROLL CENTER HT (in below top of frame)	F	13.9	14.0	14.0
	R			
ROLL STEER (DEG / DEG)	L	———	nil	———
	R	.09	.05	.08
ALIGNING MOMENT COMPLIANCE STEER (deg/in lb)	F	———	nil	———
	R			
LATERAL FORCE COMPLIANCE (deg/lb)	F	———	nil	———
	R			

INTERAXLE LOAD TRANSFER (BRAKING)
(lb/lb)

VERTICAL LOAD PER WHEEL (LB.)
AVERAGE VERTICAL DEFLECTION (IN.)

ANGLE (DEG.)
0
-10
-20
-30
-40
-50
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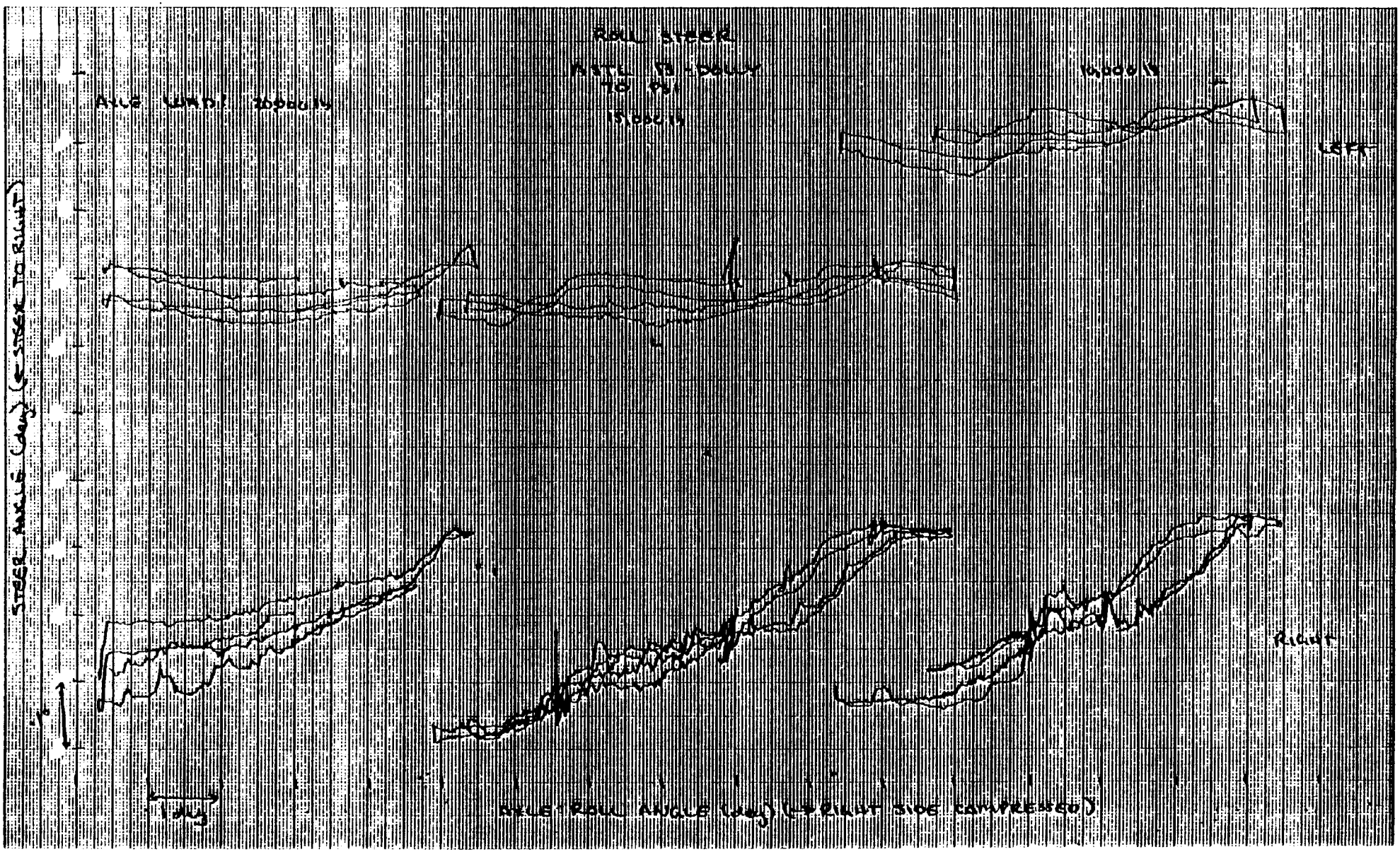

K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
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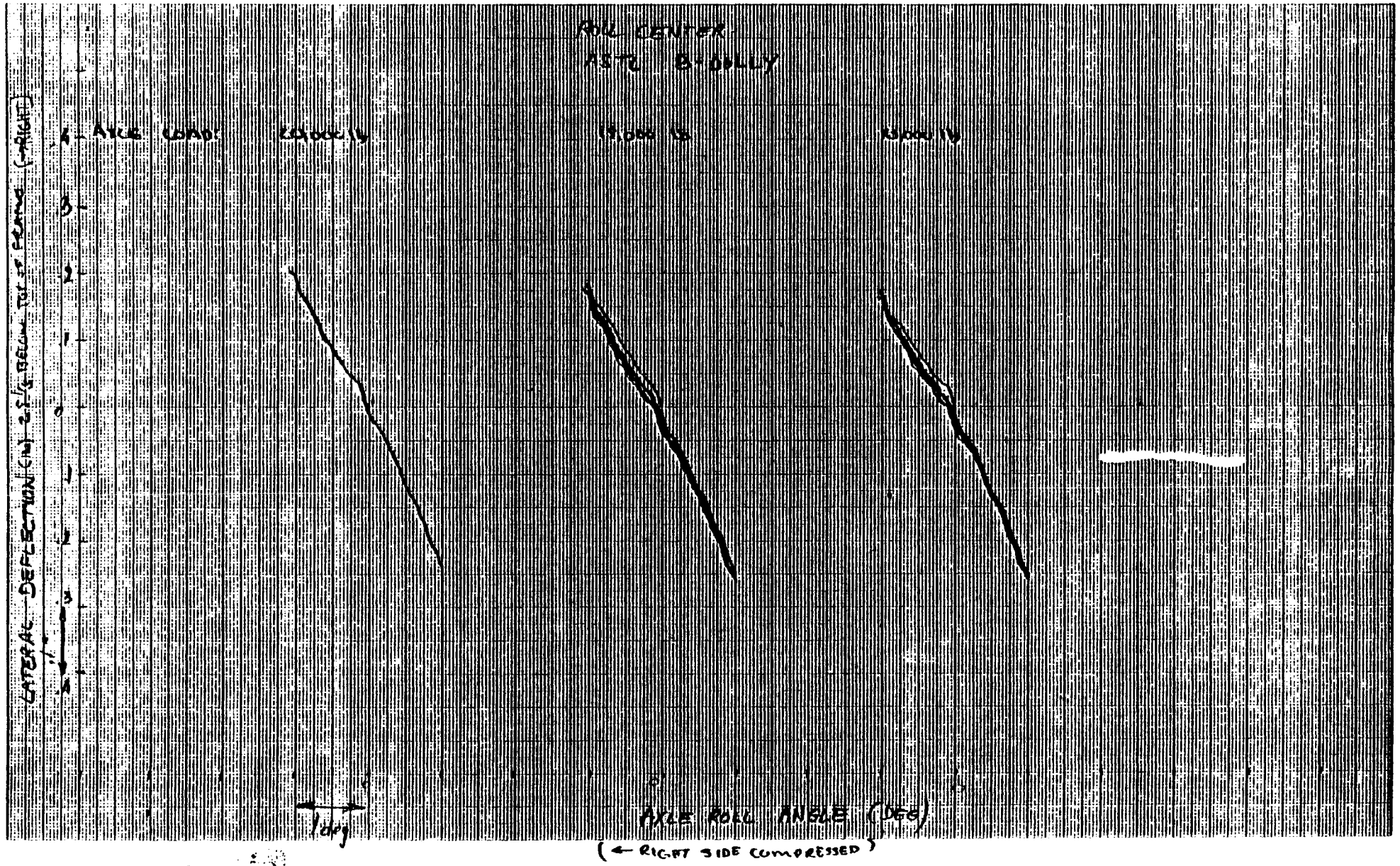

K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
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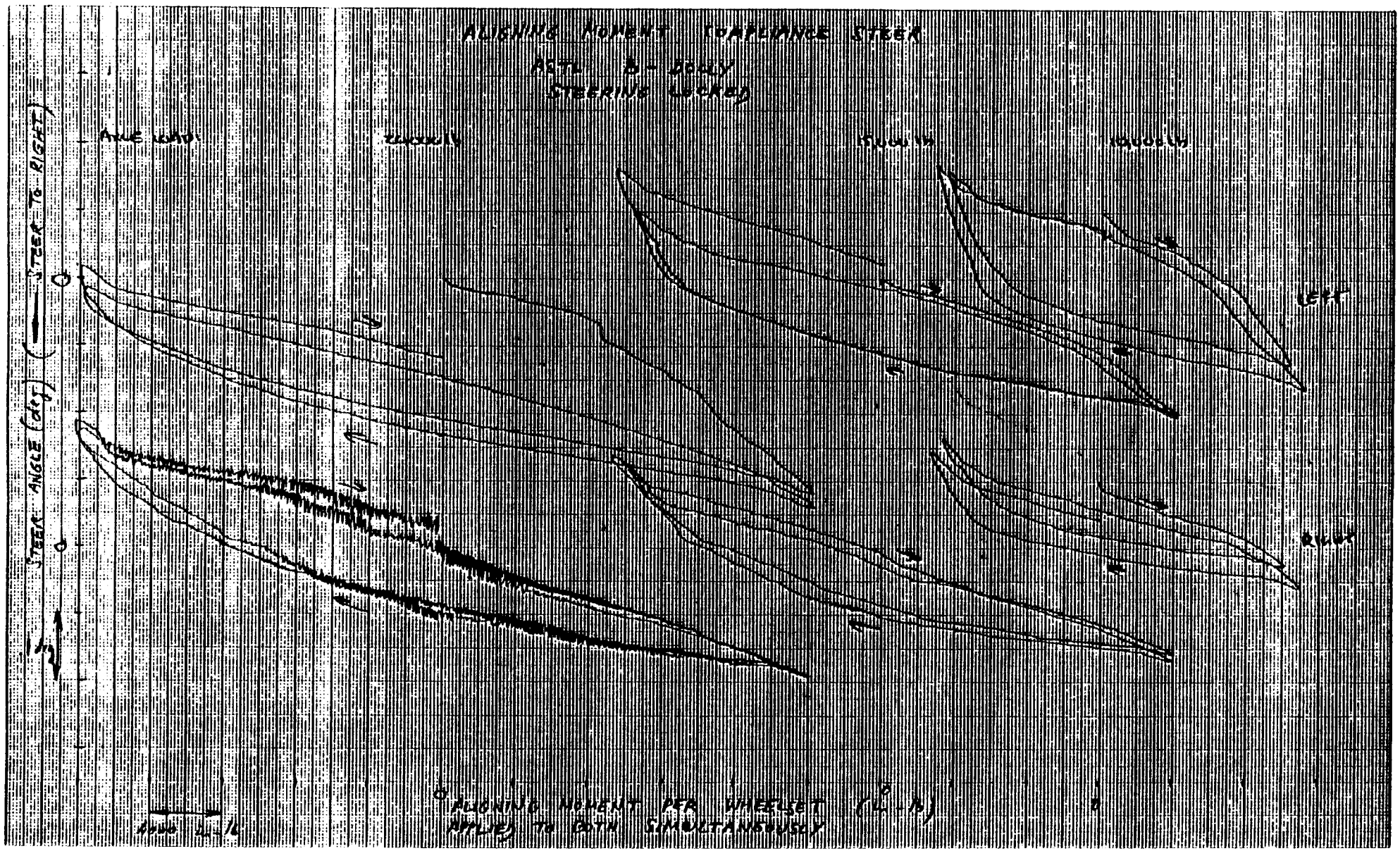
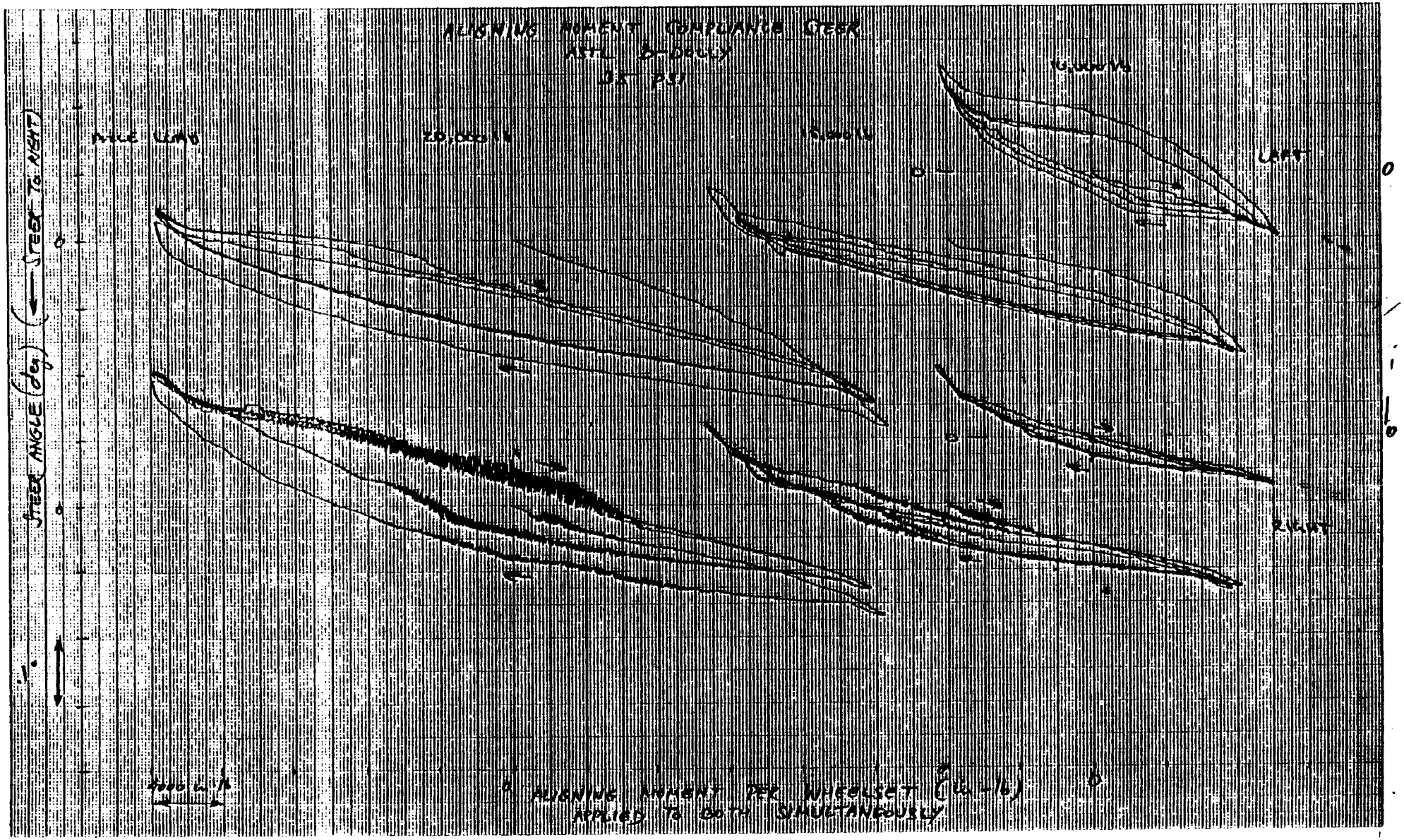

ALIGNING MOMENT COMPLIANCE STEER
ASTL B-DOLLY
STEERING LOCKED
AXLE LOAD
STEER ANGLE (deg) (— STEER TO RIGHT)
0
0
LEFT
RIGHT
ALIGNING MOMENT PER WHEELSET (L-B)
APPLIED TO BOTH SIMULTANEOUSLY

47 1512



K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
47 1512

STEER ANGLE (deg) (← STEER TO RIGHT)
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
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35
36
37
38
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STEEL PARTICLE (deg.) (← STEER TO RIGHT)
APPLIED TO REAR WHEELS SIMULTANEOUSLY
OVERALL FORCE CONTRIBUTION STEER
ANTI-CLOCKWISE
ANTI-CLOCKWISE

LATERAL FORCE PEAK ANGLE (δ)
APPLIED TO BOTH WHEELS SIMULTANEOUSLY
LATERAL FORCE PEAK ANGLE (δ)
APPLIED TO RIGHT WHEEL ONLY
STEER ANGLE (deg) (← STEER TO RIGHT)
0
0
0

STEEP ANGLE (α_{max}) (STREET TO EAVES)
α_{max}
α_{max}
ANGLE
EAVES
ROOF
BARE PLANE GRAVITY FILTER
FOLIAGE PLANE
GRAVITY FILTER
ANGLE
EAVES
ROOF
GRAVITY FILTER FOR UNIFORM SKY
ANGLE
EAVES
ROOF
GRAVITY FILTER FOR BOTH SKY AND GROUND

STEER ANGLE (δ_sw) (← STEER TO PORT)
0
δ
δ_sw, rad
Time, s
CURVES FOR UNDERSTEER GRADIENT
AT 30 MPH
CURVES FOR UNDERSTEER GRADIENT
AT 60 MPH

STEER ANGLE (deg) (+ STEER to RIGHT)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
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