U.S. Department of Transportation

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EFFECT OF WORN COMPONENTS ON BRAKE FORCES IN A FREIGHT CAR RIGGING

Office of Research and Development
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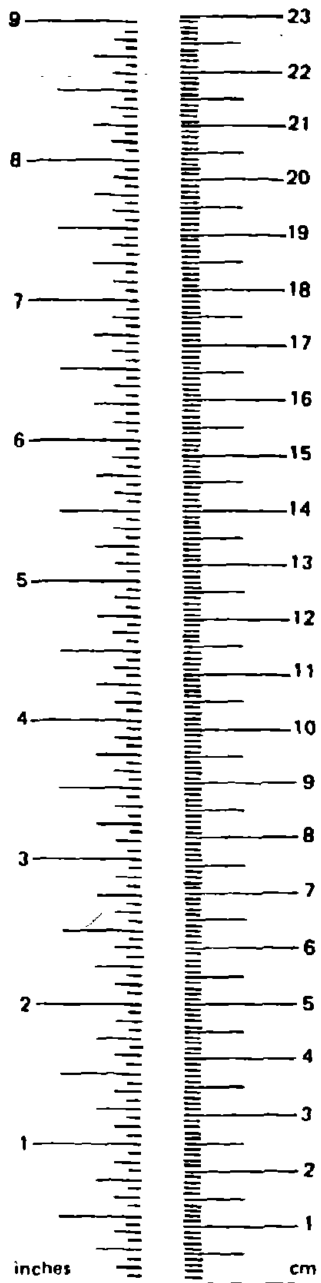
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

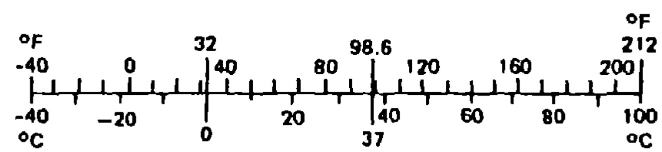
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.50	centimeters	cm
ft	feet	30.00	centimeters	cm
yd	yards	0.90	meters	m
mi	miles	1.60	kilometers	km
	AREA			
in^2	square inches	6.50	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.80	square meters	m^2
mi^2	square miles	2.60	square kilometers	km^2
	acres	0.40	hectares	ha
	MASS (weight)			
oz	ounces	28.00	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.90	tonnes	t
	VOLUME			
tsp	teaspoons	5.00	milliliters	ml
Tbsp	tablespoons	15.00	milliliters	ml
fl oz	fluid ounces	30.00	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.80	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* 1 in. = 2.54 cm (exactly)



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.40	inches	in
m	meters	3.30	feet	ft
m	meters	1.10	yards	yd
km	kilometers	0.60	miles	mi
	AREA			
cm^2	square centim.	0.16	square inches	in^2
m^2	square meters	1.20	square yards	yd^2
km^2	square kilom.	0.40	square miles	mi^2
ha	hectares (10,000 m^2)	2.50	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.10	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36.00	cubic feet	ft^3
m^3	cubic meters	1.30	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32	Fahrenheit temperature	°F



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16. Abstract

A braking test program was conducted to investigate the extent of and causes for significant variations in braking thermal input to railcar wheels. The program consisted of the following tasks:

-Brake force data was reviewed from previous test programs and computer simulations of brake forces in several types of conventional brake rigging were performed.

-Analytical and experimental investigations were conducted to evaluate the effect of worn components on the distribution of brake forces for a conventional brake rigging containing bent, unequal length levers.

-Tests were performed to determine: (1) the effect of extreme shoe placement on wheel temperatures developed during drag braking conditions, (2) friction characteristics of three brands of brakeshoes during extended drag braking, and (3) the friction characteristics of brakeshoes with simulated metal pickup.

The brake rigging, which was tested on the Transportation Test Center's Roll Dynamics Unit, and on track, exhibited wheel-to-wheel force variations for both original and worn components.

The introduction of rigging levers, with oversize pin holes and worn pins, into the above rigging decreased total car brake forces by approximately 30 percent for a 50 psi brake cylinder pressure.

Expected differences in brakeshoe coefficient of friction characteristics were observed for several types of brakeshoes during extended drag braking conditions.

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Drag braking Input to Railroad Wheels Conventional Brake Rigging with Bent, Unequal Length Levers Wheel-to-Wheel Force Variations Worn Rigging Components	This document is available through National Technical Information Service Springfield, VA 22161

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1.0 INTRODUCTION

A conclusion from the Wheel Failure Mechanisms (WFM) Program, sponsored by the Federal Railroad Administration (FRA), was that tensile wheel rim stresses produced by 30-60 minute drag braking conditions may lead to catastrophic failure of a wheel with surface imperfections that may produce cracks. In that same program, wheel-to-wheel variations in brake force were measured during drag braking tests with a conventional body-mounted brake rigging. It was suggested that irregularities in a brake rigging could lead to excessive heating of a percentage of wheels, thereby contributing to wheel failure problems.[1,2]

Therefore, a program was initiated to investigate the extent and causes of significant variations in braking thermal input to rail car wheels under a given set of braking conditions. The program consisted of the following tasks:

- Review of brake force data from previous test programs and computer simulation of brake forces in several types of conventional brake rigging.
- Analytical and experimental investigation of the effect of worn components on the distribution of brake forces for conventional brake rigging containing bent, unequal length truck levers.
- Tests to determine the effect of extreme shoe placement on wheel temperatures developed during drag braking conditions, the friction characteristics of brakeshoes during extended drag braking, and the frictional characteristics of brakeshoes with simulated metal pickup.

This report documents the respective procedures and presents the results obtained for each of the project tasks. An extensive database containing measured brake forces for a wide range of test conditions is provided in the appendices.

2.0 REVIEW OF EXISTING DATA

Four brake shoe performance tests, conducted by the Association of American Railroads (AAR) using a covered hopper car, MP 723288, were reviewed.[3,4,5,6] The car that was utilized for these tests was equipped with conventional body-mounted rigging in the bottom rod through bolster configuration. Subsequently, the same car was tested under the present program at the Transportation Test Center (TTC) on the Roll Dynamics Unit (RDU), and on the Transit Test Track (TTT) as described in Sections 4 and 5 of this report.

Additional tests reviewed included the Sanford, Florida, and Chicago wet weather brake shoe tests, and the Cowan, Tennessee, and Raton Pass lubrication tests. Although the data are not directly comparable due to the use of different instrumentation setups for each test, a limited comparison was used to identify gross trends.

Data were separated into two groups depending on whether the car was moving with its "B" end leading or trailing. Test runs with high speed and high brake cylinder pressure conditions were reviewed. Since the brake cylinder pressures varied slightly from test to test, the shoe forces were normalized to a nominal brake cylinder pressure (BCP) of 50 pounds per square inch (psi).

Figure 1 presents the average shoe forces recorded on the B-end truck for each wheel rotation direction. Figures 2 and 3 include diagrams showing the direction of travel and the magnitude of the brake normal forces, their percent contribution toward the total normal braking force on the car, and their ranking from 1 (lowest) to 8 (highest).

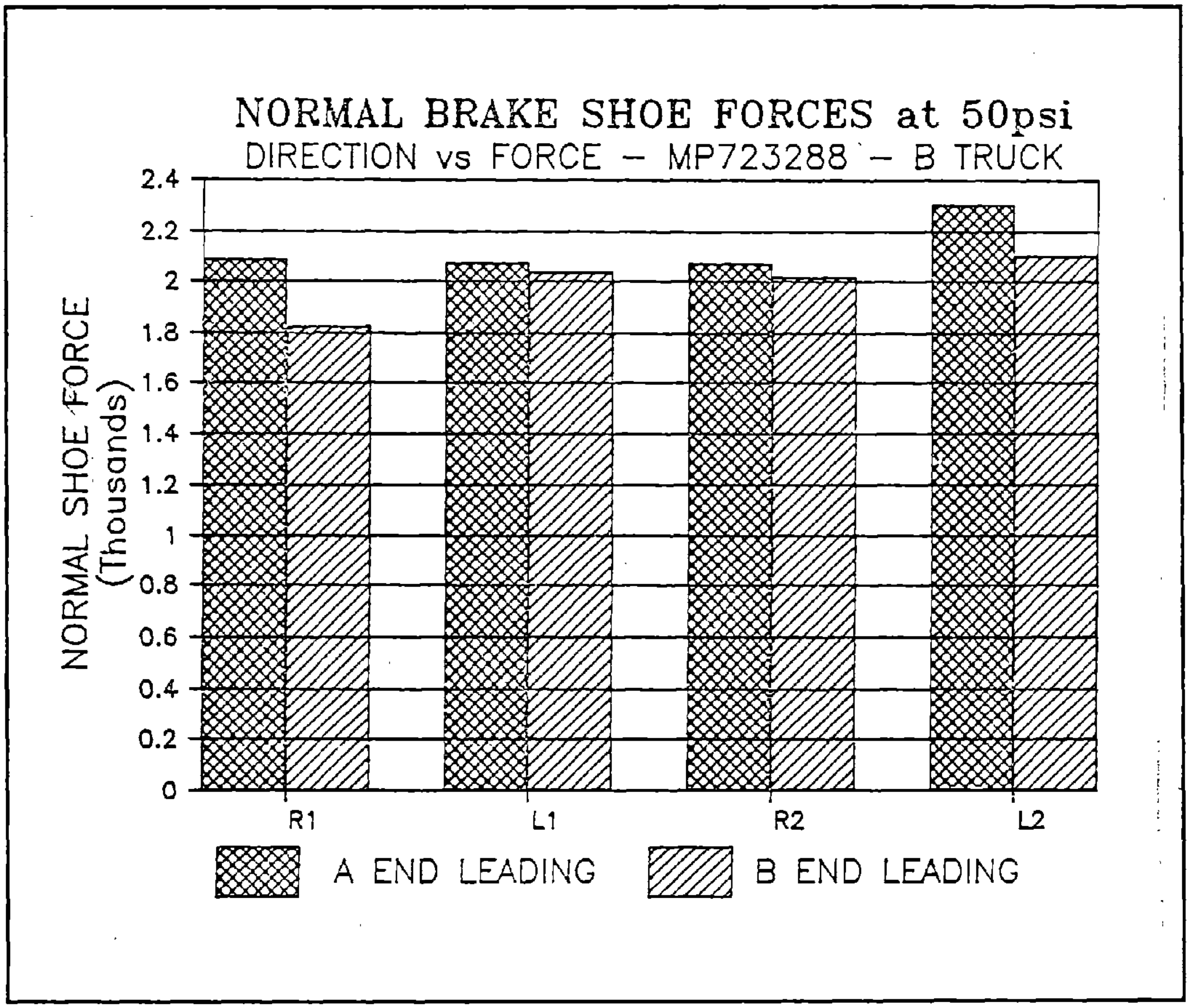


Figure 1. Average Brake Shoe Forces Measured During Previous Tests

BRAKE SHOE POSITION

	R1	L1	R2	L2	R3	L3	R4	L4
AVG. NORMAL FORCE =	1828	2039	2018	2103	2334	2264	2222	2222

TOTAL AVG. NORMAL FORCE = 17,303 B-TRUCK = 7989 A-TRUCK = 9041

DIAGRAM SHOWING PERCENTAGE OF AVERAGE ACTUAL BRAKING NORMAL FORCES
ON EACH WHEEL AND RANKING FROM 1 (LOWEST) TO 8 (HIGHEST)

	L1	L2	L3	L4
	12.0%	12.3%	13.3%	13.0%
	3	4	7	5-6
B- END	← DIRECTION OF TRAVEL			
	1	2	8	5-6
	10.7%	11.9%	13.7%	13.0%
	R1	R2	R3	R4
BEAMS	22.7%	24.2%	27.0%	26.1%
TRUCKS	46.9%		53.1%	

NET AND EMPTY BRAKING RATIOS BASED ON HIGHEST ACTUAL SHOE FORCE
NET = 7.1 % EMPTY = 30.4 %

Figure 2. Distribution Of Brake Forces For B-End Leading

BRAKE SHOE POSITION

	R1	L1	R2	L2	R3	L3	R4	L4
AVG. NORMAL FORCE =	2088	2075	2074	2310	2370	2296	2156	2243

TOTAL AVG. NORMAL FORCE = 17610 B-TRUCK = 8545 A-TRUCK = 9064

DIAGRAM SHOWING PERCENTAGE OF AVERAGE ACTUAL BRAKING NORMAL FORCES
ON EACH WHEEL AND RANKING FROM 1 (LOWEST) TO 8 (HIGHEST)

	L1	L2	L3	L4
	11.8%	13.1%	13.0%	12.7%
	1	7	6	5
B- END		DIRECTION OF TRAVEL →		
	2	3	8	4
	11.9%	11.8%	13.5%	12.2%
	R1	R2	R3	R4
BEAMS	23.6%	24.9%	26.5%	25.0%
TRUCKS	48.5%		51.5%	

NET AND EMPTY BRAKING RATIOS BASED ON HIGHEST ACTUAL SHOE FORCE
NET = 7.2% EMPTY = 30.9 %

Figure 3. Distribution Of Brake Forces For A-End Leading

The first conclusion which might be drawn from these data is there appears to be no significant difference in braking performance due to direction of wheel rotation. With a change in direction, a shoe force increase would be expected to occur on one beam, while its mate beam on the same truck would be expected to decrease. This did not occur. Forces were less on every shoe of the B-end truck when the car was moving with the B-end leading. However, due to the different load cells used in the four test programs, and due to the car running in only one direction during each of the four test programs, it is not possible to draw any valid conclusions regarding the effects of direction of wheel rotation.

Because the automatic slack adjuster causes a 100 to 300 pound loss of force to the A-end rigging, the A-end truck should have less overall braking force than the B-end truck. However, during these tests the A-end truck experienced higher normal braking forces than the B-end truck in both directions. Causes of this anomaly remain unexplained. During testing under the present program, an adjustable length top rod was installed in the B-end rigging to alleviate any angularity problem.

The greatest variation in average shoe normal forces occurred between the R3 and R1 locations when traveling with the B-end leading. R3 normal force was 2,334 pounds, or 13.7 percent of the total car normal force, while the R1 normal force was 1,828 pounds, or 10.7 percent of the total. Using the highest force at R3 on all eight wheels, the braking ratios for the car are 30.4 percent and 7.1 percent for the empty and loaded conditions respectively. Empty net brake ratio would be slightly in excess of the AAR 30 percent limit. Higher brake pipe pressures will cause shoe force increases as shown in Table 1. For the car traveling with the A-end leading, the forces were slightly higher, with the R3 location being the highest. Again using the highest shoe force, the braking net ratios are 30.9 percent and 7.2 percent for the empty and loaded conditions respectively, at a 50-psi BCP.

Analysis of past brake shoe test data reveals observed normal force variations due to body mounted brake rigging would not appear to contribute to abnormal wheel heating during normal service or emergency brake applications. Also, no firm conclusions regarding effects of wheel rotation direction on normal forces can be made.

Table 1. Effect of BPP on Total Car Brake Forces for Full Service and Emergency Service Brake Applications

BPP Start (psi)	Braking Ration Full Service Application Loaded/Empty (Percent)	BCP After Equalization Full Service Application (psi)	Estimated NBF Full Service Application (lbs)	BCP After Equalization Emergency Application (psi)	Estimated NBF Full Service Application (lbs)
70	6.5/27.8	50	17,100	60	20,500
80	7.4/31.8	57	19,500	69	23,600
90	8.4/35.8	64	21,900	77	26,300
100	9.3/39.8	71	24,300	85	29,100
110	10.2/43.8	78	26,700	93	31,800

3.0 SENSITIVITY STUDY

Two computer models were developed using LOTUS 1-2-3 software to analyze the individual effects of component friction on rigging performance. The components analyzed included:

- Brake beam guide
- Horizontal body levers
- Bent truck levers
- Pins

The forces resulting from live and dead truck levers of unequal length were also evaluated using these models.

The car model was developed to simulate a whole car conventional rigging system with a body mounted brake cylinder. Nine different types of commonly used body-mounted brake rigging were studied using the car model.

A more detailed truck model was developed for the rigging levers in one truck. The truck model uses the top rod force predicted in the car model as input, and simulates two common truck rod through bolster and truck rod under bolster rigging arrangements.

The truck model was used to analyze several different types of brake rigging. The type that showed the most variation in normal shoe force within the same truck was the truck rod through bolster rigging. The type of body rigging employed proved to have no effect on shoe force variation within a truck, since all types of body rigging deliver braking force through one top rod to each truck. Body rigging types varied mainly in efficiency, which was in inverse proportion to the number of levers and connection pins in the system.

Because MP 723288 had the rod through bolster truck rigging arrangement, and because it was used on four previous brake shoe tests, it was selected for further testing at the TTC. Figure 4 is a drawing of the truck rigging, showing the rigging elements and the shoe forces and moments about the truck levers.

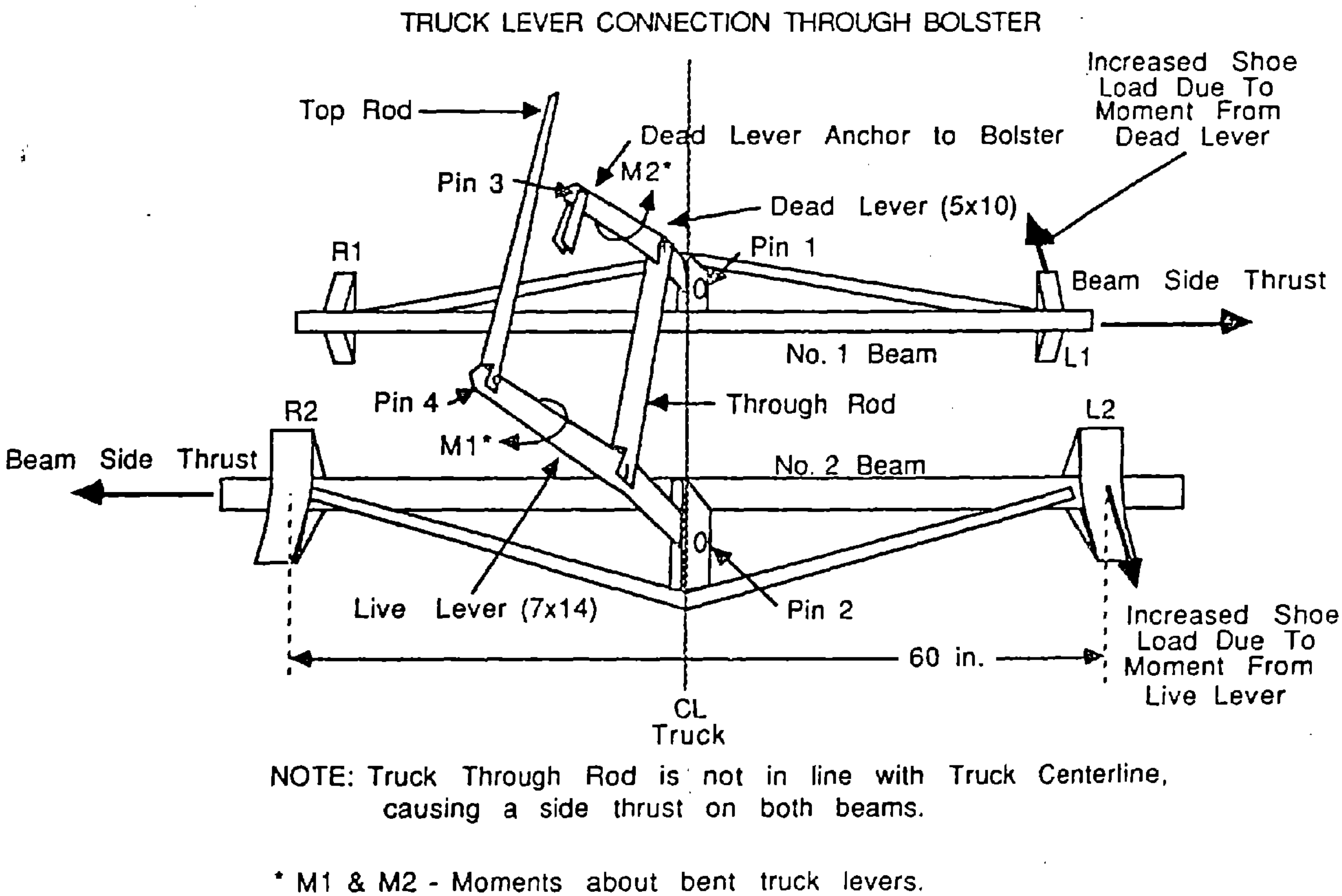


Figure 4. Truck Through Rod Rigging Arrangement for the Test Car

Figure 5 shows an example of the output from the car model for MP 723288, and Figure 6 shows a typical force calculation for a truck lever on MP 723288 using the predicted input force from the car model.

Figure 7 shows an example of the output from the truck model for the truck arrangement used on MP 723288. The truck model is more detailed than the car model. Individual lever dimensions and friction coefficients of connection pins and beam guides can be varied independently.

Notice the truck rod through truck bolster rigging design on this car requires the use of a 7x14 bent live lever and a 5x10 bent dead lever. The model regards the live lever beam as the No. 1 beam, whereas on the MP 723288 the live lever beam is the No. 2 beam. Therefore, when making comparisons between the model and the test car, the model R1 position is the R2 position on the test car, the model L1 is test car L2, and so on.

```
  TYPE 3 CENTER TOP ROD   BENT TRUCK LEVERS? (1-YES,2-NO)-----        1
top rod over centersill   DEAD LEVER ANCHOR? (TRCK-1,CARBDY-2)        1
trk. rod thru bolster           o
   HOPPERS, ETC.                |L-A      ___         LEVER RATIO=    6.59
                                |---------|
                             L-b|-/       ---     /----------------|
TYPE "Alt O" for Printout    L-1 /               / L-2a            | L-3
 "Alt M" to clear               /---------------/                  o
                         L-2 /                 / L-1a              | L-4
        |----------------------/             o      |--------------|
        | L-3                   L-1a=        15     |       o--|
        o                       L-2a=        15     | L-5      |L-5a
        | L-4                    L-a=        16     |----------|
        |--------------|         L-b=       7.5     | L-6      |L-6a
             |--o      |         L-1=        15     |          |-(
             |L-5a     | L-5     L-2=        15  )-|
             |---------|         L-3=      11.5
             |L-6a     | L-6     L-4=       9.5
           )-|         |         L-5=        14   L-5a=        10
                       |-(       L-6=         7   L-6a=         5
```

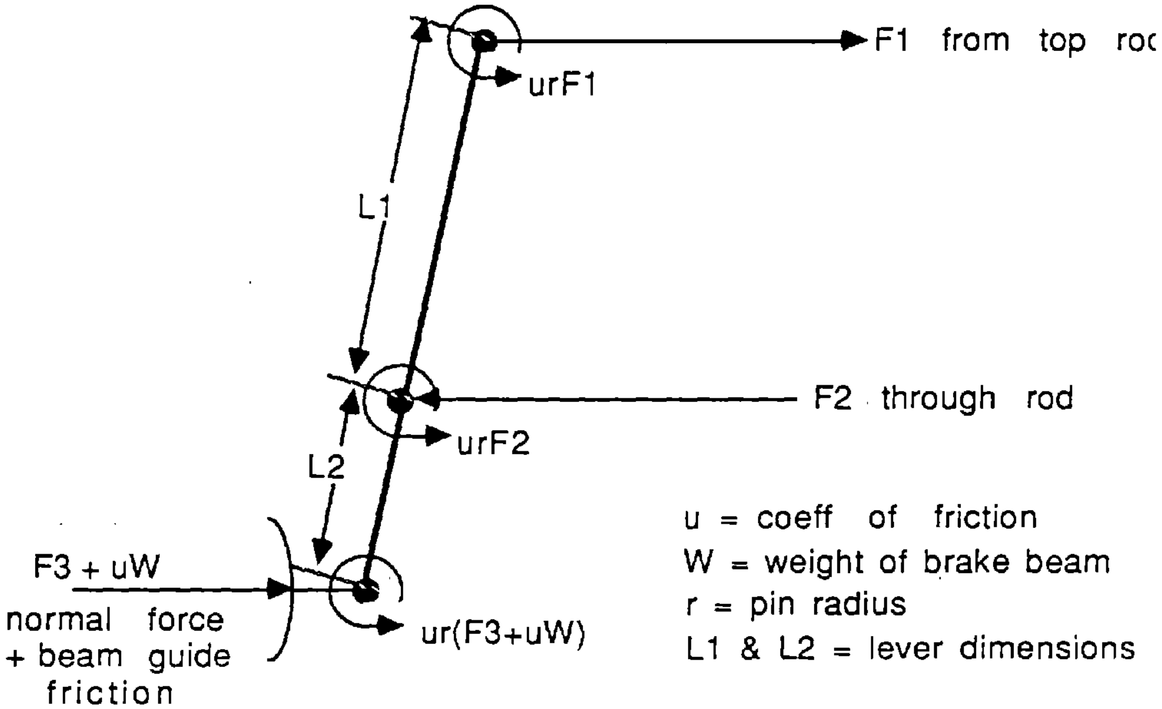
```
BODY LEVERS                                                     La=          16
  SLACK ADJUSTER ROD IN  =       4459  PIN RAD=  0.5625         Lb=         7.5
 SLACK ADJUSTER ROD OUT  =       4109     uW1=       40         L1=          15
CYLINDER LEVER OUTPUT    =       2182      uR=    0.225         L2=          15
NON-CYLINDER CENTER LEVER                 2uR=     0.45         L3=        11.5
                OUTPUT=          1973      Fp=     2317         L4=         9.5
VERTICAL BODY LEVER FOR                   uW2=       40         L5=          14
   HOPPERS (TYPE 3,5,&8)=        2317 (OUTPUT)                  L6=           7
SECOND VERTICAL BODY                                            L7=           0
         LEVER (TYPE 9 )=           0 (OUTPUT)                  L8=           0
VERT. B END BODY LEVER   =       2424 (OUTPUT)                  L9=           0
VERT. A END BODY LEVER   =       2191 (OUTPUT)                  L10=          0
VERT. UNDRSLNG B LEVER   =          0 (OUTPUT)                  L11=          0
VERT. UNDRSLNG A LEVER   =          0 (OUTPUT)                  L12=          0
HORIZ TRK LEVER - B END  =          0 (OUTPUT)                  L1a=         15
HORIZ TRK LEVER - A END  =          0 (OUTPUT)                  L2a=         15
    INPUT TO B  TRUCK    =       2424        0                  L5a=         10
    INPUT TO A  TRUCK    =       2191                           L6a=          5
               BENT LEVERS(1-YES,2-NO)=              1          L13=          0
  DEAD LEVER ANCHOR(TRUCK-1,CARBODY-2)=              1          L14=          0
TRUCK LEVERS

TRUCK BOTTOM ROD      (TYPE 1,4,7,8,&9)
                 LIVE LEVER BEAM                 DEAD LEVER BEAM
                 B END =            0            B END =          0
                 A END =            0            A END =          0
      BOTTOM ROD B END   =          0
      BOTTOM ROD A END   =          0

TRUCK THROUGH ROD, TOP ROD OVER TRK BOLSTER (OR 3 LEVER TRK RIGGING)
 (TYPE 2,3,5&6)  LIVE LEVER BEAM                 DEAD LEVER BEAM
                 B END =         4369            B END =       4311
                 A END =         3947            A END =       3894
     THROUGH ROD B END   =       6833
     THROUGH ROD A END   =       6178

    BEAM TORQUE (IN.LBS)=         0.0 LIVE LEVER BEAM B END
    BEAM TORQUE (IN.LBS)=         0.0 LIVE LEVER BEAM A END
    BEAM TORQUE (IN.LBS)=         0.0 DEAD LEVER BEAM B END               0.0
    BEAM TORQUE (IN.LBS)=         0.0 DEAD LEVER BEAM A END
```

Figure 5. Typical Car Model Output for MP 723288

```
ENTER THE FOLLOWING INFORMATION FOR NUMBERS 1 THRU 13; (TO CLEAR; ALT X)
       1 .     RIGGING PIN DIAMETER=   1.125 INCHES
                                       -----
       2 .           PISTON DIAMETER=     10 INCHES  (   78.54 SQ IN)
                                       -----
       3 .       BRAKE PIPE PRESSURE=     70 P.S.I.
                                       -----
       4 .WEIGHT OF EACH BRAKE BEAM=     100 LBS.
                                       -----
       5 .WGHT OF RIGGING ON GUIDES=     200 LBS.
                                       -----
       6 .ASSUMED PIN COEF. OF FRIC=     0.4
                                       -----
       7 .     LOADED WEIGHT OF CAR=  263000 LBS.
                                      ------
       8 .      EMPTY WEIGHT OF CAR=   61400 LBS.
                                      ------
       9 . AUTOMATIC SLACK ADJUSTER?       1   (1-YES, 2-NO)
                                        ----
      10 .    E/L PERCENT REDUCTION=          %

      11.    PISTON TRAVEL=       8 INCHES      AUX. RESERVOIR=    2500
                               ----           (NORMAL - 2500ci)    ----
      12.    B.C. PIPE DIA=    0.75 INCH
                               ----              EM. RESERVOIR=    3500
      13. B.C. PIPE LENGTH=      10 FEET
                               ----
             PISTON FORCE=     3501 POUNDS AT    50.0 PSI B.C. PRESSURE

              LEVER RATIO=     6.59

        RIGGING EFFICIENCY=   71.57 %

 TOTAL SHOE FORCE AT 50psi=   16520 LBS.
                                                 EFFECTIVE
  LOADED GROSS BRAKE RATIO=    8.78 %                LEVER RATIO=    4.72

    LOADED NET BRAKE RATIO=    6.28 %

     EMPTY NET BRAKE RATIO=   26.91 %

    BRAKE BEAM FORCES                  SIDE THRUST ON BEAMS

      #1=  4310.7 LBS.                 B TRUCK =      264 LBS.
      #2=  4369.1 LBS.                 A TRUCK =      238 LBS.
      #3=  3946.6 LBS.
      #4=  3893.8 LBS.

                   NORMAL SHOE FORCES (PRESS F10 FOR GRAPH)

       R#1         2155.3 LBS.             L#1          2155.3 LBS.
       R#2         2184.5 LBS.             L#2          2184.5 LBS.
       R#3         1973.3 LBS.             L#3          1973.3 LBS.
       R#4         1946.9 LBS.             L#4          1946.9 LBS.

                            TORQUE INPUT TO TRUCKS
 FOR PRINTOUT      :
 OF THIS DATA      :        B TRUCK =     2727 FT-LBS
```

Figure 5. Typical Car Model Output for MP 723288 -- Continued

EXAMPLE OF FORCE CALCULATION FOR A TRUCK LEVEF



SUMMING FORCES

$$F1+F3+uW-F2=0 \Rightarrow F2=F1+F3+uW$$

SUMMING MOMENTS ABOUT F3

$$F1(L1+L2) - F2(L2) - ur(F1+F2+F3+uW) = 0$$

SUBSTITUTING FOR F2; SUM OF MOMENTS IS ;

$$F1(L1-2ur) - F3(L2+2ur) - uW(L2-2ur) = 0$$

SOLVING FOR F3 (BEAM FORCE) ;

$$F3 = \frac{F1(L1-2ur) - uW(L2-2ur)}{L2 + 2ur}$$

Assuming the following;

L1=14 in, L2=7 in, u=0.4, W=100lbs, F1=2555lbs, r=0.5625ir

2ur = 0.45

$$F3 = \frac{2555(14-0.45)-0.4(100)(7-0.45)}{7+0.45} = 4619 \text{ lbs.}$$

Figure 6. Typical Force Calculation for a Truck Lever

```
    TRUCK ROD THROUGH BOLSTER RIGGING ARRANGEMENT

 L1               L2
              /-------------- F1-->          --> TO BODY RIGGING
  \          /      \
  )-\       /L1      \-(   F5<-/          ENTER LEVER DIMENSIONS
     \     /          \      /L3                L1=       14 IN.
      \   /- <--F2----F2--> -/                  L2=        7 IN.
       \ / L2          \   /L4                  L3=       10 IN.
uW+F3-> \/              \/ <-F4+uW              L4=        5 IN.
         \               \
          \               \               RIGGING ANGULARITY (DEG)
           \               \              LIVE LEVER (FROM VERT)=  0
            \               \             DEAD LEVER (FROM VERT)=  0
           )-\               \-(          TOP ROD (FROM HORZ)   =  0
              \                \

           R1              R2


ENTER THE FOLLOWING INFORMATION;

COEFF. OF FRICTION AT THE FOLLOWING LOCATIONS;        LEVER DIMENSIONS

                      BEAM GUIDE R1=     0.4          LIVE LEVER
                      BEAM GUIDE L1=     0.4               L1=        14 IN.
                      BEAM GUIDE R2=     0.4               L2=         7 IN.
                      BEAM GUIDE L2=     0.4
          LIVE LEVER TOP CONNECTION=     0.4          DEAD LEVER
       LIVE LEVER MIDDLE CONNECTION=     0.4               L3=        10 IN.
       LIVE LEVER BOTTOM CONNECTION=     0.4               L4=         5 IN.
          DEAD LEVER TOP CONNECTION=     0.4
       DEAD LEVER MIDDLE CONNECTION=     0.4          GAMMA-D=         0 RD
       DEAD LEVER BOTTOM CONNECTION=     0.4          GAMMA-L=         0 RD
                                                      TAU     =        0 RD
           BRAKE BEAM WEIGHT (EACH)=     100 LBS.

                TOP ROD INPUT FORCE=    2424 LBS.

            CONNECTION PIN DIAMETER=   1.125 INCHES (RADIUS=  0.5625 )
```

Figure 7. Typical Truck Model Output for MP 723288

```
LIVE LEVER
         ANGLE * =       3 DEGREES (ANGLE OF BEND IN LEVER)
         ANGLE # =      40 DEGREES (ANGLE BETWEEN LEVER AND VERTICAL)
DEAD LEVER
         ANGLE * =       3 DEGREES (ANGLE OF BEND IN LEVER)
         ANGLE # =      40 DEGREES (ANGLE BETWEEN LEVER AND VERTICAL)

                            /  THROUGH ROD LENGTH=   36 INCHES
                     --->| * /<---
     \                   |  /
       \                   / (L1 and L3)
         \                /
           \             /               LIVE LEVER
      ------>\ #     |<---    ###        ANG */2= 0.026 RADIANS
         (L2 & L4)|      ###             ANG #   = 0.698 RADIANS
                 \ | ###
                  ###                    DEAD LEVER
               ###                       ANG */2= 0.026 RADIANS
            ###                          ANG #   = 0.698 RADIANS

  LIVE LEVER BEAM FORCE =      4370 LBS.
      THROUGH ROD FORCE =      6832 LBS.
  DEAD LEVER BEAM FORCE =      4310 LBS.

          LIVE LEVER BEAM TORQUE ALONG LEVER AXIS=   888.3 IN-LBS.
          DEAD LEVER BEAM TORQUE ALONG LEVER AXIS=   596.1 IN-LBS.
            LIVE LEVER BEAM TWIST THRU VERT. AXIS=   665.3 IN-LBS.
            DEAD LEVER BEAM TWIST THRU VERT. AXIS=   446.4 IN-LBS.
            LIVE LEVER BEAM TWIST ALONG BEAM AXIS=   588.6 IN-LBS.
            DEAD LEVER BEAM TWIST ALONG BEAM AXIS=   395.0 IN-LBS.

  SHOE FORCES          NORMAL          TOP   MIDDLE    BOTTOM
             R1=     2143 LBS.         812    714        616 LBS.
             L1=     2187 LBS.         827    729        631 LBS.
             R2=     2120 LBS.         773    707        641 LBS.
             L2=     2150 LBS.         782    717        651 LBS.

  BRAKE BEAM SIDE THRUST =      251 LBS.
```

Figure 7. Typical Truck Model Output for MP 723288 -- Continued

Figure 5 shows the model predicts a force of 2,424 pounds at the B-end truck. Inspection of Figure 6 shows that for an input force of 2,424 pounds the resulting force into the live lever, F3, is 4,370 pounds All of the calculations for force transmission through the various rigging components were done in a similar manner.

Examination of Figure 7 shows the shoes on the left side of the truck are loaded heavier than their counterparts on the right side. Also, the live lever beam loads are heavier than those for the dead lever beam. Finally, the use of unequal length truck levers produces a tendency for the live lever beam to move toward the right side frame, and the dead lever beam to move toward the left side frame. This results in the L2 and R1 brake shoes contacting and riding against the wheel flanges.

One main reason for creating the truck model was to identify those worn rigging conditions that contribute to major force variations sufficient to cause wheel overheating. Using the model in this manner showed, in every conceivable wear condition except two, the rigging efficiency and the normal shoe forces throughout the truck decreased rather than increased.

One exception occurred when either truck lever was bent to an angle greater than the design angle. In this case, the torque about the lever axis increased. If the connection pin at the brake beam is tight and the other two pins are loose, this torque is reacted at the brake beam. This would cause the shoe force to increase on the side of the truck opposite from the top rod and decrease on the other side. Model predictions showed when the live lever bend angle increased from 3 degress to 6 degress the L1 shoe force increased from 2,307 to 2,330 pounds, and the R1 shoe force decreased from 2,261 to 2,238 pounds The bent live lever resulted in only a 1 percent increase in the L1 shoe force, which is insignificant. If the increased L1 force was used for all eight wheels, the empty and loaded braking ratios would be 30.4 and 7.1 percent, respectively.

The other exception occurred when the levers wore such that the dimensions between the pin holes changed to increase the lever ratio of the lever. The model predicted L1 normal shoe force would increase from 2,307 to 2,365 pounds if the live lever ratio increased from 2:1 to 2.05:1. This is a 2.5 percent increase, and if this value was used for all eight wheels, the empty braking ratio would be 30.8 percent. However, this is still using a pin friction coefficient of 0.4. Actually, the friction coefficient probably increases because the pin and the lever wear into each other, increasing the contact surface area between the pin and its hole. This would tend to lessen the effect of the increased lever ratio. Figure 8 is a graph comparing the predicted shoe normal forces in the stock condition, with a bent live lever, and worn levers.

Figure 9 provides an analysis of the results of rigging angularity. For this example, the vertical body lever at the end of MP 723288 is at a 30 degree angle under load. It is assumed input force to this lever is still 2,300 pounds acting along the axis of the link from the horizontal cylinder body lever (from Figure 5 cylinder lever output), and the truck live lever is still in a vertical position. Neither of these assumptions are completely accurate, but they are made to simplify the calculation. Using these assumptions, the output force acting along the axis of the top rod would be reduced from 2,555 to 2,532 pounds Under actual conditions, these forces would be even less due in part to the increased vertical loading of the horizontal body lever, which increases friction and reduces the levers' output. Output force of this lever would be reduced further due to the angle of the link to the vertical body lever. Any angularity of the truck live lever would further lessen forces due to increased angle from the horizontal of the top rod. Finally, in many cases a lever angle of 30 degrees or larger results in some part of the lever or rigging actually fouling the car body or truck, resulting in a drastic reduction of braking force.

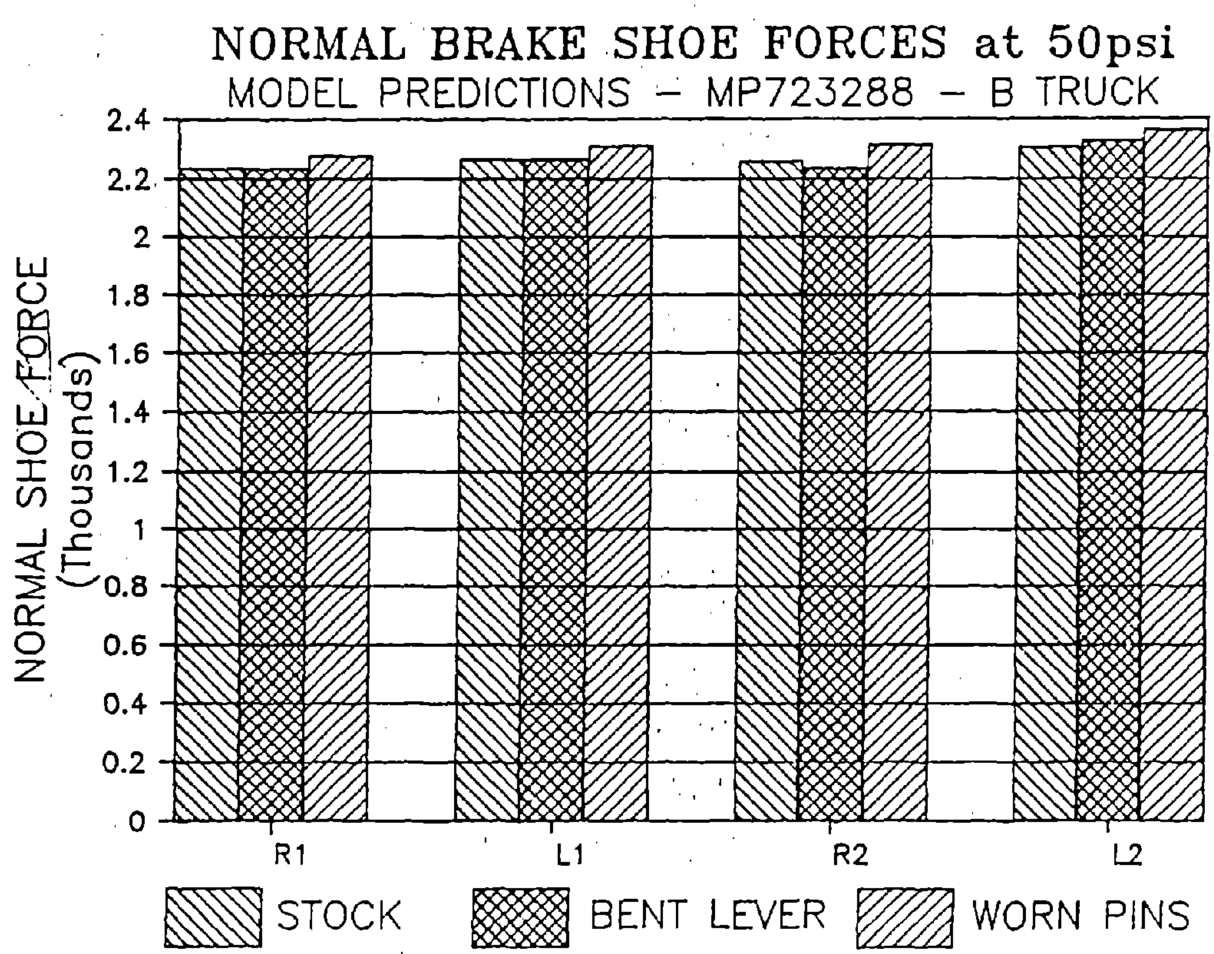
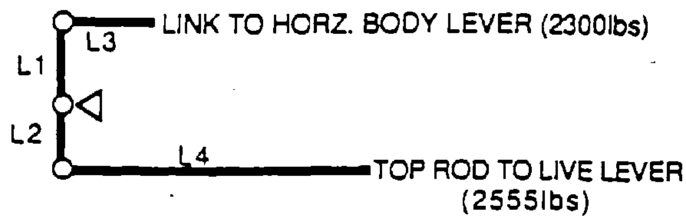
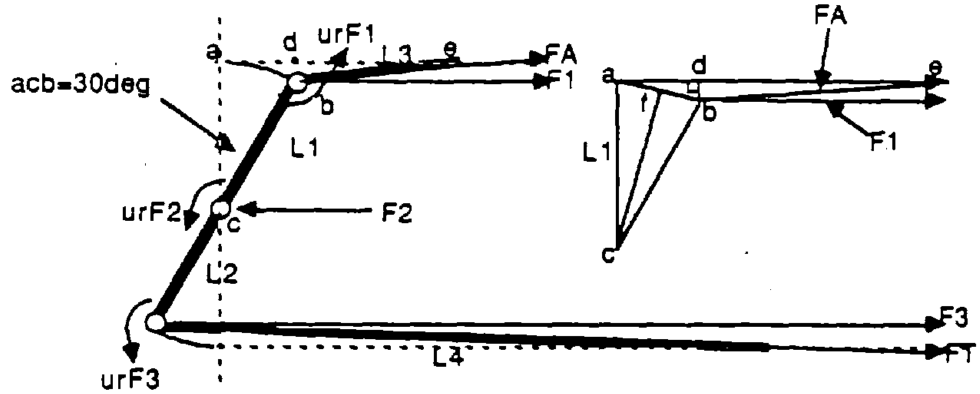


Figure 8. Comparison of Brake Force Normal Forces, Stock Condition, Bent Live Lever, Worn Pins, Worn Live and Dead Levers

ORIGINAL CONDITION - NO ANGULARITY OF VERTICAL BODY LEVER



30 DEGREE ANGULARITY OF VERTICAL BODY LEVER.



If the lever angle = 30 deg, then angle CAB = ABD = 75 deg, and since angle ABD = 90 deg, angle DAB = 15 deg.

Since angle ACF = 15 deg, AF = ACsin15 = L1sin15

So, BD = ABsin15 = 2AFsin15 = 2(L1sin15)sin15 = $2L1(\sin 15)^2$

If L1 = 11.5", $2L1(\sin 15)^2$ = 1.54"

Then angle AEB = arcsin 1.54/12 = 7.37 deg, and so if L3 = 12", and FA = 2300lbs, then

F1 = FAcos7.37 = 2281 lbs

Using the same method as in the previous lever analysis, and if L1=11.5", l2=9.5",and ur=.45,

F3 = F1(L1-2ur)/(L2+2ur) = 2533lbs

Analizing the top rod in the same way as the link, and assuming the top rod is 4 feet long,

Ft=F3cos1.84 = 2532lbs

This is 23lbs less than in the no angularity position.

Figure 9. Analysis of Forces for Rigging Angularity

4.0 CONVENTIONAL RIGGING TESTS ON THE RDU

4.1 OBJECTIVE

One of the major objectives of this task was to determine the effect of worn components on the distribution of brake forces developed in a conventional body mounted rigging. In particular, the effect of the following conditions on rigging forces was examined:

- Worn Rigging Levers
- Worn Rigging Pins
- Lever Angularity

Testing was conducted on the RDU under closely controlled conditions of running speed and BCP. Based on the results of the Sensitivity Study (presented in Section 3), a rigging with the truck lever connector through the bolster configuration and bent, unequal length truck levers was selected for testing. This type of brake rigging configuration was predicted to produce large wheel-to-wheel brake force variations within a given truck.

4.2 TEST EQUIPMENT

4.2.1 Test Car

A 100-ton capacity hopper car, MP 723288, fitted with body mounted brake rigging, was utilized for the RDU test. The rigging configuration was the truck lever connection through the bolster type with bent, unequal length truck levers. Design lever ratio for the rigging was 6.59. The car was equipped with a 10-inch diameter brake cylinder. A schematic representation of the rigging, including lever dimensions, is given in Figure 10. Figure 11 depicts relative positions of the rigging levers and brake beams. Figures 12 and 13 show overall views of the test car in position on the RDU.

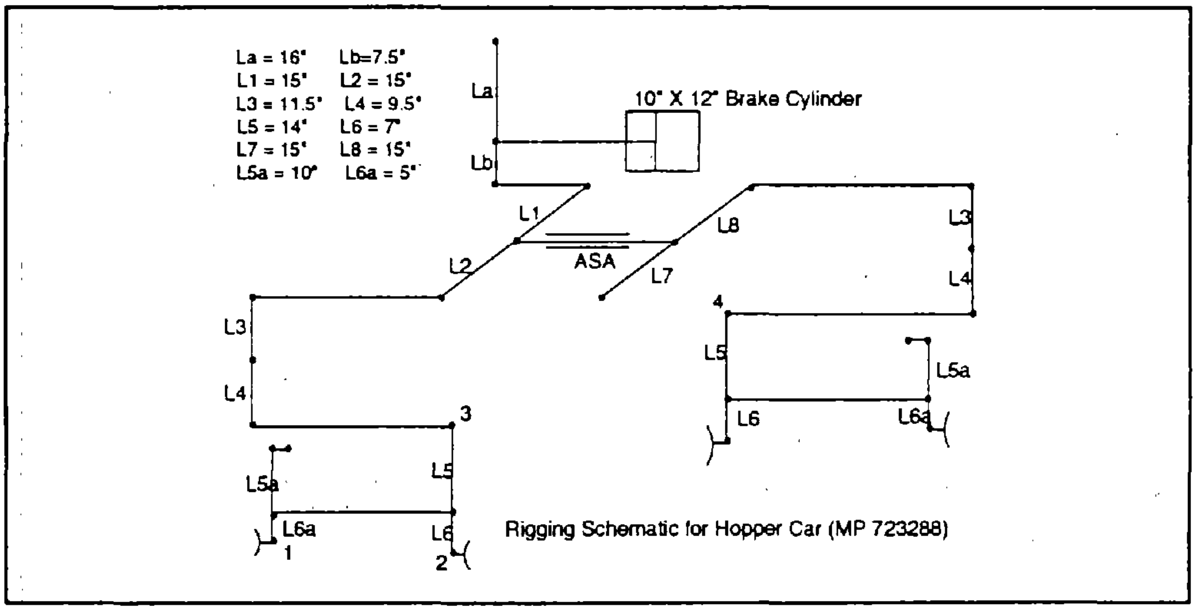


Figure 10. Brake Rigging Dimensions

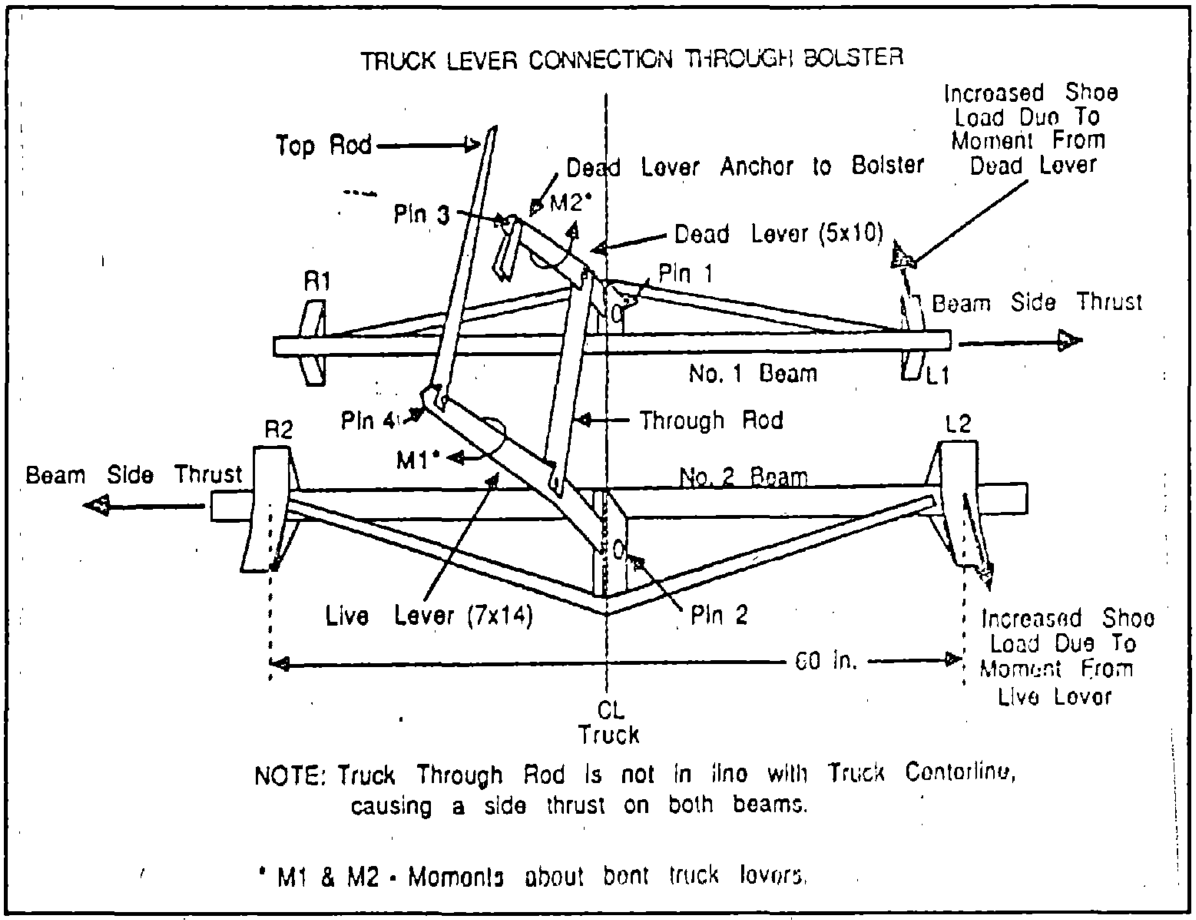


Figure 11. Truck Lever And Brake Beam Arrangement

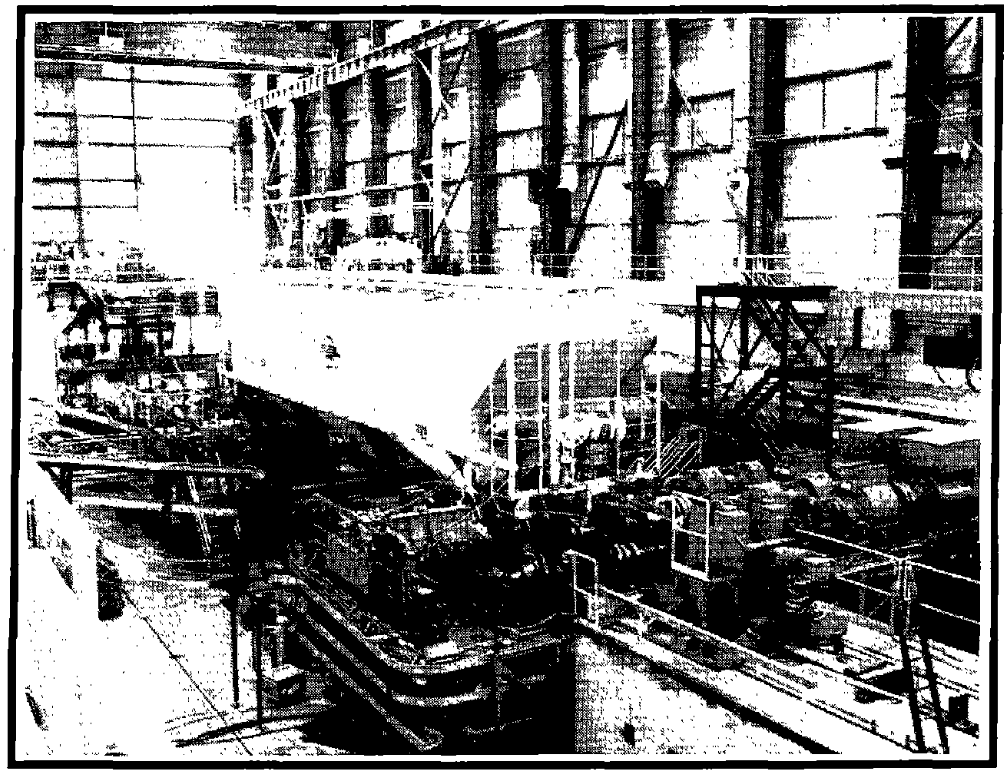


Figure 12. View of the B-end of the Test Car

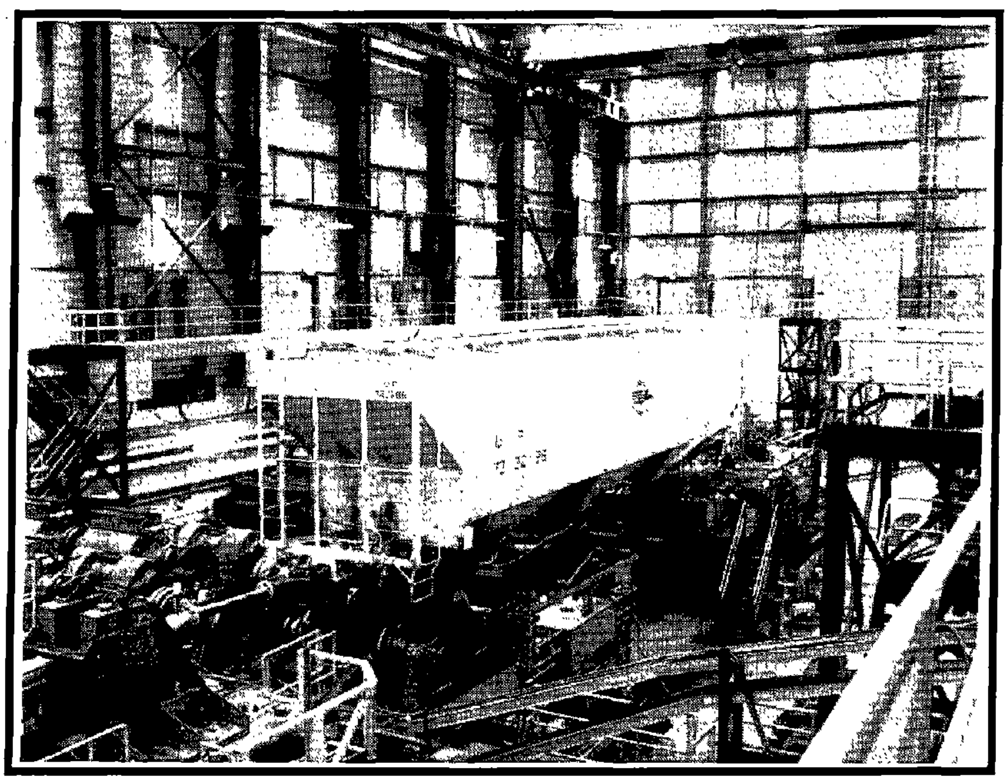


Figure 13. View of the A-end of the Test Car

4.2.2 Brake Cylinder Pressure Control

During testing, it was necessary to maintain control over the brake cylinder pressure. To achieve this, the brake cylinder feed line was connected to a pressurized air supply via a manually adjustable pressure regulator. Brake cylinder feed line pressure was monitored with a conventional Bourdon type pressure gage and pressure transducer.

4.3 INSTRUMENTATION

4.3.1 Brake Shoe Load Cells

The B-end truck of the test car was fitted with instrumented brake heads to allow measurement of normal and tangential brake forces during drag braking. Instrumented brake heads (shown in Figure 14) were calibrated at the AAR's Chicago Technical Center (CTC) using procedures established for earlier tests. Because the tests were of short duration, the instrumented brake heads were not water cooled. Descriptions of the brake shoe load cell design and calibration procedures are provided in AAR reports R-469 and R-497.

4.3.2 Instrumented Pins

Instrumented shear pins were installed at both ends of the B-end live and dead truck levers to allow measurement of rigging forces during testing (see Figures 11 and 15). Instrumented pins measured the force which is transmitted through a clevis joint. The live lever beam pin (pin 2) and the dead lever pins (pin 1 and 3) were designed for 6000-pound-shear-force capacity. The live lever/top rod pin (pin 4) was designed for 3000-pound-shear-force capacity. Each pin was factory calibrated with an output of 1 mv/volt excitation sensitivity at full load.

Figure 14. View of an Instrumented Brake Head

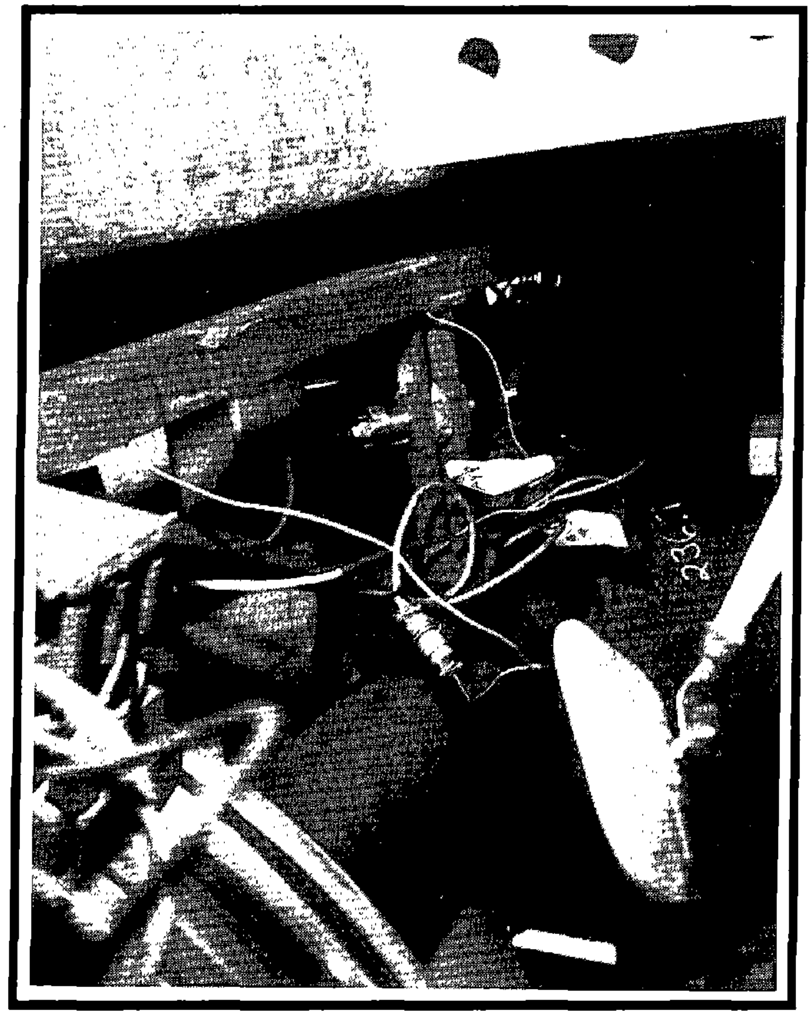


Figure 15. View of a Instrumented Shear Pin Installation

4.3.3 Brake Cylinder Pressure

A pressure transducer was inserted in the brake cylinder pipe to measure brake cylinder pressure. A Bourdon tube pressure gage was also used to confirm readings from the electronic pressure transducer.

4.3.4 Roller Speed

A tachometer was mounted on the end cap of the L2 wheel roller bearing to provide a measure of car wheel and roller speed.

4.3.5 Load Cell Temperature

During testing, it was necessary to monitor load cell temperatures to avoid damage to the strain gage circuits. A thermocouple was attached to the L2 brake shoe load cell for this purpose. Based on modeling results, the largest normal braking forces were expected at the L2 location.

4.3.6 Calibrated Brake Shoe Static Tests

A set of four load cells (single probe - perpendicular to and at brake head centers) was used to measure brake forces under static conditions. To obtain a measurement, these load cells were mounted in place of the brake shoes and a given brake cylinder pressure was applied. Forces were then read from a liquid crystal display and recorded. Static load cells were used to analyze brake forces under rapped and unrapped conditions.

4.3.7 Data Collection

A Hewlett Packard 9826 computer was used in combination with filters, amplifiers, and a multiplexer to collect data from the following instrumentation:

Channel Description	Number of Channels
Instrumented Brake shoes	8 (2 for each load cell)
Instrumented Shear Pins	4
Brake Cylinder Pressure	1
RDU Roller Speed	1
Load Cell Temperature	1

Voltage signals from each of the instruments were filtered at 10 Hz. Data were collected at a rate of 100 samples/second. Two seconds of data were collected at 20 second intervals. After each burst of data (200 data points), average values of the data were computed and printed out. All test data were saved on magnetic tape for post test analysis.

4.4 TEST PROCEDURE

4.4.1 Short Term Drag Braking Tests On The RDU - Conventional Rigging

A series of short term drag braking tests of approximately 5 minutes duration were conducted with applied BCP's of 25 and 50 psi and roller speeds of 20, 40, and 50 mph. Tests were conducted with the rigging in the as-received condition, and with six combinations of worn components. Table 2 is a matrix of test conditions.

Table 2. RDU Test Matrix

Run No.	Rigging Condition	Speed	BCP
53,54	1 - Normal Condition	20	25
57,58	1 - Normal Condition	40	25
61,62	1 - Normal Condition	50	25
55,56	1 - Normal Condition	20	50
59,60	1 - Normal Condition	40	50
63,64	1 - Normal Condition	50	50
38,39	2 - Bent Live Lever - West	20	25
44,45	2 - Bent Live Lever - West	40	25
48,49	2 - Bent Live Lever - West	50	25
42,43	2 - Bent Live Lever - West	20	50
46	2 - Bent Live Lever - West	40	50
51,52	2 - Bent Live Lever - West	50	50
65,66	3 - Bent Live Lever - East	20	25
67,68	3 - Bent Live Lever - East	50	25
69,70	3 - Bent Live Lever - East	50	50
71,72	4 - Worn Live Lever	20	25
75,76	4 - Worn Live Lever	40	25
79,80	4 - Worn Live Lever	50	25
73,74	4 - Worn Live Lever	20	50
77,78	4 - Worn Live Lever	40	50
82,83	4 - Worn Live Lever	50	50

Table 2. RDU Test Matrix -- Continued

Run No.	Rigging Condition	Speed	BCP
85,86	5 - Worn Live Lever/Pins	20	25
91	5 - Worn Live Lever/Pins	50	25
87,88	5 - Worn Live Lever/Pins	20	50
89,92	5 - Worn Live Lever/Pins	50	50
93,94	6 - Worn Shoe L2/New Shoe R2	50	25
97	6 - Worn Shoe L2/New Shoe R2	50	50
98,99	7 - Worn Shoe R2/New Shoe L2	50	25
100,101	7 - Worn Shoe R2/New Shoe L2	50	50
102,103	8 - Max Lever Angle	20	25
108,109	8 - Max Lever Angle	50	25
104,105	8 - Max Lever Angle	20	50
106,107	8 - Max Lever Angle	50	50

Brake forces, rigging pin forces, brake cylinder pressure, and running speed were recorded automatically with the computerized data collection system described in Section 4.3.7.

For a given test, this sequence of operations was followed:

1. Each of the load cells was checked for proper alignment and the B-end brakeshoes were separated from their respective wheels.
2. Wheel rim temperatures were measured on the back rim face using a hand held infrared pyrometer. Wheel rim temperatures were taken in the same sequence from test to test.
3. RDU rollers were brought up to test speed.
4. The pressure regulator was adjusted to produce the required brake cylinder pressure.
5. Data collection program was initiated.
6. Regulated compressed air supply was introduced into the brake cylinder, causing the brakes to apply.
7. Drag braking was continued for a minimum of 4 minutes.

8. Brake cylinder air supply was vented to atmosphere, releasing the brakes.

9. After the completion of each test, RDU rollers were brought up to approximately 30 mph to allow the wheels to cool to 150° F or less.

10. RDU rollers were stopped.

Following is a description of the different rigging conditions tested.

Rigging Condition 1

The rod through bolster rigging was tested with the original (as received) levers and pins. Instrumented brake beams were installed in place of the original beams in the B-end truck of the test car. In addition, the original top rod was replaced with a top rod equipped with a turnbuckle to allow length adjustments. Top rod length was adjusted as necessary to result in optimum positioning (as close to 90° position as possible) of the B-end rigging levers during a brake application. This was necessary since the instrumented beams occupy more space than standard beams and tend to alter the normal lever angles unless the top rod length is adjusted and through-rod shortened. Rigging Condition 1 was tested with the car running in the west direction, with the A-end of the car in the leading direction, and the instrumented truck in the trailing direction.

Rigging Condition 2

Rigging condition 2 was the same as condition 1 except the live truck lever was replaced with a lever which had a bend angle of approximately 6 degrees rather than the 3-degree angle for a new lever.

Rigging Condition 3

Rigging condition 3 was the same as condition 1 except the test was conducted with the test car running in the east direction.

Rigging Condition 4

Rigging condition 4 was the same as condition 1 except the live lever was replaced with a lever with oversize pin holes.

Rigging Condition 5

Rigging condition 5 was the same as condition 4 with the substitution of five worn pins (2 top rod pins, 2 truck lever connector pins, and 1 dead lever/anchor pin). Pins which were used during testing are shown in Figure 16. Pin dimensions are given in Table 3.

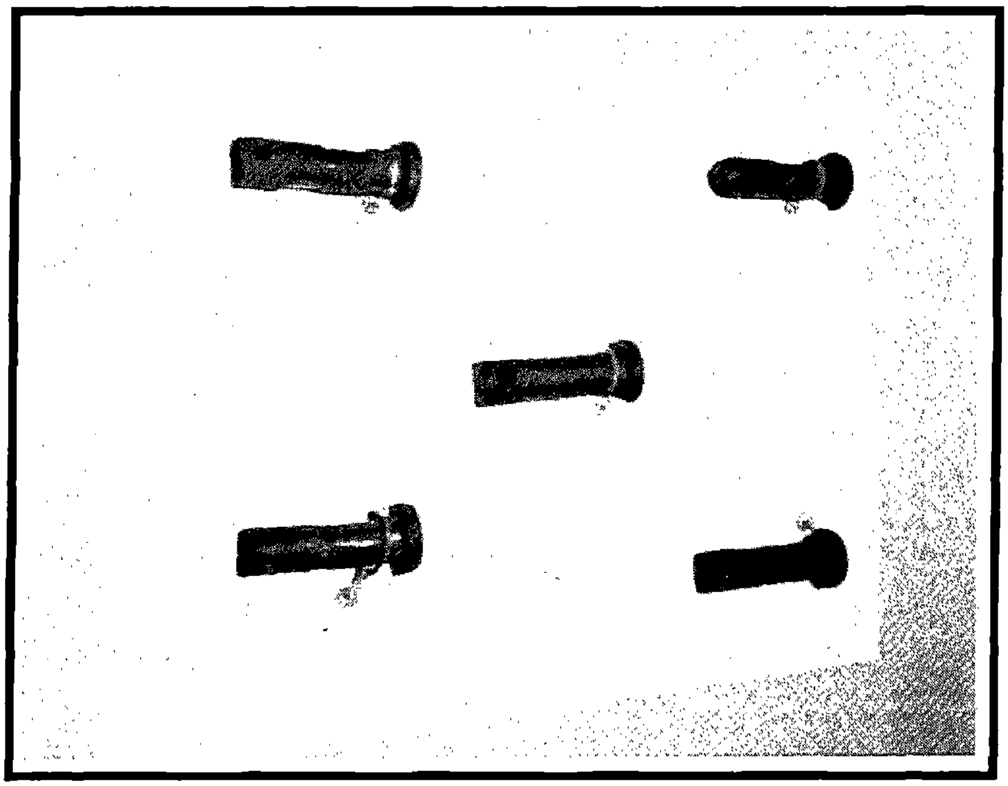


Figure 16. View of Worn Pins Used For Rigging Condition 5

Table 3. Minimum and Maximum Diameters of Worn Pins

Rigging 5 (RDU) & 3 (Track)	Top Rod to Live Lever	Top Rod to Live Lever	Live Lever to Truck Lever	Live Lever to Beam	Dead Lever to Bolster Anchor	Dead Lever to Truck Lever	Dead Lever to Beam
Min	0.946	1.015	0.977	1.094	1.017	1.015	1.094
Max	1.075	1.080	1.052	1.094	1.045	1.076	1.094
All Other Rigging Conditions							
Min	1.094	1.085	0.977	1.094	1.094	1.085	1.094
Max	1.094	1.092	1.052	1.094	1.094	1.085	1.094

NOTE: **Condemning Limit = 1.000 inches   New Diameter = 1.094 inches**

Rigging Condition 6

Rigging condition 6 was the same as condition 1 except a worn shoe was installed at the L2 location and a new shoe was installed at the R2 location. Shoes used during testing are shown in Figure 17.

Rigging Condition 7

Rigging condition 7 was same as condition 1 except that a worn shoe was installed at the R2 location and a new shoe was installed at the L2 location. The worn shoes were the same as those used in rigging condition 6.

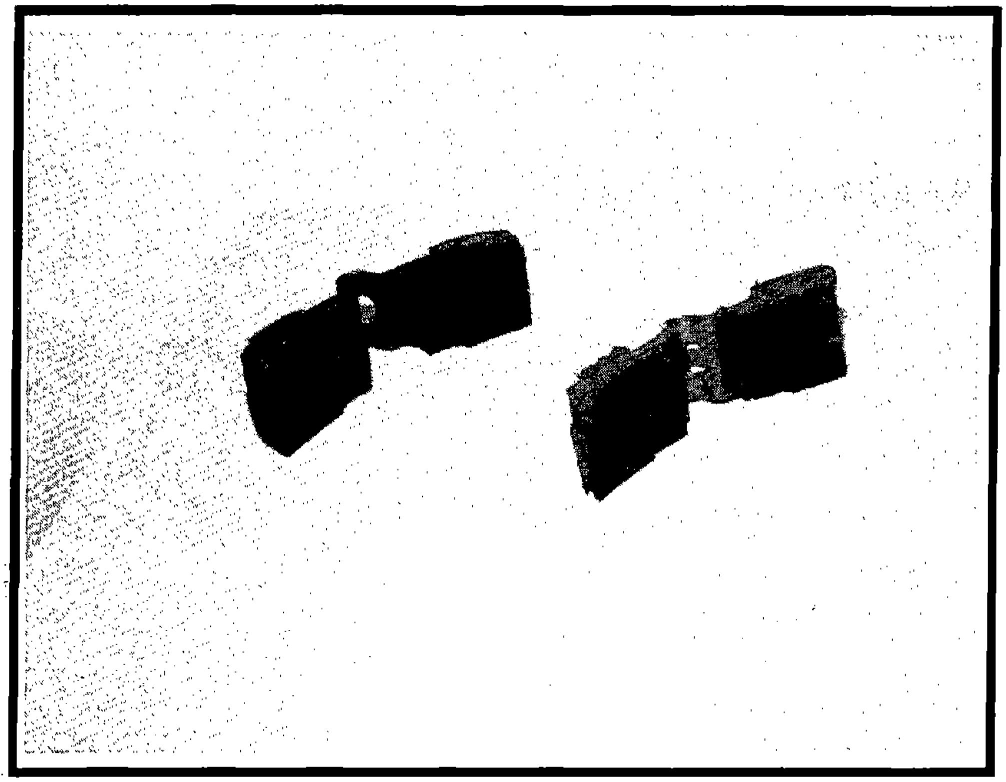
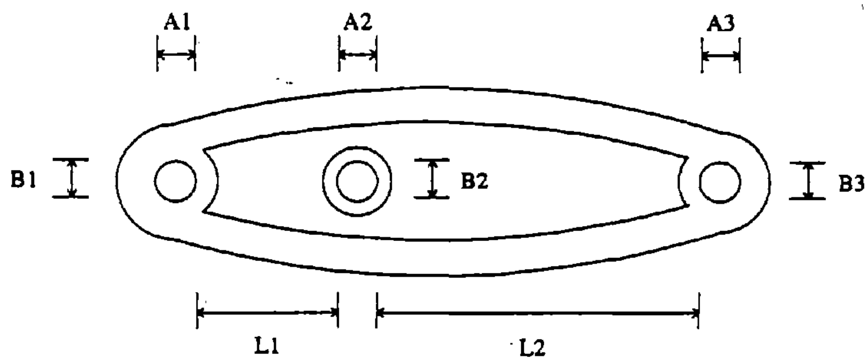


Figure 17. View Of Worn Brake Shoes Used For Rigging Conditions 6 and 7.
Left: New H4 Shoe   Right: Worn H2 Shoe

<u>Rigging Condition 8</u>

Rigging condition 8 was the same as condition 1 except the top rod was extended to introduce maximum lever angularity (i.e., the minimum possible angle between the top rod and the dead truck lever).

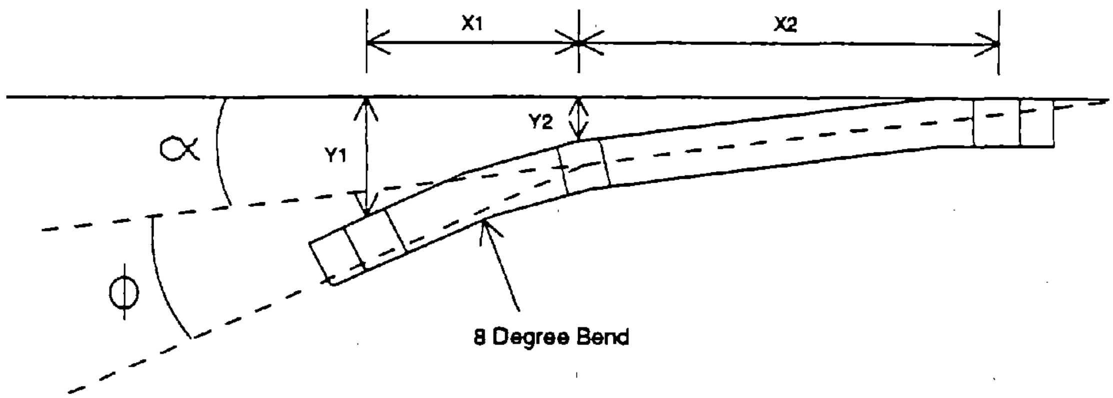
Three different live truck levers were used during testing on the RDU. Figure 18 shows the pin hole and bend angle dimensions of the three levers.



Lever Description	Lever Dimensions							
	L1	L2	A1	B1	A2	B2	A3	B3
Original Live Lever	5.67	12.83	1.14	1.14	1.14	1.14	1.14	1.13
Bent Live Lever	5.67	12.78	1.14	1.14	1.13	1.14	1.12	1.13
Worn Live Lever	5.35	12.48	1.39	1.50	1.65	1.80	1.16	1.18
Original Dead Lever	3.78	8.80	1.14	1.13	1.13	1.15	1.15	1.15
Worn Dead Lever *	3.44	8.63	1.42	1.42	1.55	1.14	1.14	1.20

* Used During Track Testing In Rigging No.'s 2 and 3

Figure 18. Rigging Lever Dimensions



Lever Description	Lever Dimensions					
	X1	Y1	X2	Y2	∝	Φ
Original Live Lever	7.05	.432	13.97	.045	3.14	.18
Bent Live Lever	6.94	.802	13.91	.084	5.91	.35
Worn Live Lever	7.10	.382	13.88	.050	2.68	.21
Original Dead Lever	5.12	.310	9.90	.020	3.24	.12
Worn Dead Lever •	5.00	.344	10.00	.000	3.94	.00

• Used During Track Testing In Rigging No.'s 2 and 3

Figure 18. Rigging Lever Dimensions -- Continued

4.4.2 Data Reduction

Upon completion of a given test series, data were transferred from the Bernoulli tape cartridges (utilized for high speed data storage during testing) to 5 1/4 inch floppy diskettes. An analysis program was used to compute parameters such as loaded net braking ratio and lever efficiency from the raw data.

4.5 RESULTS

4.5.1 Database

Brake force data acquired during testing on the RDU were compiled into two databases. The first database consisted of time histories of test data (brake forces, shear pin forces, brake cylinder pressure, running speed, and other parameters).

The second database was extracted from the first database and was compiled as an aid in the analysis process. Data corresponding to 40 seconds and 240 seconds duration of drag braking were combined into a single file.

Data were then organized into blocks corresponding to test conditions of applied brake cylinder pressure and speed. For a given test condition, 22 parameters (including brake forces, shear pin forces, and mechanical rigging efficiencies) were tabulated for each of the rigging conditions tested. Tables, presented in Appendix A, provide a comparison of a given variable for the different rigging conditions tested. Results reported in the following text are extracted from the data in Appendix A.

Extensive plots of brake force and rigging pin force data, obtained during the RDU tests, are provided in Appendix B. Plots are based upon average test data from two runs for each test condition of speed and brake cylinder pressure.

Test data were analyzed with respect to the following characteristics for various rigging conditions tested:

- B-end truck total normal brake force
- Brake force variation within B-end truck rigging
- Rigging mechanical efficiency
- Rapped and unrapped static brake forces

Detailed results to each of the above brake rigging characteristics are presented below.

4.5.2 B-End Truck Total Braking Force

One measure of brake rigging performance is the total amount of brake force delivered to the wheels of each truck associated with a given car. During the RDU drag braking tests, normal brake forces were measured at each of the B-end truck wheels. Total braking force developed in the B-end truck was observed to be a function of the rigging configuration tested and the running speed. Test results illustrating these effects are presented below.

EFFECT OF WORN RIGGING COMPONENTS ON B-END TRUCK TOTAL NORMAL BRAKING FORCE

During post-test data reduction, the B-end truck total normal braking force was computed by summing the normal brake forces measured at the L1, R1, L2 and R2 locations with the instrumented brake heads. (Normal brake force at a given location refers to the force which is transmitted through the brakeshoe in a direction normal to the tread surface of the wheel.)

The percent of change in the B-end truck total normal brake force measured after the introduction of worn components into the rigging is presented in Table 4. Values in Table 4 are based on measured total normal brake forces (measured after 40 and 240 seconds of drag braking) which were averaged for the two repetitions of each test combination of rigging condition, brake cylinder pressure, and speed.

One of the worn rigging conditions tested appeared to cause an anomaly in total truck brake forces. Total truck forces measured for rigging type No. 5 ranged from 24.1 percent less (at 20 mph, 25 psi) to 21.9 percent more (at 50 mph, 25 psi) than those measured for the original rigging. Rigging condition 5 was produced by introducing a live truck lever with worn pin holes and five worn rigging pins. Forces for rigging condition 2 ranged from 9.4 percent less to 9.7 percent more than those measured for the original rigging. The corresponding range for rigging condition 8 was -8.6 to +6.0 percent.

It may be noted that at higher speeds and BCP's, there was relatively little variation in total truck force from one rigging condition to the next. At the 50-mph, 50-psi test conditions, all of the modified rigging conditions produced forces that were within 7 percent of those corresponding to the original rigging condition (after 240 seconds).

Table 4. Percent Change in B-end Truck Total Normal Brake Forces Worn Component Condition

SPEED (mph)	BRAKE CYLINDER PRESSURE (psi)	ELAPSED TIME (sec)	ORIGINAL RIGGING B-END TRUCK TOTAL BRAKE FORCE (lbs)	% CHANGE IN B-END TRUCK TOTAL NORMAL BRAKE FORCE FOR MODIFIED RIGGING CONDITION (AS COMPARED TO THE ORIGINAL RIGGING) <-----------RIGGING TYPE-----------> 2	3	4	5	6	7	8
20	25	40	3313	-10.1	-5.5	-10.6	-23.3			-7.1
40	25	40	3517	-10.7		-14.6				
50	25	40	3459	2.8	-4.3	-9.5	19.8	-6.0	-2.0	-2.0
20	50	40	6957	-7.7		0.0	-9.0			6.4
40	50	40	7535	-2.4		-8.4				
50	50	40	7779	0.2	-4.8	-11.3	-11.6	3.8	0.6	5.9
20	25	240	3686	-9.4	-10.5	-11.9	-24.1			-8.6
40	25	240	3924	4.5		-10.3				
50	25	240	3920	9.7	-5.2	-5.9	21.9	-1.8	0.9	3.2
20	50	240	8093	2.2		-5.2	-8.7			0.9
40	50	240	8934	3.6		-8.0				
50	50	240	8820	5.3	-5.3	-5.2	-4.5	-7.0	5.4	6.0

RIGGING TYPES:
1 - Original rigging components, west running direction (A-end leading)
2 - Same as No. 1 except live lever with more bend angle
3 - Same as No. 1 except east running direction (B-end leading)
4 - Same as No. 1 except live lever with worn pin holes
5 - Same as No. 1 except live lever with worn pin holes and 5 worn pins (2 top rod pins, 2 truck lever connector pins, and dead lever/anchor pin)
6 - Same as No. 1 except worn shoe L2 and new shoe R2
7 - Same as No. 1 except worn shoe R2 and new shoe L2
8 - Same as No. 1 except top rod extended to introduce lever angularity

Absolute value of the average measured truck forces for all rigging conditions and test conditions of speed and BCP are provided in Figures 19 and 20.

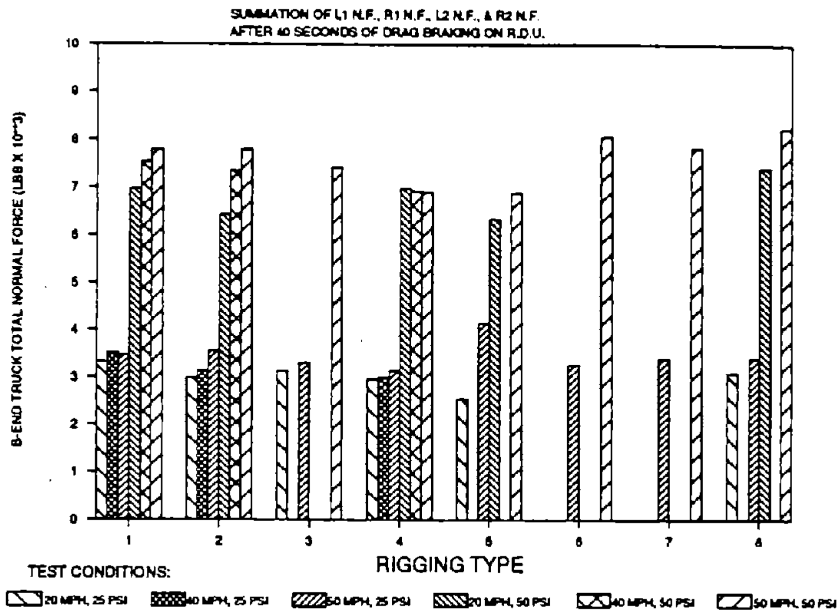


Figure 19. B-end Truck Total Normal Brake Force Measured After 40 Seconds

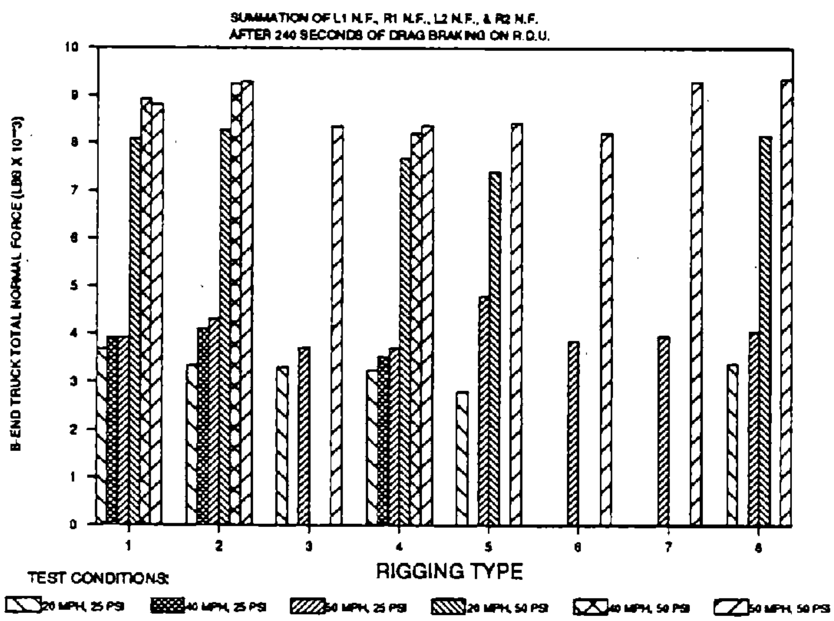


Figure 20. B-end Truck Total Normal Brake Force Measured After 240 Seconds

DISCUSSION

Interestingly, in separate tests, rigging condition 5 produced brake forces which were both more and less than the forces produced in the original condition. This particular rigging had the largest amount of combined wear in the live truck lever and rigging pins. Because of the large clearances that were present in the rigging lever connections, it is quite likely the relative angles of the levers and positions of the pins in the pin holes varied slightly from one test to the next. This variable positioning of the rigging components would affect:

- The amount of friction occurring between pin/lever connections
- The effective lever ratio of the rigging

Both of these effects would alter the total braking forces developed. It should be noted that, for a given set of nominal test conditions, there was generally an appreciable change in brake forces from one test to the next (two tests were conducted for each test combination of rigging condition, speed, and brake cylinder pressure). To characterize this variability, 95-percent confidence intervals were computed for the difference between total truck forces measured for each pair of tests. Resulting values are given in Table 5 for both RDU and on-track tests.

Table 5. Difference Between Total Truck Force First and Second Tests -- Same Test Condition

Test Phase	BCP (psi)	Total Tests	Mean Total Truck Force	Difference in Total Truck Force For Test Pairs (95% Confidence Interval) (lbs)
RDU	25	16	3844	-356, +327
RDU	50	14	8616	-830, +598
Track	25	9	3624	-604, +498
Track	50	6	7926	-666, +239

Total truck forces for each pair of tests are within approximately plus or minus 10 percent of the mean values for the two tests for rigging condition 1. The smallest change in measured forces for consecutive tests was generally observed at the higher brake cylinder pressure of 50 psi. This variability may be due to:

- The large number of friction interfaces in the rigging
- Variable positioning of the rigging which is made possible by large clearances at the pin/lever connections

Based on calibration data for the instrumented brake heads, and static brake force measurements (see Section 4.5.5), the accuracy of the instrumented brake head measurements would appear to be within 5 percent. Under drag braking conditions, an extra degree of uncertainty would be introduced. However, for a given applied load, the repeatability of a given measurement could still be expected to fall within a band of plus or minus 5 percent. Thus, a measured difference between brake forces which exceeds 5 percent of a nominal value should be interpreted to represent a difference in actual forces.

EFFECT OF RUNNING SPEED ON B-END TRUCK TOTAL NORMAL FORCES

Running speed was observed to have a pronounced effect on total truck force developed after 240 seconds for a given brake cylinder pressure for most of the rigging conditions tested on the RDU. Plots of average truck total brake force measured after 240 seconds are given in Figures 21 and 22. These rigging conditions were tested on the RDU at three speeds 20, 40, and 50 mph at 25- and 50-psi BCP. For rigging condition 2 (which contained a live lever with an approximate 6-degree bend angle rather than the design 3-degree bend) and 25-psi BCP, the total brake force was 28.8 percent higher at 50 mph than at 20 mph. For the same rigging and 50-psi BCP, the total brake force was 12.3 percent higher at 50 mph than at 20 mph.

Rigging conditions tested at only two running speeds, 20 and 50 mph, also exhibited force increases at the higher speeds (see Appendix E).

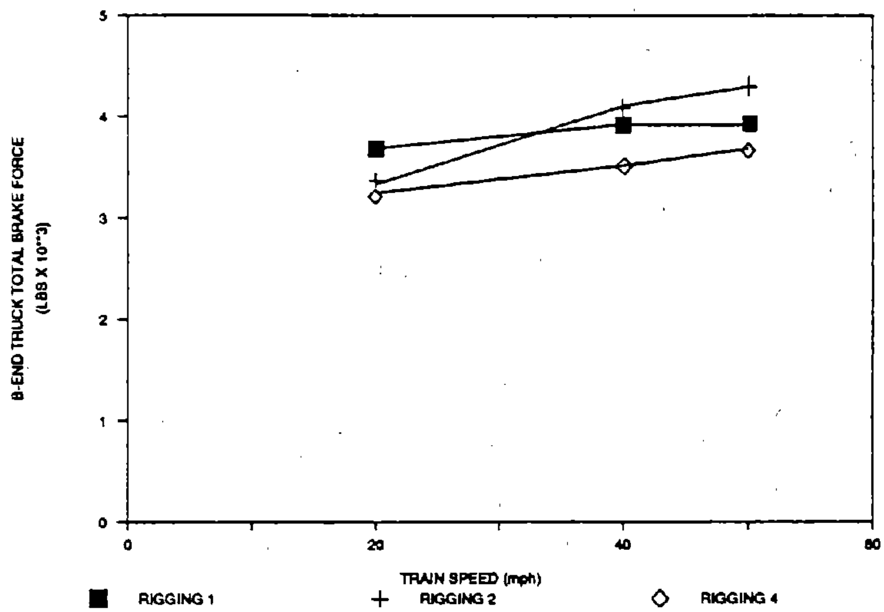


Figure 21. B-end Truck Total Normal Brake Force vs Running Speed 25-psi BCP, Testing on RDU

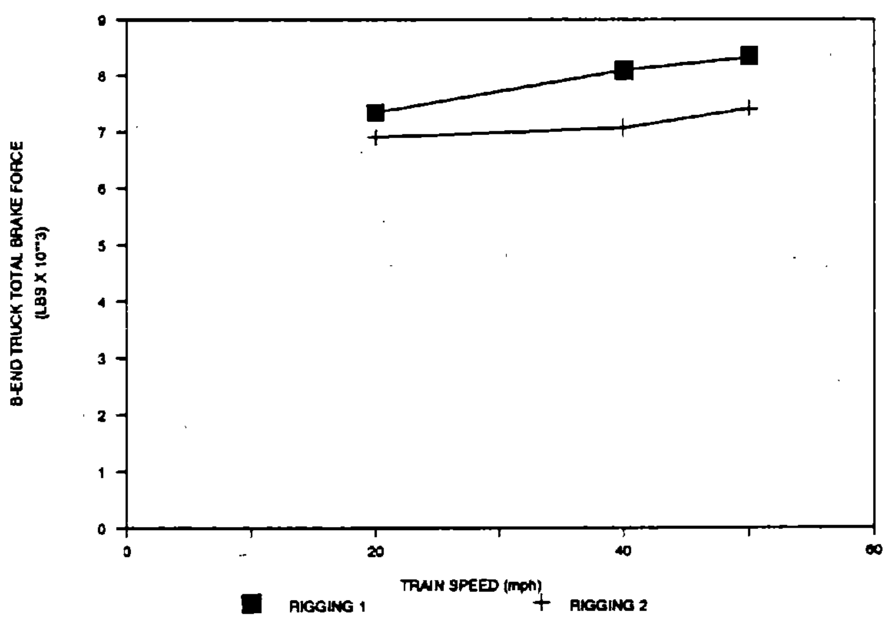


Figure 22. B-end Truck Total Normal Brake Force vs Running Speed 50-psi BCP, Testing on Track

DISCUSSION

The effect of running speed on total brake force developed after 240 seconds of drag braking is consistent with static brake force measurements made in separate tests (see Section 4.5.5). These tests demonstrated total force developed in a rigging was much greater after the rigging was rapped (subjected to impacts with a hand held hammer at pin/lever connections). Rapping has the effect of overcoming binding friction in the rigging connections. At higher speeds, it is expected that rapping of the rigging (due to normal in-transit vibrations) would take place in a shorter period of time, which explains the higher forces measured at the higher test speeds.

EFFECT OF ELAPSED TIME OF DRAG BRAKING ON B-END TRUCK TOTAL NORMAL FORCES

During testing, it was observed after a given brake application brake forces (as well as rigging pin forces) increased steadily for about 5 minutes until a maximum level was attained. This is due to gradual rapping of the rigging as a result of system vibration. This phenomenon may merit further investigation.

Brake forces were observed to increase during the first few minutes of drag braking for all combinations of rigging condition, speed, and pressure tested on the RDU. This can be seen in Figures 23 through 30, in which live histories of normal brake forces and truck lever/beam pin forces are plotted for rigging conditions 1 and 5.

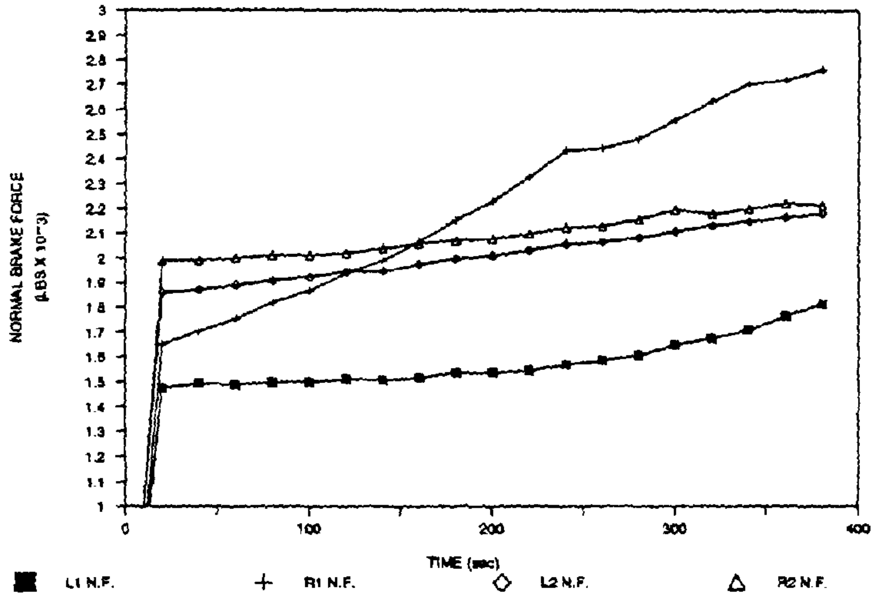


Figure 23. Brake Force Time History (Run 56)
20 mph, 50 psi, Normal Rigging

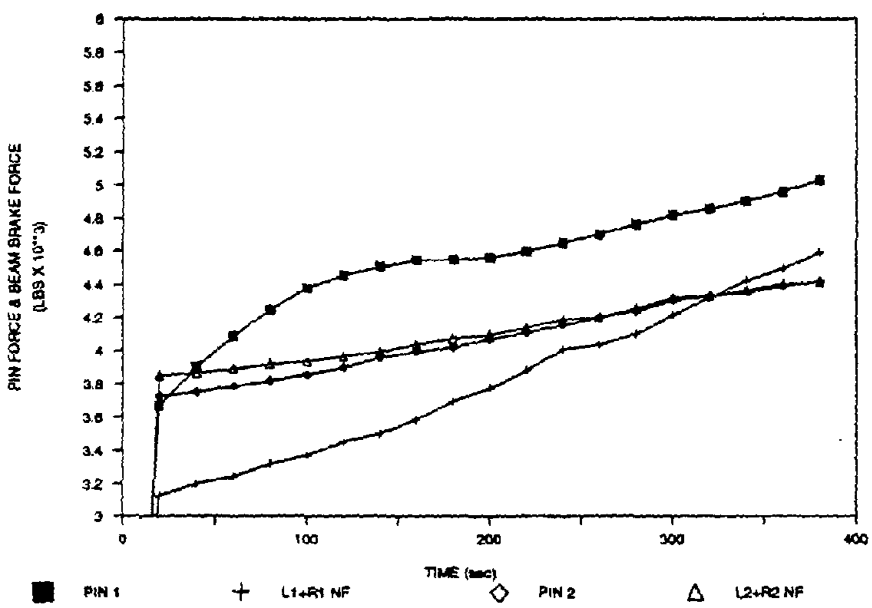


Figure 24. Beam Pin Force/Total Beam Brake Force (Run 56)
20 mph, 50 psi, Normal Rigging

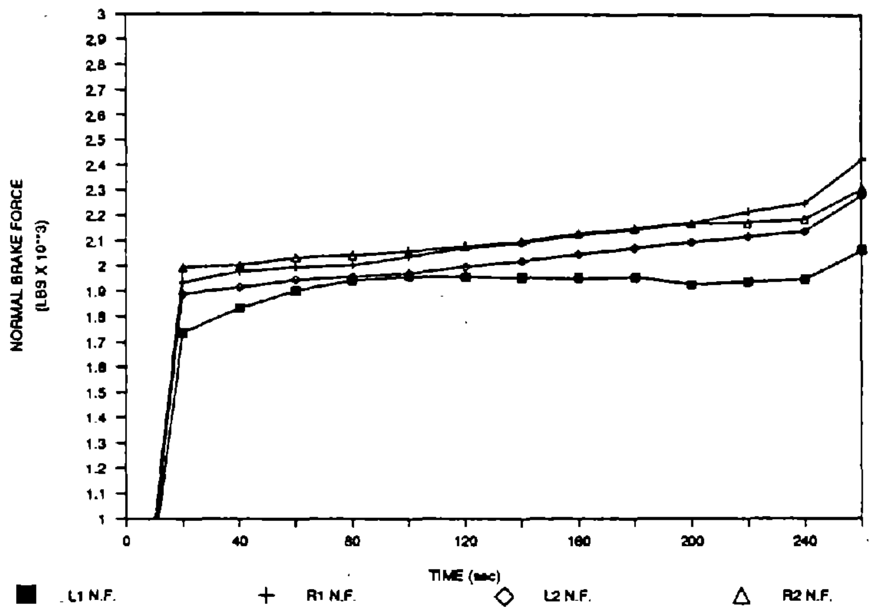


Figure 25. Brake Force Time History (Run 64)
50 mph, 50 psi, Normal Rigging

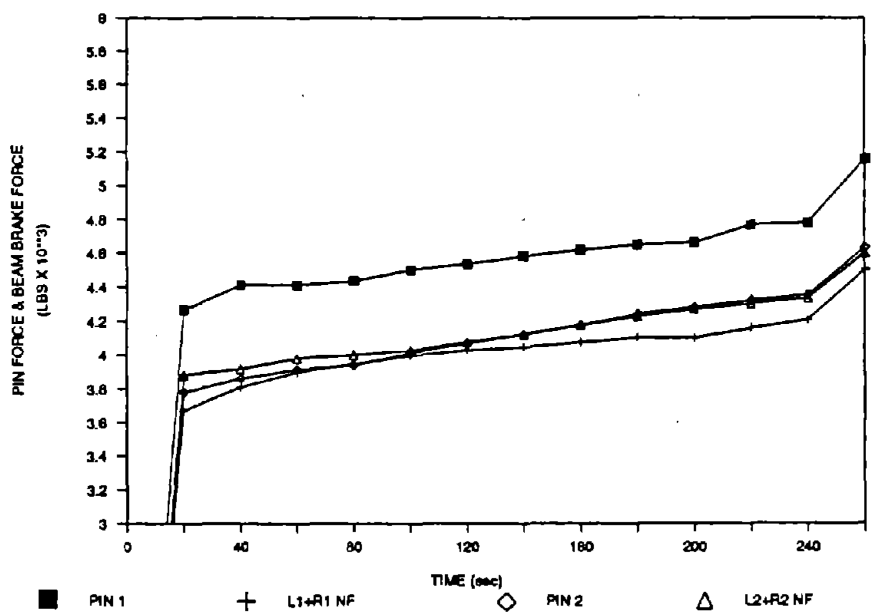


Figure 26. Beam Pin Force/Total Beam Brake Force (Run 64)
50 mph, 50 psi, Normal Rigging

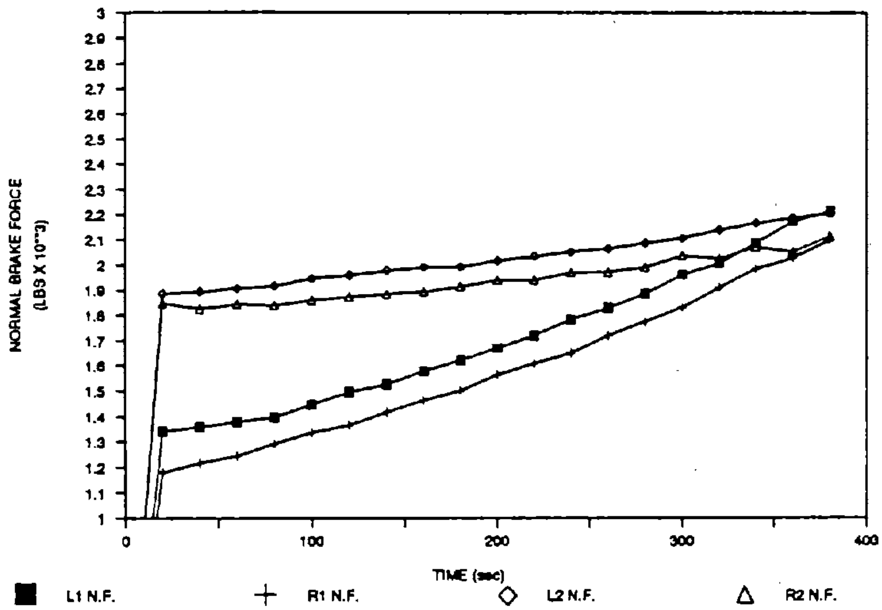


Figure 27. Brake Force Time History (Run 88)
20 mph, 50 psi, Worn Lever/Pins

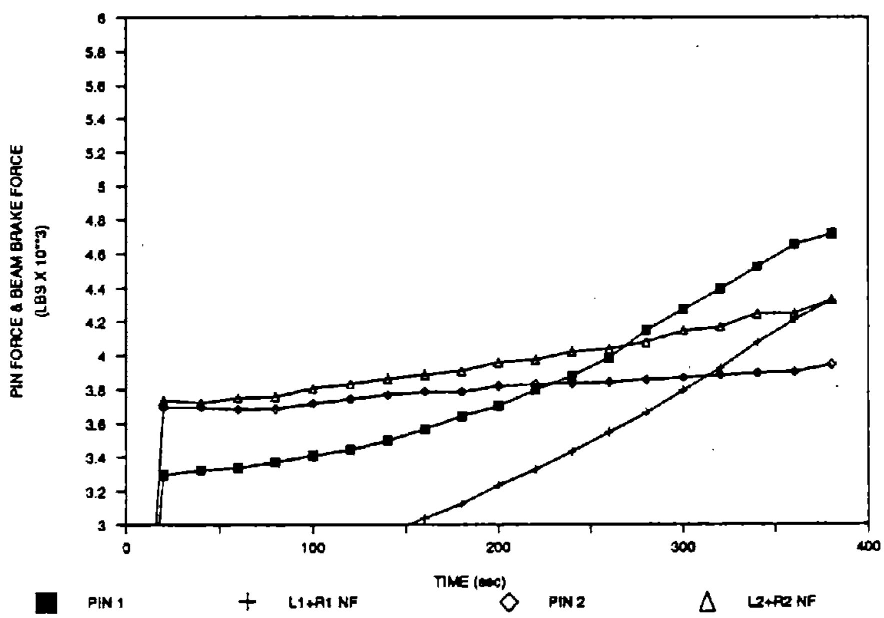


Figure 28. Beam Pin Force/Total Beam Brake Force (Run 88)
20 mph, 50 psi, Worn Lever/Pins

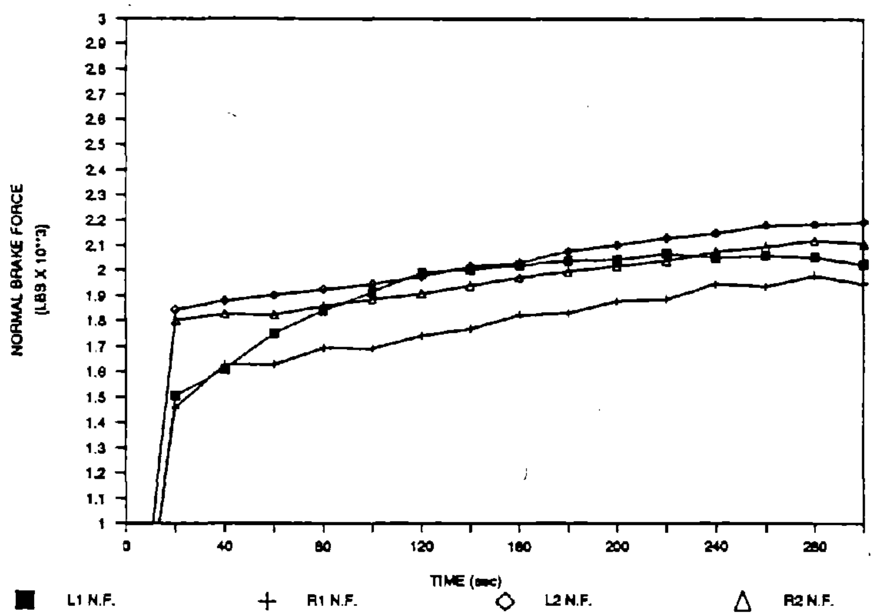


Figure 29. Brake Force Time History (Run 92)
50 mph, 50 psi, Worn Lever/Pins

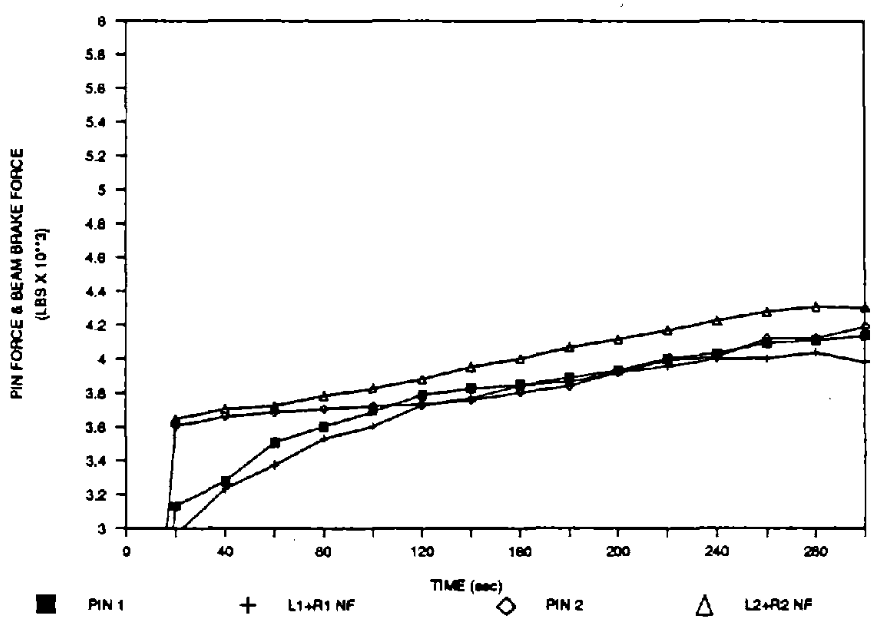


Figure 30. Beam Pin Force/Total Beam Brake Force (Run 92)
50 mph, 50 psi, Worn Lever/Pins

In the above figures, it is seen that over time increases in shoe forces are consistent with force increases measured with the instrumented truck lever/beam pins.

The percent increase in total truck forces measured between 40 and 240 seconds of drag braking for all test combinations is given in Figure 31. For testing conditions of 50 mph and 25 psi, the percent increase for all eight rigging configurations fell in the range of 12.3 to 21.0.

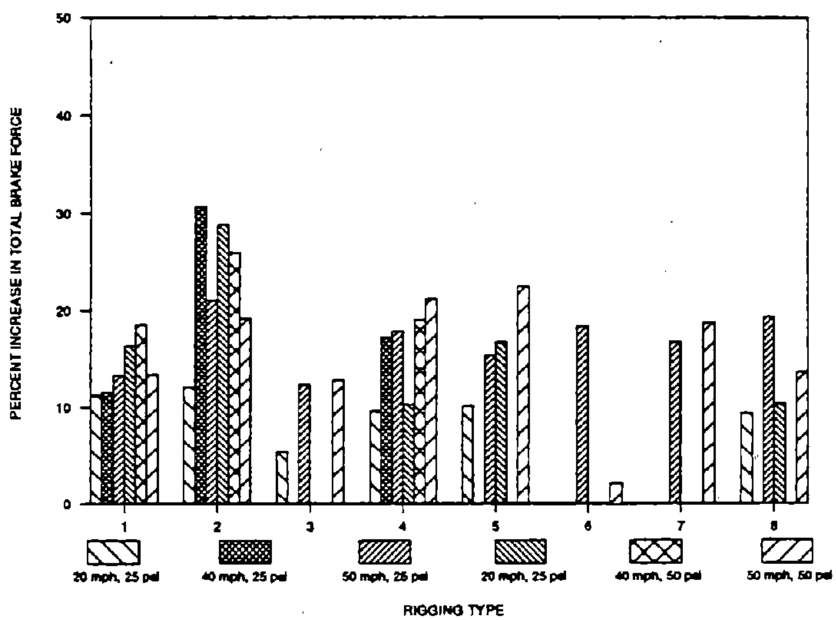


Figure 31. Change in Total Brake Force Between 40 and 240 Seconds

DISCUSSION

Time dependence of brake forces is a result of the rapping which takes place at the beginning of a drag braking period. It is seen that steady state forces were approached more quickly at higher test speeds.

4.5.3 Wheel-To-Wheel Brake Force Variations Within B-End Truck Rigging

Establishing the distribution of brake forces within a conventional brake rigging with various combinations of worn rigging components was one of the major goals of the braking research program. Variations in brake forces, measured at the L1, R1, L2, and R2 locations during testing, were expressed as percent variation which was computed as follows:

$$\%\ Variation = \frac{(Maximum\ normal\ brake\ force - Minimum\ normal\ brake\ force)}{(Minimum\ normal\ brake\ force)} x100$$

The percent variation in normal brake forces was determined for all combinations of rigging condition, speed, and BCP during testing on the RDU. Table 6 lists minimum and maximum values of percent variation for each of the rigging conditions.

Table 6. Percent Variation Minimum and Maximum Values
All Combinations of Running Speed and BCP.

Duration (seconds)		**Rigging Condition**							
		1	**2**	**3***	**4**	**5***	**6***	**7***	**8**
40	MIN	7.5-	7.9-	11.0-	13.5	16.9	10.7-	6.0-	15.2-
40	MAX	35.8	43.6	16.6	35.0	60.0	19.4	20.2	44.0
240	MIN	6.1-	4.9-	8.9-	6.0-	10.3-	8.1-	7.6-	7.5-
240	MAX	55.0	38.3	23.9	41.1	45.5	13.2	15.5	26.1

* **Rigging conditions 3, 5, 6 and 7 were not tested at all six combinations of speed and BCP**

Composite (all eight rigging conditions):

- 6.0 - 60.0 percent (After 40 seconds drag braking)
- 4.9 - 55.0 percent (After 240 seconds drag braking)

The percent variation for all of the tests and rigging conditions performed on the RDU are provided in Table 7. Data in the table corresponds to measurements made after 40 and after 240 seconds of drag braking.

Table 7. Wheel-to-Wheel Brake Force Variations

			<-------------RIGGING TYPE------------->															
	BRAKE CYLINDER	ELAPSED	1		2		3		4		5		6		7		8	
SPEED (mph)	PRESSURE (psi)	TIME (sec)	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2
20	25	40	18.7	21.3	15.9	12.9	16.1	16.6	28.8	25.8	60.0	62.6					43.5	38.2
40	25	40	9.5	7.6	12.4	9.3			19.5	24.2								
50	25	40	10.1	11.9	6.3	7.5	14.3	11.2	14.8	13.5	22.9		18.6	19.4	9.7	20.2	27.1	22.3
20	50	40	35.8	33.3	43.6	39.9			28.1	35.0	55.0	55.5					33.0	44.0
40	50	40	15.8	15.4	17.8				19.3	26.5								
50	50	40	7.5	9.2	12.1	7.9	11.1	11.0	25.0	23.1	27.9	16.9	10.7		6.0	12.9	19.2	15.2
20	25	240	9.9	10.7	9.2	7.7	17.1	23.9	21.5	15.4	41.3	34.9					12.1	21.5
40	25	240	11.3	8.1	4.9	9.1			6.0	9.5								
50	25	240	6.1	11.2	8.1	10.5	18.3	15.6	6.5	9.8	16.3		13.2	8.1	8.5	7.6	8.4	18.0
20	50	240	9.4	55.0	23.0	38.3			29.1	41.1	45.5	24.3					26.1	7.5
40	50	240	14.5	9.6	8.3				9.9	13.8								
50	50	240	12.3	15.3	11.7	11.2	8.9	16.0	15.6	14.7	15.3	10.3	11.8		15.5	13.6	17.5	20.1

RIGGING TYPES:

1 - Original rigging components, west running direction (A-end

2 - Same as No. 1 except live lever with more bend angle

3 - Same as No. 1 except east running direction (B-end leading)

4 - Same as No. 1 except live lever with worn pin holes

5 - Same as No. 1 except live lever with worn pin holes and 5 worn pins (2 top rod pins, 2 truck lever connector pins, and dead lever/anchor pin)

6 - Same as No. 1 except worn shoe L2 and new shoe R2

7 - Same as No. 1 except worn shoe R2 and new shoe L2

8 - Same as No. 1 except top rod extended to introduce lever angularity

Measured percent variation in normal braking forces was substantial for all of the rigging types tested and for a wide range of running speeds and BCP's. None of the rigging conditions tested can be singled out as having a small or large percent variation with respect to the other rigging conditions.

4.5.4 Mechanical Efficiency Losses In Rigging

During the drag braking tests on the RDU, forces were measured at several locations in the rigging including:

- Top rod/truck lever pin
- Live truck lever/beam pin
- Dead truck lever/beam pin
- Brake shoe forces at wheels (L1, R1, L2, R2)

Based on the above measurements, and given the known brake cylinder area and applied BCP, the following mechanical efficiencies were computed:

- B-end truck rigging mechanical efficiency (based on measured shoe forces)
- Mechanical efficiency at top rod/live lever pin
- Mechanical efficiency at beam pins

In addition, an overall car rigging efficiency was computed based on an estimate of total car brake force. The above rigging efficiencies are tabulated in Appendix B.

Once the rigging efficiencies were obtained, efficiency losses were computed for different sections of the brake rigging. The following efficiency losses were computed:

- Between the brake cylinder piston and the B-end top rod/live lever pin
- Between the top rod/live lever pin and truck lever beam pins
- Between the truck lever beam pins and the brakeshoe/wheel interface

B-end truck overall rigging efficiencies measured during testing on RDU, as well as the three efficiency losses described above are given in Appendix C.

EFFECT OF BRAKE CYLINDER PRESSURE ON BRAKE RIGGING EFFICIENCY

For each of the rigging conditions tested, efficiencies measured for a 50 psi applied BCP were higher than those measured for a 25 psi applied BCP. Percent increase in rigging efficiency measured between 25- and 50-psi BCP for each of the rigging types is plotted in Figure 32. Values plotted in Figure 32 are based on average efficiencies computed for each span of tests conducted for each combination of rigging condition, speed, and BCP.

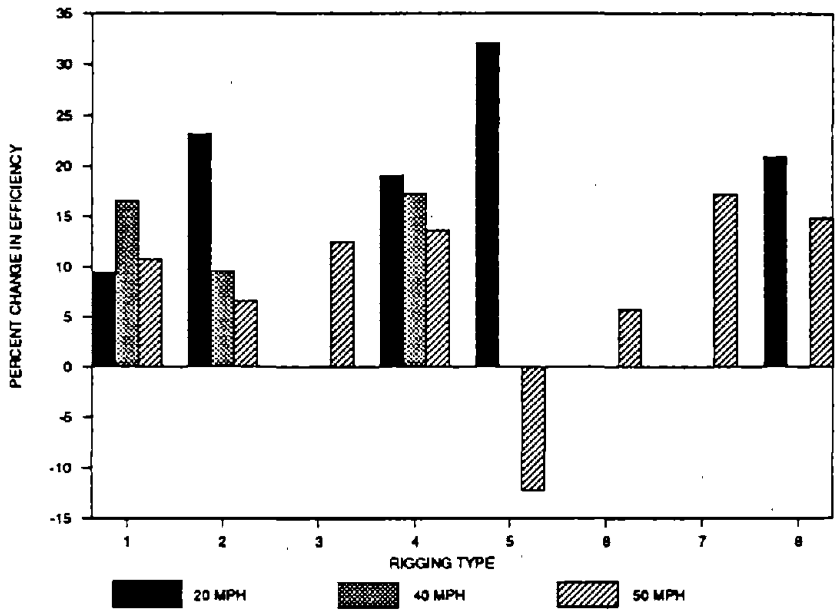


Figure 32. Percent Change In Efficiency Between 25- and 50-psi BCP

In Figure 32 it is evident that most of the rigging conditions tested (1, 2, 4, 5, 7, and 8) exhibited efficiencies that were more than 15 percent higher at 50-psi BCP than at 25-psi BCP for at least one of the running speeds. In addition, it may be noted that rigging condition 5 exhibited a 32 percent increase in efficiency for 50-psi BCP as compared to 25-psi at a 20 mph running speed.

The approximately 12 percent decrease in efficiency measured for rigging condition 5 for the higher BCP at 50 mph is the result of unusually high brake forces obtained at 25-psi BCP during a single test for rigging condition 5. High brake forces (as measured by the instrumented brake heads) were consistent with high pin forces measured during the same test.

DISCUSSION

Static brake force measurements (see Section 4.5.5) indicated test rigging (with original components) exhibited a linear total brake force vs brake cylinder pressure relationship which may be expressed as:

$$F = mP + B$$

The ratio of force over pressure may be written:

$$\frac{F}{P} = m\left[\frac{B}{mP} + 1\right]$$

Where

F = *total brake force (lbs)*

m = *proportional constant*

P = *brake cylinder pressure (psi)*

B = *constant term*

For positive m and negative B, it is readily seen that ratio F/P, which is proportional to rigging efficiency, becomes larger as pressure is increased. In physical terms this means that the constant frictional force term becomes a smaller fraction of the total brake force as pressure is increased, resulting in a higher efficiency.

Based on the static rapped brake forces measured with the instrumented brake beams, rigging efficiencies of 68.6 and 82.3 percent were computed for an applied BCP of 25 psi and 50 psi, respectively. The difference between the two efficiencies, 13.7 percent, is of similar magnitude to efficiency differences measured during drag braking on the RDU.

RIGGING EFFICIENCY LOSSES

Rigging efficiency losses were computed for three sections of the brake rigging. Losses are expressed as a percentage of the total B-end truck rigging brake force, which would be expected for a given brake cylinder pressure in the absence of any friction losses.

Rigging efficiency loss No. 1 was found to fall in the range from 19.5 percent to 40 percent. Efficiency loss No. 1 constituted the bulk of the mechanical efficiency loss which occurred in the B-end truck rigging.This loss represents the friction losses incurring between the brake cylinder and the top rod/live lever pin connection (the top rod/live lever pin is the 10th lever/pin connection in the rigging starting from the piston rod lever/anchor pin).

Rigging efficiency loss No. 2 was found to vary from essentially zero to 9.8 percent. This loss represents the loss incurred between the top rod/live lever pin and the two beam pins.

Rigging efficiency loss No. 3 was found to vary in the range from -4.1 to 7.9 percent (a negative loss indicates the sum of the brake shoe forces L1, R1, L2, and R2 was greater than the sum of the forces measured at the truck lever/beam pin connections).

DISCUSSION

There are two possible explanations for the occurrence of measured brake forces which were higher than pin forces in some cases. The first explanation is if the shear pins were loaded off-center, the measured pin forces would be less than the actual shear force. In fact, this would explain why most of the negative values of loss No. 3 occurred for rigging conditions 4 and 5. These rigging conditions included a live truck lever with oversize pin holes, which would allow some skewing of the lever relative to the pin. The second possible explanation is some force was transmitted through friction between the truck levers and the brake beam cross pieces. In other words not all the force was transmitted through the pins. It is certain there was some friction at the lever/beam interfaces since the truck levers transmit both a side thrust force (tending to push the No. 2 beam into the R1-R2 sideframe and the No. 1 beam into the L1-L2 sideframe) and a twisting moment (tending to increase the brake forces at the L2 and L1 locations) to the brake beams. For example, rigging model calculations predicted beam side thrust forces of approximately 300 pounds per beam for a 50-psi BCP. If the coefficient of friction between the truck levers and beams is assumed to be 0.4, a total of 240 poundss could be transmitted through friction at those interfaces. In addition, the calculated moment transmitted through the lever/beam interface would be approximately 615 ft-lbs (about the vertical axis) for a 50-psi BCP. If this moment acted at an average radius of one inch, a total contact force of 615 pounds would be present at the interface. If the coefficient of friction is again assumed to be equal to 0.4, the total force that could be transmitted through friction would be 492 pounds (for both beams). Summing both of the friction forces gives 732 pounds, or 5.7 percent of the theoretical total brake force for the B-end truck. Based on these calculations, it would be possible to develop a -5.7 percent efficiency "loss" between the instrumented pins and the instrumented brake shoes.

4.5.5 Rapped And Unrapped Static Brake Forces

B-end truck brake forces were measured for a range of brake cylinder pressures with and without rapping. In separate tests, the forces were measured with instrumented brake heads, and static load cells. Static load cells, which were designed to be used with the wheels stationary, were used to confirm readings obtained with the instrumented brake heads.

Rapped and unrapped brake forces measured with the instrumented brake heads are plotted in Figures 33 and 34 for the L1, R1, C2, and R2 locations. Corresponding plots based on data obtained using the static shoe load cells is given in Figures 35 and 36. For both sets of measurements, the rapped forces were much higher than the unrapped forces.

The sum of the brake forces L1, R1, L2, and R2 (total truck brake forces) measured using the two sets of instruments are plotted in Figures 37 and 38. Rapped forces are given in Figure 37; unrapped forces are given in Figure 38.

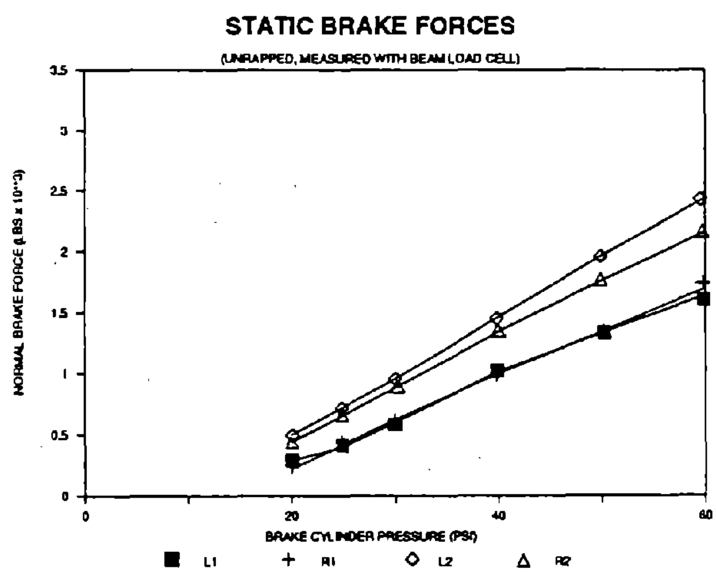


Figure 33. Unrapped Brake Forces Measured with Instrumented Brake Heads

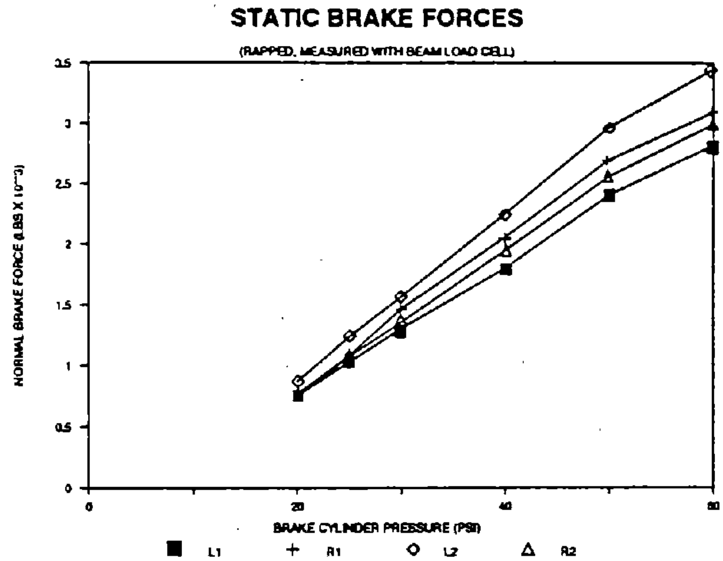


Figure 34. Rapped Brake Forces Measured with Instrumented Brake Heads

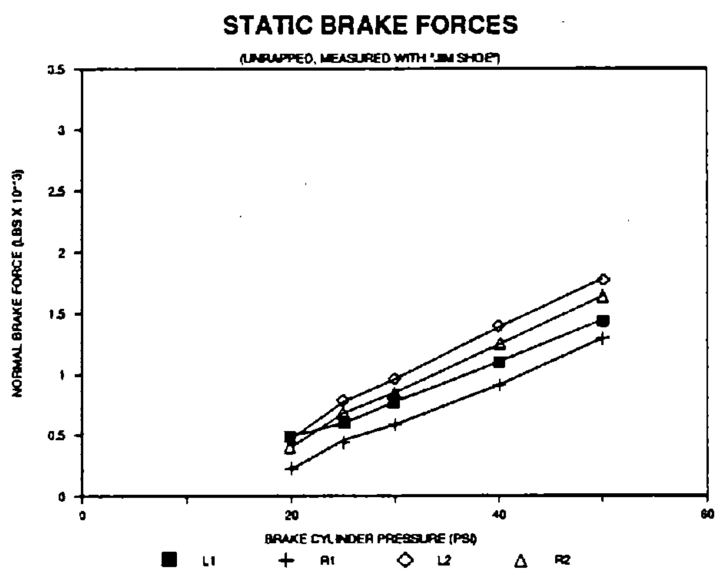


Figure 35. Unrapped Brake Forces Measured with Static Load Cells

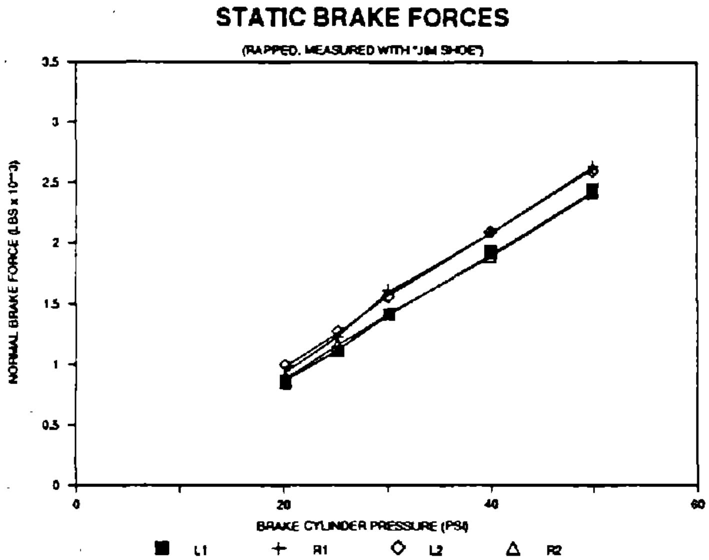


Figure 36. Rapped Brake Forces Measured with Static Load Cells

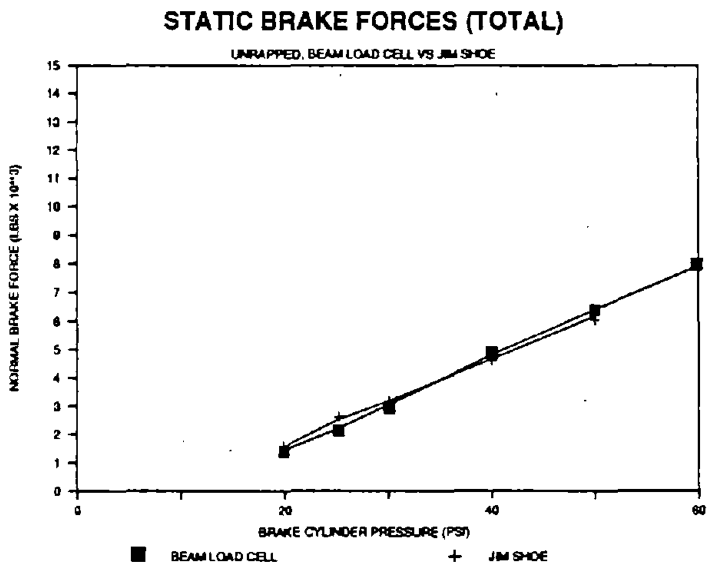


Figure 37. Unrapped B-end Truck Brake Force Measured with Instrumented Brake Heads and Static Load Cells

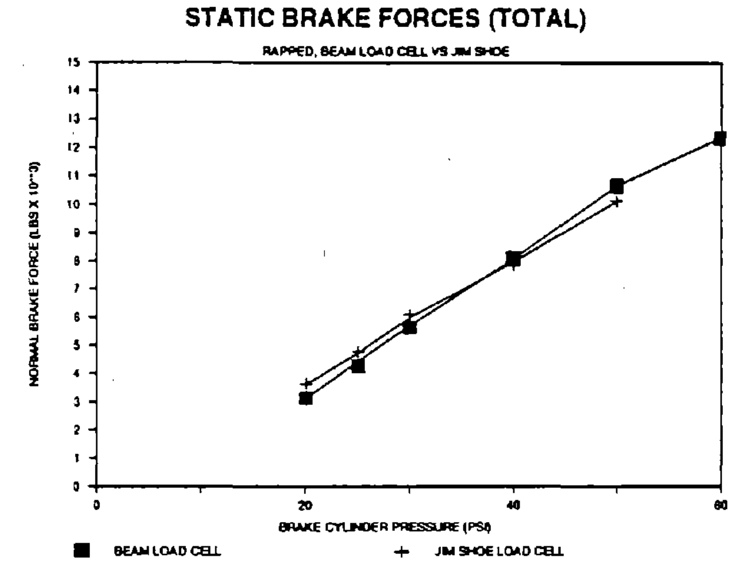


Figure 38. Rapped B-end Truck Brake Forces Measured with Instrumented Brake Heads and Static Load Cells

It is seen that brake forces measured using the two sets of instruments are in fairly close agreement. Exact agreement was not expected since a separate series of brake applications was performed for the two measurement techniques.

4.6 CONCLUSIONS FROM RDU TESTS

Analysis of the RDU test data yields the following conclusions:

- The worn rigging condition produced uneven brake forces, which in separate tests, were substantially higher and substantially lower than the forces produced with original rigging components that had a small amount of wear.
- A large difference was observed between rapped and unrapped brake forces measured during a static test. (For the L1 and R1 locations, the rapped forces at 25-psi BCP were more than twice as large as the unrapped forces.) Rapped and unrapped brake forces represent the maximum and minimum brake forces that may be achieved within a given rigging.
- For all of the rigging conditions tested, total brake forces were observed to increase steadily during the first few minutes of drag braking as a result of rapping. Steady state forces were developed more rapidly at higher test speeds.

- All of the rigging conditions tested exhibited substantial wheel to wheel brake force variations for a wide range of speeds and applied BCP's. Percent difference between maximum and minimum brake forces for a given speed and BCP ranged from 5 percent to 50 percent.
- Most of the rigging conditions tested exhibited a moderate increase in mechanical efficiency at 50-psi BCP as compared to 25 psi.
- The bulk of the mechanical efficiency losses in the rigging (approximately 80%) were observed to occur between the brake cylinder and the top rod/live lever pin.

5.0 CONVENTIONAL RIGGING ON-TRACK TEST

5.1 OBJECTIVE

The objective of the on-track tests was to evaluate the most severe RDU cases in simulated revenue service. The "abnormally bent live lever" configuration was chosen as a test case along with the worn pins and levers combination. Both cases produced lower total braking force than the normal rigging when tested on the RDU. In addition to the rigging anomalies, the effect of an unreleased handbrake in the normal rigging situation was also examined.

5.2 TEST EQUIPMENT/INSTRUMENTATION

Test equipment and instrumentation used during track testing were identical to those used in RDU testing. The only difference between the two was the change in brake rigging configurations.

5.2.1 Instrumented Pin Configuration

Instrumented pins were configured in the arrangement shown in Figure 39.

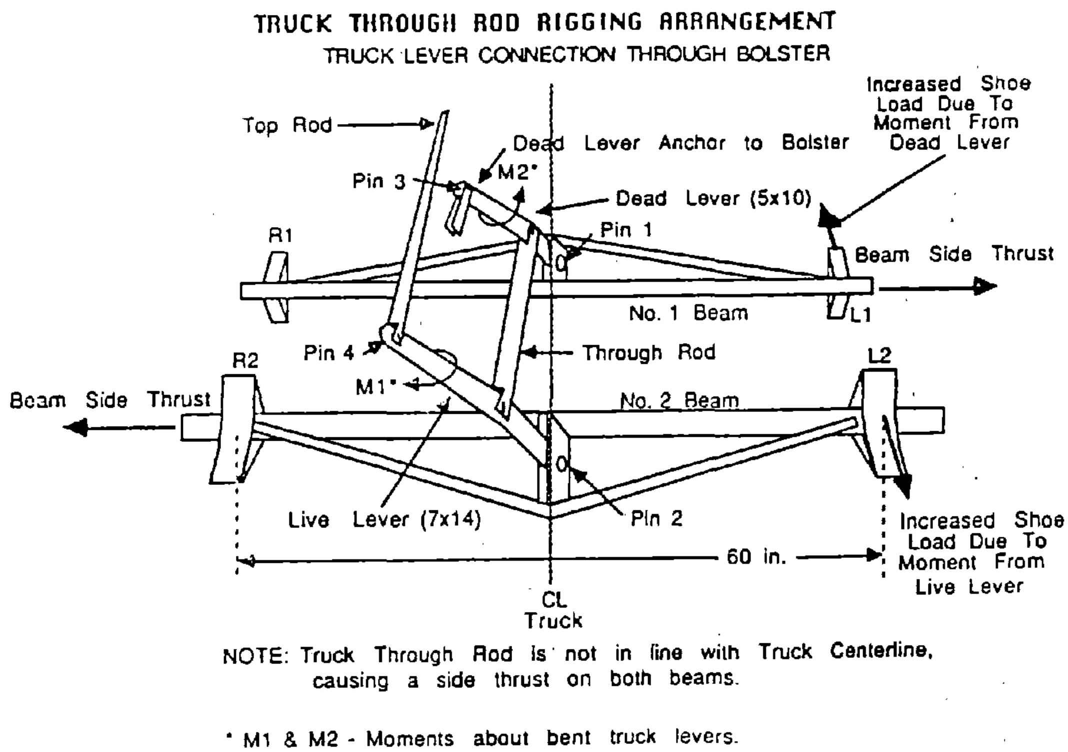


Figure 39. Instrumented Pin Configuration

Pin 1 was installed at the dead lever connection on beam 1. Pin 2 was installed in the same position on beam 2. Pin 3 was installed at the top, or anchor, of the dead lever. Pin 4 was the live lever/top rod connection.

5.2.2 Rigging Configurations

Rigging condition 1 was the same as that used during the RDU tests. As-received rigging components (except for the instrumented brake heads) were used.

Rigging condition 2 was the same as No. 1 except the live truck lever was replaced with a lever which had a bend angle of approximately 6 degrees rather than the 3 degree angle for a new lever. In addition, a worn pin was installed at the live lever/top rod connection (the same pin was previously used in rigging condition 5 during the RDU tests).

Rigging condition 3 was produced by substituting truck levers with worn pin holes for the original truck levers. In addition, five worn pins (two top rod pins, two truck lever connector pins, and one dead lever/anchor pin) previously used during the RDU tests were installed (see Figure 16 and Table 3). Dimensions of each of the truck levers are given in Figure 18.

5.3 ON-TRACK TEST PROCEDURE

Drag braking tests were conducted for each of the three rigging conditions. Each condition was tested at 20, 40, and 50 mph with BCP's of 25 and 50 psi.

In addition, one test was performed with an engaged handbrake. This test consisted of accelerating the test car consist from zero to 50 mph with the handbrake applied and then allowing the consist to come to a stop. No brake cylinder pressure was applied during this test. Table 8 lists track test run numbers and conditions.

Table 8. Track Test Matrix

Run No.	Rigging Condition	Speed	Brake Pressure
140, 141	1 - Normal	20	25
142-145	1 - Normal	40	25
146, 147	1 - Normal	50	25
148, 149	1 - Normal	20	50
150, 151	1 - Normal	40	50
152, 154	1 - Normal	50	50
155, 156	2 - Bent Lever	20	25
157, 158	2 - Bent Lever	40	25
159, 160	2 - Bent Lever	50	25
161, 162	2 - Bent Lever	20	50
163, 164	2 - Bent Lever	40	50
165, 166	2 - Bent Lever	50	50
167, 168	3 - Worn Pins/Levers	20	25
169, 170	3 - Worn Pins/Levers	40	25
171, 172	3 - Worn Pins/Levers	50	25
173	1 - Normal	20	25
174	1 - Normal	40	25
175	1 - Normal	50	25
176	1 - Normal	20	50
178, 179	1 - Normal	40	50
180	1 - Normal	50	50
181	1 - Engaged Handbrake	0-50	0

All runs were made in the same direction with the B-end leading. The consist, pictured in Figure 40, was run counterclockwise on the TTT.

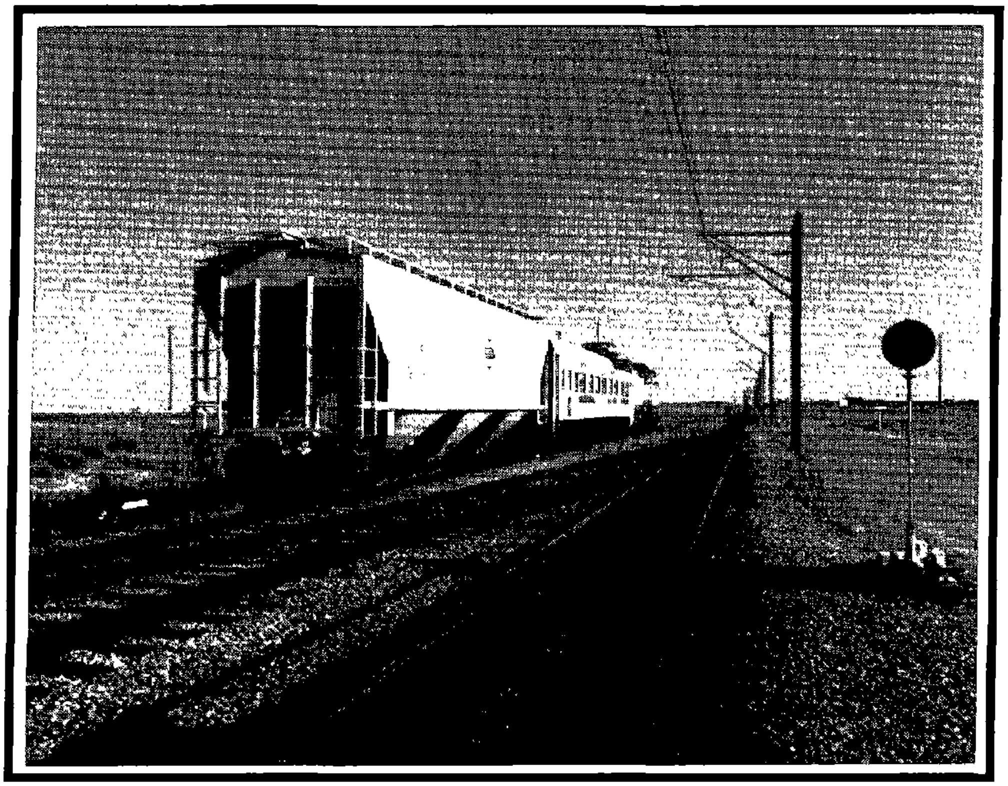


Figure 40. Test Consist

5.3.1 Rigging Condition 1 Test Procedure

General procedure was the same for all three rigging conditions. The train was run in the counterclockwise direction at all times. When the train reached test speed and was in proper position, the brakes were applied only to the hopper car. A remote air line and regulator, installed in the instrument car, were used to control brake application.

During a 20-mph run, the brakes were applied at station 41 on a tangent section of the TTT. For a 40- or 50-mph run, the brakes were applied at station 43, as shown in Figure 41.

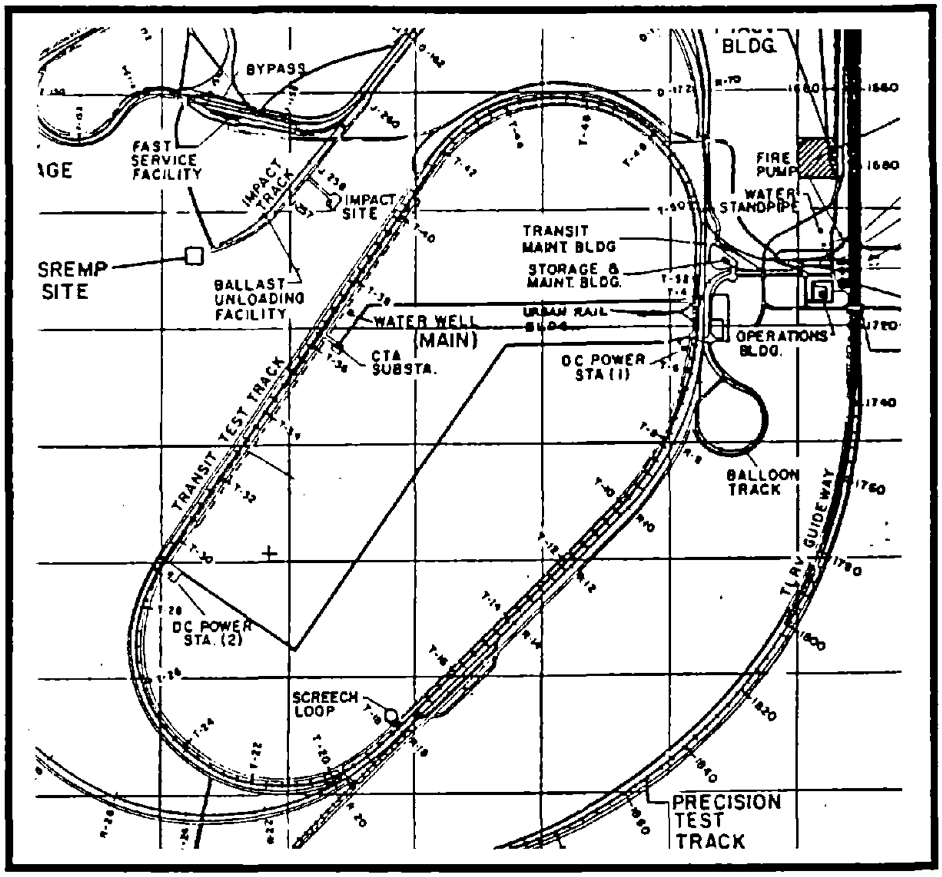


Figure 41. Transit Test Track

Brakes were applied continuously on the tangent section and into the first curve. The time the consist entered the curve during the test was noted. The length of the tangent section of track was such that a minimum of two minutes of drag braking was completed before entering the first curve.

The same measurements were made for track testing and RDU testing, including brake shoe normal and tangential force and beam pin forces. Coefficient of friction and brake horsepower values were calculated for each wheel.

Upon releasing the brakes on the hopper car, the train was brought to a stop using the locomotive and instrument car brakes. A hand held infrared pyrometer was used to measure wheel tread temperature at two locations on each wheel. Those temperatures were recorded and averaged later.

A post test lap was made to cool the wheels and position the consist for the next run. Data, including time history graphs, were printed immediately, then stored on diskette.

5.3.2 Rigging Condition 2 Test Procedure

The same bent live lever used in RDU testing was used in track testing. The instrumented pin at the top of the live lever was so snug that it didn't allow the bent lever to move the way it might with a slightly worn pin. The No. 4 instrumented pin, top of live lever, was replaced with a worn pin. The through rod pin was also replaced with a worn pin. The pins were the ones used in the RDU worn pin test.

5.3.3 Rigging Condition 3 Test Procedure

The amount of wear on the pins and levers used in the on-track test was more severe than during the RDU test. In addition to a worn live lever, a worn dead lever was installed. The five worn pins used in RDU testing were also installed. Only 25-psi tests were conducted. There was so much slack in the rigging the R1 shoe barely made contact when the brakes were applied. It was determined that 50-psi data would not reveal any additional information.

5.3.4 Engaged Handbrake Test Procedure

After the drag braking tests with the three rigging conditions were completed, a handbrake test was performed. The handbrake on the hopper car was set as tight as the test controller could set it. The train was then accelerated from a stop to 50 mph. It then decelerated back to a stop. The same measurements as in the previous tests were made while running and stopped.

5.4 RESULTS

5.4.1 Database

Brake force data acquired during on-track testing were compiled into two databases. The first database consisted of time histories of test data including brake forces, shear pin forces, brake cylinder pressure, running speed, and other parameters.

The second database was extracted from the first database and compiled as an aid in the analysis process. Data corresponding to 40- and 120-seconds duration of drag braking were combined into a single file. For all of the on-track tests analyzed, the test consist was on tangent track for at least 120 seconds of testing. Data were then organized into blocks corresponding to test conditions of applied BCP and speed. For a given test condition, 22 parameters including brake forces, shear pin forces, and mechanical rigging efficiencies were tabulated for each of the rigging conditions that were tested. Resulting tables are presented in Appendix D. The tables in Appendix D provide for ready comparison of a given variable for the different rigging conditions which were tested. Many of the results which are reported in the following text are extracted from the data given in Appendix D.

Extensive plots of brake and pin force data obtained during tests on the RDU are provided in Appendix E. Plots are based on average test data from two runs for each test condition of speed and applied BCP.

Test data were analyzed with respect to the following characteristics for the worn rigging conditions tested:

- B-end truck total normal brake force
- Brake force variation within B-end truck
- Rigging mechanical efficiency
- Wheel temperature/Brake force correlation

Brake forces measured during testing with a stuck handbrake (with the original rigging configuration) are analyzed in a separate section. Detailed results relating to each of the above brake rigging performance characteristics are presented below.

5.4.2 B-end Truck Total Normal Brake Forces

EFFECT OF WORN RIGGING COMPONENTS ON B-END TRUCK TOTAL NORMAL BRAKE FORCES

Percent change in the B-end truck total normal brake force, measured after the introduction of worn components, is presented in Table 9. Values in Table 9 are based on total normal brake forces, measured after 40 and 120 seconds of drag braking, averaged for the two repetitions of each test. Absolute value of the average measured truck forces for all rigging conditions and test conditions of speed and applied BCP are presented in Figures 42 and 43.

Table 9. Percent Change In B-end Truck Total Normal Brake Forces with Worn Components

SPEED (mph)	BRAKE CYLINDER PRESSURE (psi)	ELAPSED TIME (sec)	ORIGINAL RIGGING B-END TRUCK TOTAL BRAKE FORCE (lbs)	% CHANGE IN B-END TRUCK TOTAL NORMAL BRAKE FORCE FOR MODIFIED RIGGING CONDITION (AS COMPARED TO THE ORIGINAL RIGGING) RIGGING TYPE 2	RIGGING TYPE 3
20	25	40	3032	-8.9	-40.7
40	25	40	3564	-14.4	-33.3
50	25	40	3622	-15.7	-35.8
20	50	40	6807	-1.4	
40	50	40	7125	-11.6	
50	50	40	7406	-11.4	
20	25	120	3254	-10.5	-36.4
40	25	120	3794	-6.1	-31.7
50	25	120	3824	-8.8	-26.5
20	50	120	7356	-6.1	
40	50	120	8096	-12.6	
50	50	120	8327	-10.9	

RIGGING TYPES:

1 - Original rigging components, B-end leading
2 - Same as No. 1 except live lever with more bend angle and 2 worn pins (top rod/live lever pin and live lever/truck lever connector pin)
3 - Same as No. 1 except live lever with worn pin holes and 5 worn pins (2 top rod pins, 2 truck lever connector pins, and dead lever/anchor pin)

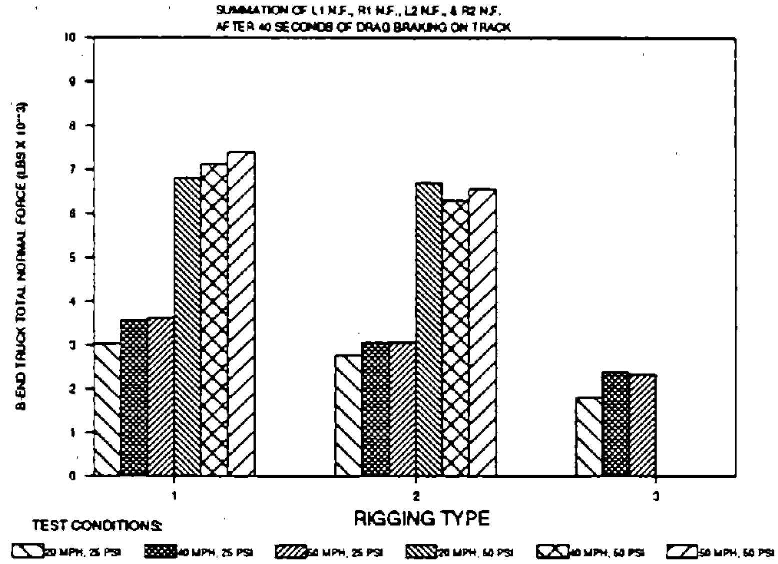


Figure 42. B-end Truck Total Normal Force Measured After 40 Seconds

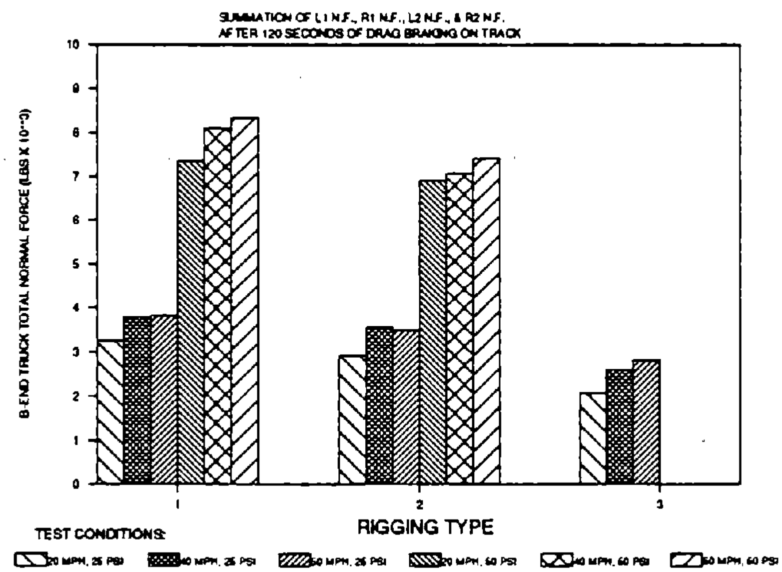


Figure 43. B-end Truck Total Normal Force Measured After 120 Seconds

Both of the worn rigging conditions tested produced lower total brake forces than the original rigging. Rigging condition 3 (worn pins/levers) produced forces which ranged from 26.5 to 36.4 percent less than those produced by the original rigging after 120 seconds of drag braking. Note that this rigging condition was only tested at 25 psi.

Rigging condition 2, (worn pins/bent lever) produced total brake forces which ranged from 6.1 to 12.6 percent less than those produced with the original rigging.

DISCUSSION

Percent change in total truck brake force measured in the on-track tests for the different rigging conditions differed in several respects from those obtained in RDU tests. For the worn rigging conditions evaluated in the on-track test, the percent change in total brake force was negative for all test combinations of running speed and BCP. This was not the case in the RDU tests. In addition, the percent change for rigging condition 3 obtained in the on-track tests were larger (-26.5 to -36.4% vs -24.1 to 21.9%) and fell within a tighter range than those obtained for the corresponding rigging (rigging condition 5) tested on the RDU. The difference in results may be due to the test car running with the B-end leading during track testing while the A-end was leading during RDU testing. In addition, the on-track test environment differed from the RDU test environment in several respects. For example, the rollers of the RDU provide a smoother running surface to the wheels than the track.

EFFECT OF RUNNING SPEED ON B-END TRUCK TOTAL NORMAL FORCES

Total truck brake force measured after 120 seconds of drag braking was observed to increase with running speed for both original and worn rigging conditions. Plots of average truck total brake force versus speed are provided in Figures 44 and 45 for the three rigging conditions tested.

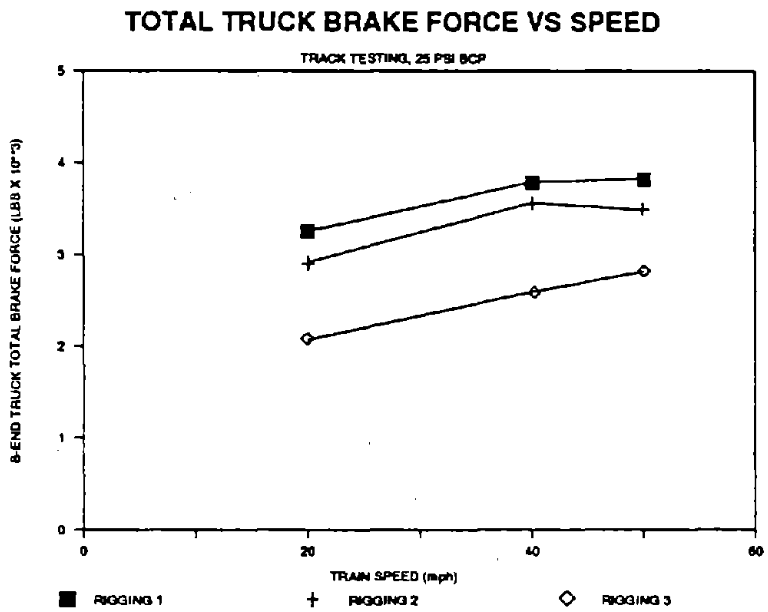


Figure 44. B-end Truck Total Normal Brake Force Measured After 120 Seconds

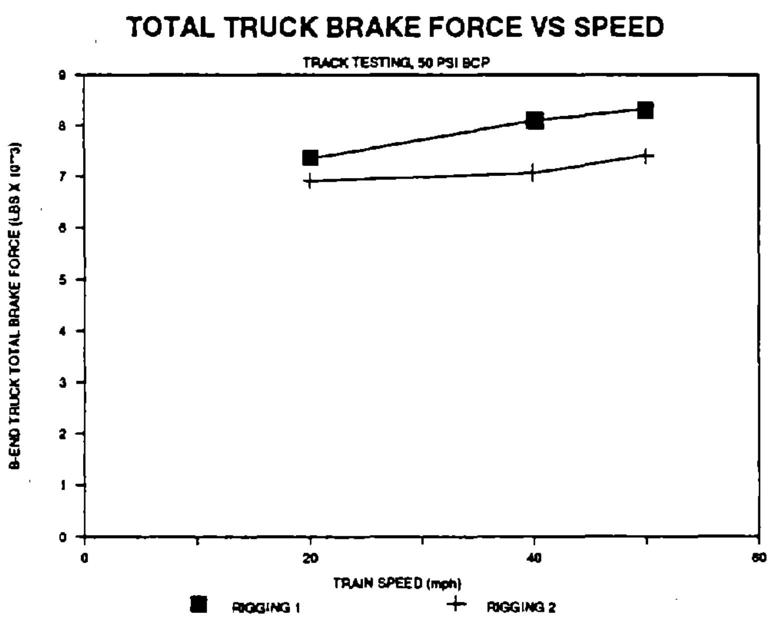


Figure 45. B-end Truck Total Normal Brake Force Measured After 120 Seconds

For rigging condition 2 at 25-psi BCP, the total brake force was 19.7 percent higher at 50 mph than at 20 mph. For the same rigging at 50-psi BCP, the total brake force was 7.4 percent higher at 50 mph than at 20 mph.

DISCUSSION

Running speed was observed to have a similar effect on braking forces during RDU testing. The higher forces, which were measured for higher speeds, are thought to be due to the faster rate of rapping which occurs at those speeds.

EFFECT OF ELAPSED TIME OF DRAG BRAKING ON B-END TRUCK TOTAL NORMAL FORCES

Brake forces were observed to increase during the first two minutes of short term drag braking for all of the rigging conditions tested. However, for many of the tests the car entered a curved section of track after two minutes of braking. Since curving affects the position of the rigging levers, and since the presence of a pressure regulator would tend to neutralize any force changes due to curving, the data collected after 120 seconds elapsed time was not analyzed.

Percent change in the total truck brake forces measured after 40 and 120 seconds of drag braking for all test combinations is given in Figure 46.

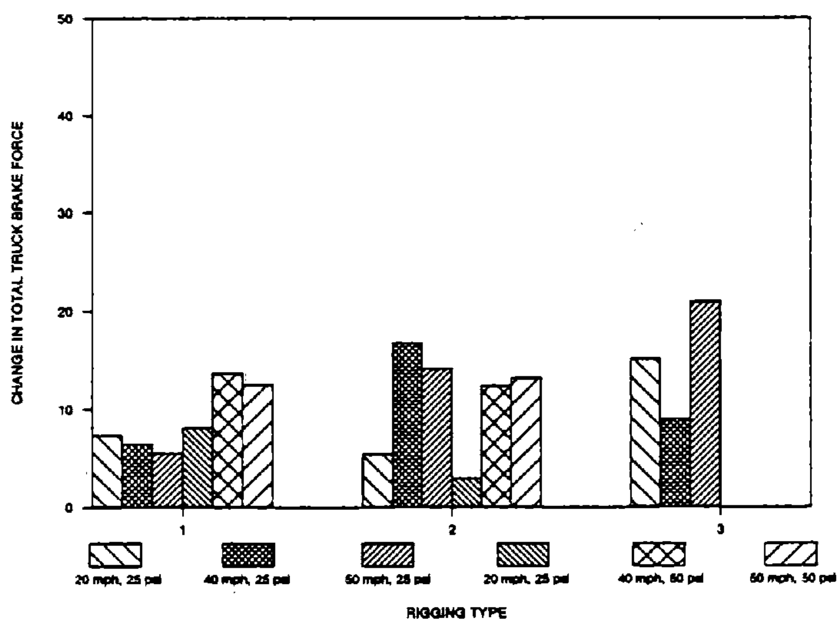


Figure 46. Change in Total Brake Force Measured Between 40 and 120 Seconds, Track Testing

For testing conditions of 50 mph and 25-psi BCP, the percent increase fell in the range from 5.6 (rigging condition 1) to 20.9 percent (rigging condition 3). For testing conditions of 50 psi, 40 and 50 mph, the percent increases for riggings conditions 1 and 2 ranged from 12.3 to 13.6. Rigging condition 3 was not tested at 50 psi.

5.4.3 Wheel-To-Wheel Brake Force Variations Within Truck B

Percent variation in normal brake forces was determined for all combinations of rigging condition, speed, and BCP tested. Table 10 lists the minimum and maximum values of percent variation for each of the rigging types.

Table 10. Minimum and Maximum Percent Variation in Normal Brake Force All Combinations of Rigging, Speed and BCP

Duration (seconds)		Rigging 1	Rigging 2	Rigging 3*
40	MIN	11.7	7.6	13.0
40	MAX	45.8	28.8	93.7
240	MIN	10.7	14.2	36.0
240	MAX	31.7	34.2	92.6

*** Rigging condition 3 was not tested at 50 psi.**

Percent variation for rigging conditions 1 and 2 were of similar magnitude. Rigging condition 3 exhibited the largest wheel to wheel variation in brake forces. It should be noted that rigging condition 3 contained levers with oversize pin holes.

Percent variation in normal brake force for all of the rigging conditions are provided in Table 11. Data in table corresponds to measurements made after 40 and 120 seconds of drag braking.

Table 11. Wheel-to-Wheel Brake Force Variations

SPEED (mph)	BRAKE CYLINDER PRESSURE (psi)	ELAPSED TIME (sec)	RIGGING TYPE 1 TEST 1	RIGGING TYPE 1 TEST 2	RIGGING TYPE 2 TEST 1	RIGGING TYPE 2 TEST 1	RIGGING TYPE 3 TEST 1	RIGGING TYPE 3 TEST 2
20	25	40	45.8	24.9	23.7	13.4	93.7	76.3
40	25	40	27.2	27.5	21.5	28.8	13.0	17.2
50	25	40	14.5	13.0	26.9	27.4	43.8	66.1
20	50	40	14.1	13.8	7.6	8.4		
40	50	40	11.7	14.3	17.9	22.0		
50	50	40	11.8	12.9	12.5	16.5		17.9
20	25	120	30.6	31.7	19.8	34.2	92.6	42.3
40	25	120	19.2	19.6	20.2	23.3	44.7	36.0
50	25	120	14.7	19.4	27.6	30.4	37.6	
20	50	120	25.6	19.0	14.8	14.2		
40	50	120	16.6	24.0	19.0	16.1		
50	50	120	10.7	13.5	15.3	17.9		

RIGGING TYPES:

1 - Original rigging components, B-end leading
2 - Same as No. 1 except live lever with more bend angle and 2 worn pins (top rod/live lever pin and live lever/truck lever connector pin)
3 - Same as No. 1 except live lever with worn pin holes and 5 worn pins (2 top rod pins, 2 truck lever connector pins, and dead lever/anchor pin)

5.4.4 Mechanical Efficiency Losses In Rigging

Data from track testing were used to compute mechanical efficiencies at several points in the brake rigging. The efficiencies were computed from measured brake shoe forces and rigging pin forces and are tabulated in Appendix D.

These efficiencies were used to compute the following efficiency losses:

Loss 1: Between the brake cylinder piston and the top rod/live lever pin

Loss 2: Between the top rod/live lever pin and truck lever beam pins

Loss 3: Between the truck lever beam pins and the brakeshoe/wheel interface

B-end truck rigging efficiencies, as well as the three efficiency losses described above, are given in Appendix F.

EFFECT OF BCP ON BRAKE RIGGING EFFICIENCY

For each of the rigging conditions tested, efficiencies measured for a 50-psi BCP were higher than those measured for 25-psi BCP. The percent increase in rigging efficiency measured between 25- and 50-psi BCP for each of the rigging types is plotted in Figure 47. Values plotted in Figure 47 are based on average efficiencies computed for each pair of tests conducted for each combination of rigging condition, speed, and BCP.

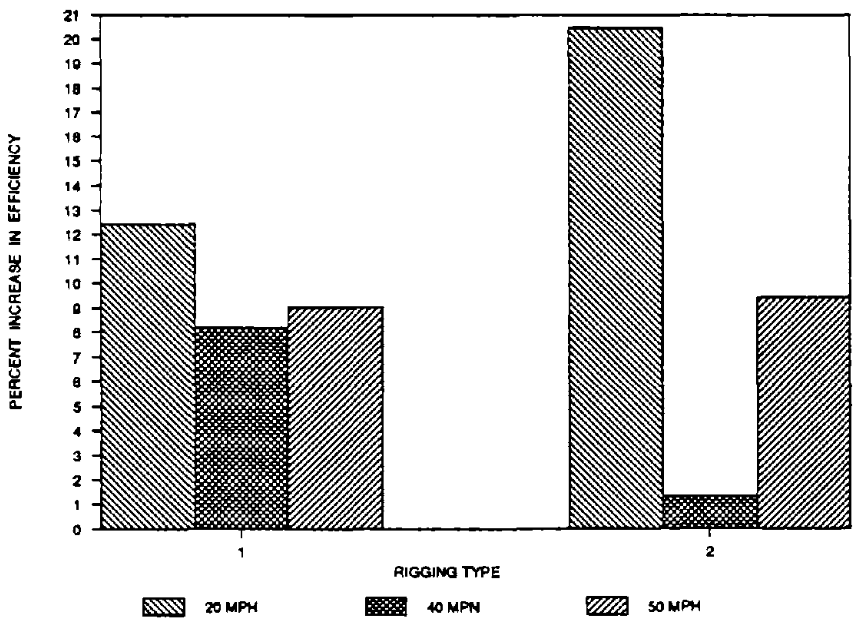


Figure 47. Percent Increase In Efficiency Between 25- and 50-psi BCP, Track Testing

Percent increases ranged from 8.2 to 12.4 for rigging condition 1, and 1.4 to 20.5 for rigging condition 2.

RIGGING EFFICIENCY LOSSES

The range of efficiency losses calculated for each rigging condition is given in Table 12.

Table 12. Percent Rigging Efficiency Losses

Rigging Condition		Rigging Loss 1	Rigging Loss 2	Rigging Loss 3
1	Min	26.0	0.7	0.3
	Max	44.7	6.1	6.4
2	Min	*	*	3.0
	Max	*	*	5.0
3	Min	*	*	0.1
	Max	*	*	6.2

*NOTE: Because the instrumented top rod pin was replaced by worn pins for rigging conditions 2 and 3, it was not possible to compute efficiency for rigging losses No. 1 and 2 for these rigging conditions.

It is seen that, for rigging condition 1, efficiency loss No. 1 ranged from 26.0 to 44.7 percent for the test conditions of 20, 40, and 50 mph, at 25 and 50 psi.

Maximum rigging loss No. 3 varied from 5 percent to 6.4 percent over the three rigging conditions tested.

5.4.5 Wheel Temperature/Brake Force Correlation

Wheel rim temperatures were measured before and after each of the on-track tests. Temperatures were measured in two locations (30° clockwise and 30° counterclockwise from the wheel/rail contact) on the back rim face of each wheel and averaged. Tables 13 and 14 present the average wheel temperatures, along with normal force data (at 120 seconds) for the tests of rigging conditions 1 and 2 respectively.

Table 13. Normal Forces And Wheel Rim Temperatures Measured During On-Track Tests -- Rigging Condition 1

TEST #	SPEED (mph)	BRAKE CYLINDER PRESSURE (psi)	NORMAL FORCE AFTER 120 SECONDS (lbs) <-----LOCATION-----> L1	R1	L2	R2	WHEEL RIM TEMPERATURES MEASURED WITH INFRARED PYROMETER (degrees F) BEFORE TEST <-------LOCATION-------> L1	R1	L2	R2	AFTER TEST <-------LOCATION-------> L1	R1	L2	R2
140	20	25	732	662	829	865								
143			861	716	900	943	70	65	73	69	147	108	129	137
144	40	25	942	884	1038	1054	104	97	110	98	310	180	205	268
145			880	827	989	973	158	146	180	168	241	209	246	231
146	50	25	914	927	1048	1031	112	104	114	109	253	232	341	246
147			854	912	1019	944	149	138	173	154	261	197	332	269
148	20	50	1755	1658	2082	1877	144	126	152	144	353	337	362	260
149			1754	1673	1990	1923	169	179	209	187	355	273	428	331
150	40	50	1905	2086	2222	2042	209	177	219	194	314	258	390	290
151			1829	1887	2268	1954	174	154	213	170	316	284	309	315
152	50	50	2035	2087	2215	2253	65	63	66	62	277	305	248	337
154			1927	1914	2171	2053	129	118	129	128	455	265	368	328

Table 14. Normal Forces And Wheel Rim Temperatures Measured During On-Track Tests -- Rigging Condition 2

TEST #	SPEED (mph)	BRAKE CYLINDER PRESSURE (psi)	NORMAL FORCE AFTER 120 SECONDS (lbs) <-----LOCATION-----> L1	R1	L2	R2	WHEEL RIM TEMPERATURES MEASURED WITH INFRARED PYROMETER (degrees F) BEFORE TEST <-------LOCATION-------> L1	R1	L2	R2	AFTER TEST <-------LOCATION-------> L1	R1	L2	R2
155	20	25	727	696	824	688	120	123	127	126	159	139	172	148
156			729	599	804	756	129	115	134	127	181	178	206	191
157	40	25	846	819	985	926	132	124	143	131	250	196	266	282
158			854	786	969	938	168	177	183	180	246	184	321	293
159	50	25	899	853	1088	948	189	164	205	177	227	281	326	282
160			766	698	911	810								
161	20	50	1629	1715	1870	1681	60	60	60	60	260	195	272	237
162			1658	1647	1881	1740	155	126	163	157	357	275	331	337
163	40	50	1757	1652	1966	1901	189	136	213	186	362	285	420	372
164			1650	1628	1889	1707	182	155	197	173	303	239	325	336
165	50	50	1793	1765	2034	1845	164	147	181	161	239	256	305	332
166			1750	1739	2051	1860	243	202	257	216	292	239	330	340

A review of the data revealed maximum wheel temperatures measured after the test did not necessarily correspond to the wheel location where the largest brake force was measured. Many of the tests are not directly comparable due to (1) different initial wheel temperatures, and (2) different test durations.

In all of the tests conducted with rigging conditions 1 and 2, it may be noted the sum of the brake forces L2 and R2 was greater than the sum of the L1 and R1 forces, as expected. For those same tests, the maximum wheel temperatures most frequently occurred on either wheel L2 or R2 (17 out of 22 tests). A more specific correlation was not evident.

A gross comparison may be made between wheel temperatures and brake forces for tests with the same train speed and different applied brake cylinder pressures. In most cases, brake forces produced by a 50-psi BCP were more than double those produced by a 25-psi BCP. For a given test speed, the post test wheel temperatures were appreciably higher for the higher pressures.

5.4.6 Engaged Handbrake Test

The engaged handbrake test consisted of accelerating the consist to 50 mph with the handbrake applied and then allowing the consist to come to a stop. Brake forces measured during the engaged handbrake test are plotted in Figure 48. The data correspond to forces which were measured (1) after the consist attained a 50-mph speed from a stopped position, and (2) at the point in time when the sum of the B-end truck normal forces reached a peak value. Brake force data from on-track test runs 152 and 154 are also shown in Figure 48.

It is seen that brake forces measured during drag braking with 50-psi BCP were similar to those measured for the engaged handbrake.

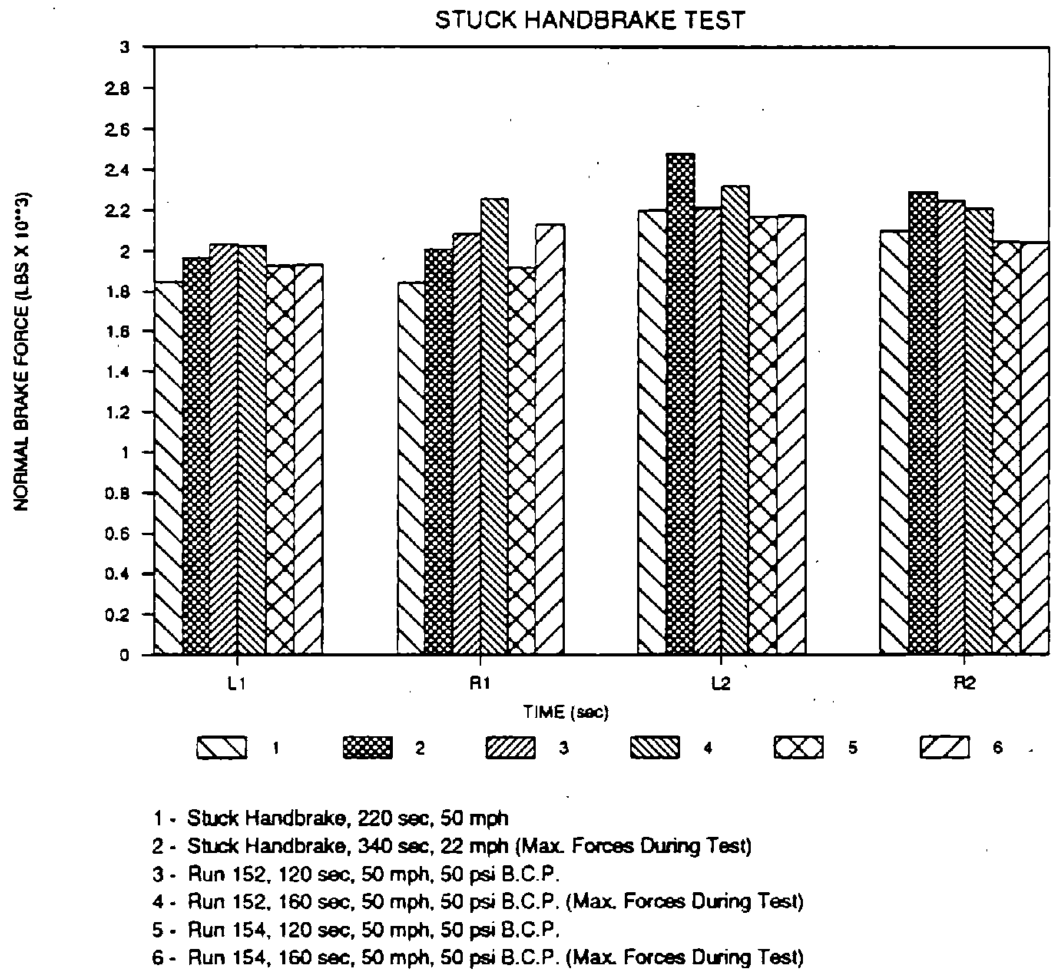


Figure 48. Handbrake Forces vs Drag Braking ForcesFor Runs 152 and 154

5.5 CONCLUSIONS FROM ON-TRACK BRAKING TESTS

Analysis of the on-track test data support the following conclusions:

- The two worn rigging conditions tested produced substantially lower forces than the original rigging. The lowest forces resulted from the use of truck levers with oversize pin holes and five worn rigging pins.
- Brake forces were observed to increase during the first several minutes of a brake application as a result of rapping. This rapping was observed to occur at a faster rate for higher test speeds.

- Each of the brake rigging conditions produced an uneven distribution of forces within the B-end truck. Rigging containing a truck lever with oversize pin holes and worn rigging pins produced force variations which fell in the range of 36 percent to 93 percent for a given test speed and BCP.
- The bulk of the rigging efficiency losses occurred between the brake cylinder and the top rod pin.

6.0 DRAG BRAKING TESTS ON DYNAMOMETER

6.1 BRAKE SHOE COEFFICIENT OF FRICTION TESTS

6.1.1 Objective

Brake shoe tests were conducted to evaluate the performance of several brands of brake shoes under extended drag braking conditions.

6.1.2 Test Procedure

Brake shoes were tested with an applied normal brake force of 1500 pounds and a wheel rotational speed corresponding to 40 mph for a period of 45 minutes.

A set of three shoes were tested from each of three manufacturers. Prior to testing, each of the shoes were worn to fit the cylindrical tread profile of a 33 inch diameter wheel. The dynamometer was then brought up to a 40-mph wheel speed and the brake was applied with the test shoe in place. Brake force and braking torque data were sampled once a second and averaged over 5 minute intervals using the dynamometer instrumentation/data collection system. Brake shoe coefficient of friction (COF) values were calculated from the measured brake forces and torques.

6.1.3 Results

Test results are given in Figures 49, 50, and 51 and in Table 15. Three brands of brakeshoes were generically designated as Brand A, Brand B, and Brand C.

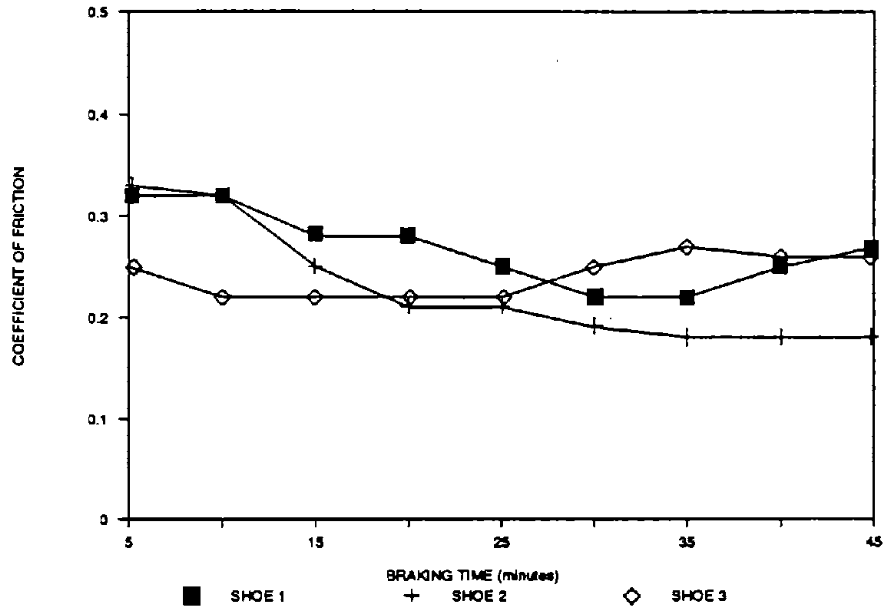


Figure 49. Brake Shoe Coefficient Of Friction vs Time, Brand A Shoes

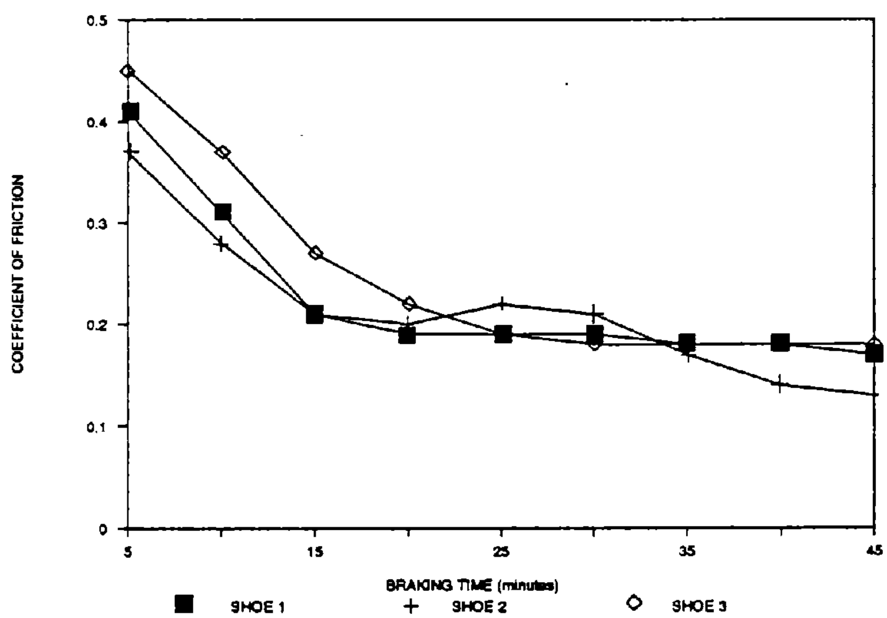


Figure 50. Brake Shoe Coefficient Of Friction vs Time, Brand B Shoes

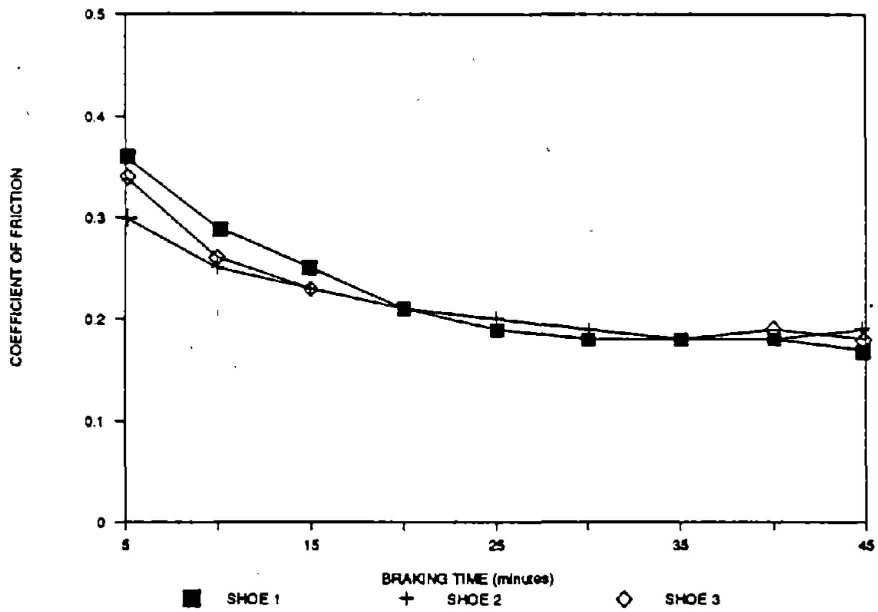


Figure 51. Brake Shoe Coefficient Of Friction vs Time, Brand C Shoes

Table 15. Brake Shoe Coefficient of Friction 40 mph, 1500 pounds. Brake Force Drag Braking Test

<-------------------Brake Shoe Coefficient Of Friction------------------->

TIME (min)	Brand A Shoe No. 1	Brand A Shoe No. 2	Brand A Shoe No. 3	Brand B Shoe No. 1	Brand B Shoe No. 2	Brand B Shoe No. 3	Brand C Shoe No. 1	Brand C Shoe No. 2	Brand C Shoe No. 3
5	0.32	0.33	0.25	0.41	0.37	0.45	0.36	0.3	0.34
10	0.32	0.32	0.22	0.31	0.28	0.37	0.29	0.25	0.26
15	0.28	0.25	0.22	0.21	0.21	0.27	0.25	0.23	0.23
20	0.28	0.21	0.22	0.19	0.2	0.22	0.21	0.21	0.21
25	0.25	0.21	0.22	0.19	0.22	0.19	0.19	0.2	0.19
30	0.22	0.19	0.25	0.19	0.21	0.18	0.18	0.19	0.18
35	0.22	0.18	0.27	0.18	0.17	0.18	0.18	0.18	0.18
40	0.25	0.18	0.26	0.18	0.14	0.18	0.18	0.18	0.19
45	0.27	0.18	0.26	0.17	0.13	0.18	0.17	0.19	0.18
Average	0.27	0.23	0.24	0.23	0.22	0.25	0.22	0.22	0.22

Brand A shoes exhibited the smallest decrease in coefficient of friction values during extended braking (fade) of the three brands that were tested. However, these shoes were also the most inconsistent in performance, as judged by the spread in COF values for the three tested shoes. Average values for the 45 minute test period were 0.27, 0.23, and 0.24, respectively.

Brand B shoes exhibited the least resistance to fade in COF values. During the first 5 minutes of testing, the COF values ranged from 0.37 to 0.45. During the last 5 minutes of testing, the values ranged from 0.13 to 0.18.

Brand C shoes exhibited the most consistent COF characteristics of the three brands. There was very little difference in performance from one shoe to the next. These shoes also exhibited a substantial fade in COF values during the 45 minute tests.

6.2 BRAKE SHOE PLACEMENT TESTS

6.2.1 Introduction

During ideal service conditions, brake shoes are centered on the wheel treads. However, because of truck component tolerances and wear, the shoes can be placed slightly to one side or the other with respect to the tread center. Such placement is believed to be partly responsible for unequal heating of wheels. Analytical studies have shown that an extreme misalignment of the brake shoe produces higher wheel rim temperatures.[5] To evaluate the effects of extreme brake shoe placement on wheel tread temperatures, four wheels were tested on the brake dynamometer.

6.2.2 Test Procedure

Two wheels were tested with an extreme overhanging brake shoe position (center of shoe at end of tread/front face radius), and two wheels were tested with an extreme overriding position (inner edge of shoe aligned with flange tip); the same positions used in the previous analytical study. These positions represent an extreme condition which rarely (if ever) occurs in service with the standard three-piece truck. Previously, as part of the WFW Program, two identical wheels were tested with the brake shoe centered on the tread. Straight and S-plate, J-33 wheels were tested. For all the tests, the dynamometer track wheel was not used in order to reduce thermal energy dissipation (and maximize wheel temperatures) as earlier tests showed that approximately 15 percent of thermal energy created by drag braking was dissipated through conduction at the wheel/rail interface.[6]

Tests consisted of 25 repeated drag cycles with a brake force of 1500 pounds and a speed of 40 mph. The intended braking time for these H-2 (1 1/2 inch thick) shoes was 45 minutes.

However, this time was not usually obtained because of rapid brake shoe wear. The test wheel was cooled with water after each braking cycle. A sliding thermocouple was positioned on the tread at midwidth of the heated portion to provide a measure of tread temperature.

6.2.3 Results

Representative dynamometer records are presented in Appendix G, and complete records are on file at the AAR's CTC. Test results are summarized in Table 16. The duration of each test and maximum tread temperature is shown for each of the wheels tested. Data obtained during previous WFM tests for centered brake shoes are included in the table.

A review of the data reveals that higher tread temperatures were obtained during testing of a S-plate wheel with the overhanging shoe condition as opposed to the overriding condition. The temperatures were approximately 100° F higher than for the former conditions.

During the above tests with the brake shoe placed in both off-center positions, rapid disintegration of the brake shoes was observed. In several cases the useful life of a given brake shoe was less than 15 minutes, after which steel-on-steel contact would occur between the brake shoe backing and the wheel tread. (It should be noted, however, the dynamometer tests were conducted without a rail wheel, which would normally provide a heat sink.)

Table 16. Maximum Wheel Tread Temperatures vs Brake Shoe Position
S-Plate and Straight Plate Wheels

Serial No.	49547		49544		49550		5576		4907		5584	
Plate Shape	Straight		Straight		Straight		S		S		S	
Shoe Position	Over Hanging		Centered		Over Riding		Over Hanging		Centered		Over Riding	
Test No.	TEST DURATION (min.)	MAX. TREAD TEMP. (deg. F)	TEST DURATION (min.)	MAX. TREAD TEMP. (deg. F)	TEST DURATION (min.)	MAX. TREAD TEMP. (deg. F)	TEST DURATION (min.)	MAX. TREAD TEMP. (deg. F)	TEST DURATION (min.)	MAX. TREAD TEMP. (deg. F)	TEST DURATION (min.)	MAX. TREAD TEMP. (deg. F)
1	18	689	45	900	36	658	14	477	45	610	4	200
2	12	696	45	745	4	271	30	811	45	695	10	526
3	28	779	45	795	8	704	32	806	45	730	16	648
4	42	763	45	725	12	469	30	844	45	775	22	676
5	36	750	45	725	45	778	32	801	45	705	26	696
6	34	781	45	750	45	728	28	831	45	620	26	685
7	30	762	45	740	20	687	30	815	45	600	28	705
8	32	761	45	760	45	806	28	822	45	590	28	700
9	32	737	45	630	38	805	30	844	45	600	30	715
10	32	760	45	715	32	785	32	801	45	600	30	714
11	32	804	45	700	45	815	28	823	45	595	12	323
12	32	780	45	815	45	789	30	806	45	600	20	700
13	34	774	45	860	45	805	26	830	45	590	32	736
14	34	756	45	790	42	796	30	804	45	600	34	739
15	32	777	45	825	45	804	28	835	45	600	16	396
16	28	802	45	650	45	821	30	831	45	600	36	742
17	32	771	45	635	45	835	26	840	45	605	32	733
18	34	787	45	600	45	841	30	821	45	600	34	746
19	28	786	45	695	30	767	26	829	45	600	36	777
20	28	797	45	810	34	822	32	823	45	600	24	652
21	26	790	45	710	36	869	28	836	45	600	36	770
22	30	812	45	750	28	844	28	823	45		30	732
23	30	780	45	800	28	783	28	863	45		30	710
24	30	775	45	745	15	819	30	801	45		4	175
25	30	778	45	820	24	715	28	829	45		30	732
AVERAGE	30	770	45	748	33	753	29	810	45	625	25	637

6.3 BRAKE SHOE METAL PICKUP TESTS

6.3.1 Objective

The objective of this test was to determine the effect of metal pickup on the coefficient of friction of composition brake shoes. During earlier braking tests conducted at Peotone and Pueblo, the surfaces of certain brakeshoes were found to be impregnated with metal.

6.3.2 Test Procedure

A series of braking tests were conducted on the Brake Dynamometer in an attempt to reproduce the metal pickup condition which was observed in previous tests. The condition could not be reproduced; therefore, metal pickup was simulated by drilling ten 1/2 inch diameter holes in the face of a brake shoe and cementing steel rods in the holes. Prior to drilling the shoe, six dry stop tests were conducted with an initial speed of 50 mph, a brake shoe force of 2000 pounds, and an equivalent wheel load of 21,000 pounds. Similar tests were conducted after the rods were inserted. The dynamometer data acquisition system was used to determine maximum, minimum, and average braking torque values during each of the tests.

6.3.3 Results

Results from the brake shoe metal pickup tests are given in Table 17. Braking torques developed during the stop tests were essentially the same before and after steel was embedded in the shoe surface. Therefore, the presence of approximately 2 square inches of steel on the brake shoe surface had little observed effect on the brake shoe coefficient of friction during stop braking tests.

Table 17. Brake Shoe Test Data Shoes With and Without 2 Square Inches of Steel Embedded In Shoe

STOP TEST NO.	INITIAL SPEED (rpm)	INITIAL SPEED (mph)	REV'S TO STOP	STOP DIST. (ft)	STOP TIME (sec)	MAX. TORQUE (lb-ft)	AVG. TORQUE (lb-ft)	AVG. FORCE (lb)	REL. SPEED (rpm)	CYCLE TIME (sec)	MIN. TORQUE (lb-ft)	INITIAL TORQUE (lb-ft)	MIN. FORCE (lb)	MAX. FORCE (lb)	INITIAL FORCE (lb)	INITIAL TEMP. (deg. F)	FINAL TEMP. (deg. F)
BEFORE STEEL PLUGS EMBEDDED IN BRAKE SHOE																	
1	506	50.1	266.2	2320	64.2	920	840	2000	2	0	760	800	1870	2120	1930	30	0
2	503	49.8	270.4	2357	63.98	1000	850	2000	2	1884	770	770	1870	2120	1880	99	209
3	509	50.4	281.8	2456	65.63	990	830	1980	2	330	430	430	1000	2130	1000	113	216
4	507	50.2	273.7	2385	63.52	1070	880	2000	1	409	760	760	1870	2130	1900	117	228
5	509	50.4	271.2	2364	62.55	1110	890	2000	2	416	770	770	1870	2120	1910	114	223
6	510	50.5	269.8	2351	62.14	1140	900	2000	2	398	760	770	1870	2130	1870	114	253
AFTER STEEL PLUGS EMBEDDED IN BRAKE SHOE *																	
4	506	50.1	250.2	2181	57.26	1240	960	1980	2	0	450	460	970	2.11	980	100	203
5	508	50.3	264.1	2302	60.65	1140	930	2000	1	348	800	800	1870	2.12	1930	109	234
6	509	50.4	267.3	2330	61.04	1130	920	2000	2	412	790	790	1880	2.12	1940	107	232
7	509	50.4	267.9	2335	61.32	1140	920	2000	2	416	690	690	1600	2.12	1600	108	225
8	510	50.5	269.6	2350	61.48	1130	920	2000	2	406	770	770	1870	2.12	1880	103	225
9	513	50.8	266.1	2319	60.08	1200	930	1990	2	1067	530	530	1180	2.12	1180	108	222

* Three preliminary stops were used to break in steel plugs.

7.0 OVERVIEW OF THE RESULTS

A braking test program was conducted to investigate the extent and causes for significant variations in braking thermal input to rail car wheels. The program consisted of the following tasks:

- Brake force data were reviewed from previous test programs and computer simulation of brake forces in several types of conventional brake rigging was performed.
- Analytical and experimental investigations were conducted to evaluate the effect of worn components on the distribution of brake forces for a conventional brake rigging containing bent, unequal length truck levers.
- Tests were performed to determine the effect of shoe placement on wheel temperatures developed during drag braking conditions, the friction characteristics of three brands of brakeshoes during extended drag braking, and the friction characteristics of brakeshoes with simulated metal pickup.

The freight car utilized during testing was equipped with conventional rigging with the truck lever connection through the bolster and bent, unequal length truck levers. This particular rigging was known to have the following characteristics which result from the design geometry:

- During a brake application, a thrust force was produced which tended to displace each of the brake beams laterally. As a result, the brake shoes tended to ride in an off-center position with respect to the wheel sets, with one shoe riding closer to the flange and the other shoe riding closer to the outer edge of the tread.
- Bending moments were produced which tended to rotate the brake beams about the vertical axis. This had the effect of increasing the brake force on one side of the beam and decreasing the brake force on the opposite side.
- A review of brake force data obtained during four previous brake tests revealed that none of the measured brake forces were excessively large in relation to AAR prescribed limits for freight car brake ratios. However, in some cases the largest brake force occurring within the car was approximately 28 percent larger than the smallest.
- Both experimental data and preliminary analysis of the rigging design indicated conventional brake rigging with bent, unequal length levers was more likely to produce an uneven distribution of braking forces compared to other brake rigging designs. Therefore, the above rigging was selected for the RDU and on-track tests.

7.1 MODELING RESULTS

Results of brake force model simulations performed to evaluate the effect of worn components on brake forces for a specified brake cylinder pressure are presented below:

- The majority of wear conditions resulted in a decrease in brake forces throughout the car.
- The presence of a truck lever with a large degree of bend slightly increased the brake forces on one side of a beam and decreased forces on the other side.
- Maximum B-end truck brake forces were predicted to be approximately 4 percent larger than the smallest brake forces for each of the wear conditions which were modeled. Thus, the presence of worn dimensions did not appear to affect the wheel-to-wheel variation in brake forces.

7.2. RDU AND ON-TRACK TESTS

A major portion of the program consisted of a series of short term drag braking tests performed on the RDU and on the TTT. The B-end of the test car was equipped with instrumented brake heads, and drag braking tests were performed with several combinations of worn components installed in the B-end truck rigging. In all, six combinations of worn rigging components were tested on the RDU. After a review of the results obtained during the RDU testing phase, two combinations of worn components which appeared to produce substantial changes in brake forces were selected for evaluation in the on-track tests. Results from the RDU and on-track tests may be summarized as follows:

- The type of brake rigging tested (rod-through bolster, with bent, unequal length levers) produced an uneven distribution of brake forces when tested with as-received components and with several combinations of worn components in laboratory and track tests.
- Installation of worn levers and pins resulted in a substantial decrease in brake forces developed during drag braking tests on track. The presence of a bent live truck lever with two worn pins decreased brake forces by approximately 10 percent (as compared to the as-received components) for a range of test speeds and applied brake cylinder pressures. The presence of a lever with an over-size pin hole in combination with five worn pins decreased brake forces by approximately 30 percent.

- During static brake force measurements, rapped brake forces were observed to be approximately twice the magnitude of unrapped forces. Rapped brake forces are representative of service conditions.
- Brake forces were observed to increase steadily during the first several minutes of a brake application before reaching a peak value. This gradual increase was observed for virtually every testing condition of train speed and BCP.

7.3. <u>BRAKE DYNAMOMETER TESTING</u>

In addition to the tests that were performed at TTC, a number of braking tests were performed at CTC. In the first test series on the CTC dynamometer, the coefficient of friction of three brands of brake shoes was measured during 45 minutes of drag braking at a speed of 40 mph with a normal shoe force of 1500 pounds. Three shoes of each brand were tested.

Coefficient of friction of each of the shoes tested, decreased from its initial value to a steady state lesser value after 25 minutes of drag braking. For example, the average coefficients of friction that were measured, between 20 and 25 minutes at 40 mph and 1500-pound brake force, fell in the range between 0.19 and 0.25.

Thus, for the given applied normal braking force, the shoe that exhibited a 0.25 coefficient of friction developed 32 percent more braking horsepower than the shoe with the 0.19 coefficient of friction during the 20- and 25-minute test periods. During the last 5-minute period of the testing (between 40 and 45 minutes elapsed time), the coefficients fell in a substantially broader range from 0.13 to 0.27. Under less severe drag braking conditions the differences in coefficients of friction are likely to be less.

8.0 OVERVIEW, CONCLUSIONS AND RECOMMENDATIONS

One goal of the present test program was to identify possible modifications to brake rigging equipment and/or operating procedures that would produce a relatively even distribution of braking forces within a given freight consist. This section presents an overview of factors affecting the distribution of braking forces and resulting thermal input to wheels. This is followed by conclusions and recommendations for improving the performance of freight car air brakes in revenue service operations. Future research needs are also identified.

8.1 OVERVIEW OF CAUSES OF VARIATIONS OF NON-UNIFORM BRAKING FORCES

Braking thermal input to wheels is proportional to normal brake force, brake shoe coefficient of friction, and train speed. Preceding sections of this report have quantified the following:

- Wheel-to-wheel brake force variations for a test car with body-mounted brake rigging containing bent, unequal length truck levers for a wide range of brake cylinder pressures and train speeds in tests conducted on the RDU and the TTT.
- The effect of worn rigging components on total car brake forces.
- Friction characteristics of three types of composition brake shoes during extended drag braking conditions on the Brake Dynamometer at the CTC.

Based on the extensive data which has been compiled during the current test program and in previous programs, it is now possible to quantify many of the factors affecting the normal brake forces and brake shoe coefficients of friction attained during drag braking. Table 18 presents the approximate percent variation in brake forces which may be expected for a number of control factors. It may be noted that, in addition to the factors described in Table 18, braking ratios, defined as the total car brake force divided by the gross car weight, for loaded cars may vary throughout a given consist within the AAR prescribed limits of 6.5 to 10 percent. If one car within a consist were to have a brake ratio of 6.5 percent while another car, of equal weight, were to have a 10 percent brake ratio, the total brake force in the second car would be 54 percent more than in the first car.

Table 18. Factors Affecting Wheel-to-Wheel and Car-to-Car Variations in Brake Force.

FACTOR ↓ / RESULT →	% Difference Between Maximum And Minimum Total Brake Forces	% Difference Between Maximum And Minimum Brake Forces Within A Freight Car	Source
Malfunctioning/ Improper setting Of Dual Capacity Brake Equipment	40		1
Extreme Wear In Rigging Pins And Truck Levers	30 *		2
Rigging Design: Conventional Body-Mounted Brake Rigging With Bent Unequal Length Levers (50 psi Brake Cylinder Pressure)		20 *	3
Brakeline Pressure Losses (Full Service Reduction From 75 psi Initial Brakeline Pressure 5 psi Loss From Loco To Caboose.)	7 **		4
Train Speed 20 - 50 mph (50 psi Brake Cylinder Pressure). Conventional Body-Mounted Brake Rigging With Bent Unequal Length Levers	15 *		5

* Extracted From Test Data ** Calculated

<u>Sources For Values In Table 18</u>

1. Blaine, D. *Modern Freight Car Air Brakes*; see reference 9
2. Section 5 of this report
3. Sections 4, 5 of this report

Table 19 presents the approximate percent variation in coefficient of friction which may be expected for composition brake shoes during extended drag braking. Values are based on brake force measurements performed during tests on the CTC Brake Dynamometer and on track at TTC.

Table 19. Factors Affecting Brake Shoe Coefficient of Friction.

RESULT → / FACTOR ↓	% Difference Between Maximum and Minimum Coefficient of Friction	% Decrease in Coefficient of Friction	Source
Variable Friction Properties Of Composition Brakeshoes During Extended Drag Braking			
After 20 min Braking On Track With 2300 lb Brake Force at 20 mph	30 *		6
After 20 min Braking on CTC Roll Dynomometer With 1500 lb Brake Force at at 40 mph	47 *		7
Moisture On Wheel Tread Surface		60 *	8
* Extracted From Test Data		** Calculated	

Sources For Values In Table 19

4. AAR Report R-497; see reference 8
5. Section 6 of this report

Data provided above may be used to obtain a general picture of factors affecting brake forces and brake shoe coefficients in body mounted freight car rigging. Note the test car used in the testing program contained bent, unequal length levers. Other types of body mounted rigging containing straight, equal length levers could be expected to produce somewhat less wheel-to-wheel variation in brake forces.

8.2 CONCLUSIONS

- Worn rigging conditions result in a decrease of brake forces and therefore do not result in excessive wheel heating for a car with worn rigging components.

- Unequal length bent truck levers can produce substantial wheel-to-wheel force variations during drag braking conditions.
- The presence of levers with oversize pin holes and worn pins installed can increase the wheel-to-wheel variation in brake forces.
- Misaligned brake shoes wear at accelerated rate which can result in metal-to-metal contact as the shoe wears to the backing.
- During full service drag braking conditions, the wheel to wheel variation in brake shoe coefficient which may occur is on the order of 30 percent.
- During drag braking conditions, the coefficient of friction of a given brake shoe decreases from a starting value at brake application to a lower steady state value. Decrease in coefficient which occurs as the brakeshoe temperature rises effectively places an upper limit on the amount of thermal input to the wheel which can be sustained.

8.3 RECOMMENDATIONS

Achieving a uniform distribution of brake forces within a given freight car consist is desirable from several standpoints. Occurrence of non-uniformly distributed brake forces within a drag braking consist will produce higher individual brake forces than would be required if braking were uniform. Higher individual brake forces may be expected to produce higher wheel temperatures and accelerated wear of the brake shoe and wheel tread. For cases of extreme wheel heating, there is the possibility of producing tensile, crack-opening stresses in the rim of the wheel.

The following strategies are recommended as a means for producing the most uniform possible distribution of forces within a freight consist and for reducing the possibility of excessive thermal input to wheels during drag braking.

- Where possible, newly specified rigging should exhibit less than a 10 percent wheel-to-wheel variation in forces. In this regard, the use of bent, unequal length levers should be avoided in conventional rigging.
- Worn truck levers and pins should be replaced as per AAR maintenance specifications.
- Consideration should be given to the possibility of amending brake equipment specifications to include maximum wheel-to-wheel variation in rapped brake forces measured with static load cells.

- Consideration should be given to the possibility of examining brake shoe certification Dynamometer tests to determine if the variation in friction coefficients can be reduced.

8.4 FUTURE RESEARCH NEEDS

The following tasks are suggested for further research to gain further understanding of the distribution of brake forces and wheel temperatures which develop within a freight consist during extended drag braking.

- Examine derailment reports for correlation between wheel failures and type of brake rigging mounted on cars containing failed wheels.
- Measure wheel temperatures of a drag braked train in cars equipped with several types of body and truck mounted rigging. Measurements should be performed for several representative grades.
- Investigate possible measures to increase heat dissipation from wheels during extended drag braking.
- Propose and test modifications to car mounted brake rigging to achieve a more uniform distribution of brake forces.
- Investigate alternative brake system technologies which eliminate the direct contact between the brake shoes and the wheel tread.

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APPENDIX A

Drag Braking and Data Computed
Parameters From Testing on the R.D.U.

DRAG BRAKING DATA FROM TESTING ON R.O.U.   DATA COLLECTED AFTER 40 SECONDS OF DRAG BRAKING

TEST PARAMETER	1		2		3		4		5		6		7		8	
	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2
TEST #	53	54	38	39	65	66	71	72	85	86					102	102
SPEED (mph)	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.8					19.9	19.9
BRAKE CYLINDER PRESSURE (psi)	25.7	25.5	25.1	24.9	25.7	25.8	25.4	25.8	25.7	25.3					25.6	25.3
ELAPSED TIME (sec)	40	40	40	40	40	40	40	40	40	40					40	40
RIGGING TYPE	1	1	2	2	3	3	4	4	5	5					8	8
WHEEL L1 NORMAL FORCE	739	738	729	719	746	701	626	722	508	539					509	540
WHEEL R1 NORMAL FORCE	793	803	681	710	746	727	675	666	494	499					710	787
WHEEL L2 NORMAL FORCE	842	795	789	801	836	808	806	858	791	795					846	835
WHEEL R2 NORMAL FORCE	947	895	758	772	865	817	780	810	727	740					841	860
MAXIMUM N.F./MINIMUM N.F.	1.19	1.21	1.16	1.13	1.14	1.17	1.29	1.26	1.60	1.63					1.44	1.38
TOTAL NORMAL FORCE TRUCK B	3396	3235	2958	3002	3195	3063	2887	3056	2520	2563					2986	3172
TOTAL ESTIMATED FORCE TRUCKS A & B	6551	6234	5709	5794	6169	5911	5573	5659	4863	4946					5762	6122
OVERALL CAR LEVER EFFICIENCY	49.3	47.3	44.0	45.9	45.2	44.3	42.4	43.9	36.5	37.8					43.5	46.7
MEASURED EFFICIENCY AT TOP ROD/LIVE LEVER PIN	59.4	57.3	55.4	57.2	55.3	53.7	53.2	53.9							55.7	57.2
MEASURED EFFICIENCY AT TRUCK LEVER/BEAM PINS	52.6	52.3	49.8	51.1	51.8	49.8	49.2	47.2	43.4	45.7					49.9	51.7
MEASURED EFFICIENCY AT SHOE/WHEEL INTERFACES	51.1	48.9	45.6	46.5	42.0	45.9	43.9	45.5	37.8	39.2					45.0	49.3
LOADED BRAKE RATIO	2.49	2.37	2.17	2.20	2.35	2.25	2.17	2.23	1.85	1.88					2.19	2.33
EMPTY BRAKE RATIO	10.80	10.27	9.40	9.54	10.16	9.74	9.18	9.65	8.41	8.15					9.49	10.29
L1-R1 BEAM PIN FORCE	1768	1779	1679	1680	1512	1700	1654	1613	1544	1608					1575	1722
L1 N.F. + R1 N.F.	1607	1540	1410	1429	1492	1430	1301	1388	1002	1028					1299	1427
L2-R2 BEAM PIN FORCE	1729	1670	1554	1617	1643	1621	1383	1534	1344	1384					1638	1640
L2 N.F. + R2 N.F.	1759	1690	1548	1573	1704	1625	1586	1647	1518	1535					1567	1745
DEAD LEVER - ANCHOR PIN FORCE	915	910			929	693	541	855							665	917
LIVE LEVER - TOP ROD PIN FORCE	770	945	899	923	920	895	874	893							925	975
L2 INSTRUMENTED BRAKEHEAD TEMPERATURE	90	106	161	152	77	52	96	81	96	100					77	93
TEST #	57	58	44	45			75	76								
SPEED (mph)	39.8	39.9	39.8	39.9			39.3	39.9								
BRAKE CYLINDER PRESSURE (psi)	25.6	25.4	24.9	24.6			25.8	26.0								
ELAPSED TIME (sec)	40	40	40	40			40	40								
RIGGING TYPE	1	1	2	2			4	4								
WHEEL L1 NORMAL FORCE	930	873	742	745			683	682								
WHEEL R1 NORMAL FORCE	864	858	802	775			763	662								
WHEEL L2 NORMAL FORCE	859	853	833	814			815	823								
WHEEL R2 NORMAL FORCE	941	896	792	776			782	794								
MAXIMUM N.F./MINIMUM N.F.	1.09	1.08	1.12	1.09			1.19	1.24								
TOTAL NORMAL FORCE TRUCK B	3593	3410	3169	3110			3043	2961								
TOTAL ESTIMATED FORCE TRUCKS A & B	6935	6559	6117	6003			5873	5715								
OVERALL CAR LEVER EFFICIENCY	52.3	50.5	47.6	47.1			44.1	42.4								
MEASURED EFFICIENCY AT TOP ROD/LIVE LEVER PIN	59.3	59.2	59.1	58.6			53.6	53.4								
MEASURED EFFICIENCY AT TRUCK LEVER/BEAM PINS	53.5	53.7	53.8	54.9			46.1	45.2								
MEASURED EFFICIENCY AT SHOE/WHEEL INTERFACES	54.1	52.3	49.2	48.7			45.6	43.9								
LOADED BRAKE RATIO	2.64	2.52	2.35	2.28			2.23	2.17								
EMPTY BRAKE RATIO	11.43	10.94	10.09	9.97			9.68	9.42								
L1-R1 BEAM PIN FORCE	1826	1828	1771	1775			1574	1503								
L1 N.F. + R1 N.F.	1793	1751	1544	1520			1445	1345								
L2-R2 BEAM PIN FORCE	1717	1705	1692	1670			1459	1463								
L2 N.F. + R2 N.F.	1800	1729	1675	1590			1598	1616								
DEAD LEVER - ANCHOR PIN FORCE	951	942					831	863								
LIVE LEVER - TOP ROD PIN FORCE	984	973	950	935			893	904								
L2 INSTRUMENTED BRAKEHEAD TEMPERATURE	79.1	103.8	107.1	109.1			124.6	83.2								

RIGGING TYPES:
1 - Original rigging components, west running direction (A-end leading)
2 - Same as No. 1 except live lever with more bend angle
3 - Same as No. 1 except east running direction (B-end leading)
4 - Same as No. 1 except live lever with worn pin holes
5 - Same as No. 1 except live lever with worn pin holes and 5 worn pins (2 top rod pins, 2 truck lever connector pins, and dead lever/anchor pin)
6 - Same as No. 1 except worn shoe L2 and new shoe R2
7 - Same as No. 1 except worn shoe R2 and new shoe L2
8 - Same as No. 1 except top rod extended to introduce lever angularity

DRAG BRAKING DATA FROM TESTING ON R.D.U. DATA COLLECTED AFTER 240 SECONDS OF DRAG BRAKING

TEST PARAMETER	RIGGING TYPE 1		2		3		4		5		6		7		8	
	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2
TEST #	53	54	38	39	45	66	71	72	85	86						
SPEED (mph)	19.9	19.9	19.9	19.9	19.9	19.8	19.8	19.9	19.9	19.9					19.7	19.8
BRAKE CYLINDER PRESSURE (psi)	25.0	25.1	24.8	24.6	25.3	25.1	25.1	25.3	25.1	25.0					24.7	25.0
ELAPSED TIME (sec)	240	240	240	240	240	240	240	240	240	240					240	240
RIGGING TYPE	1	1	2	2	3	3	4	4	5	5					8	8
WHEEL L1 NORMAL FORCE	929	859	777	841	749	739	726	763	591	631					818	747
WHEEL R1 NORMAL FORCE	945	942	770	862	777	791	848	744	606	607					[illegible]	825
WHEEL L2 NORMAL FORCE	907	851	841	905	875	875	882	859	835	819					[illegible]	907
WHEEL R2 NORMAL FORCE	997	940	808	876	875	916	853	818	751	758					[illegible]	870
MAXIMUM N.F./MINIMUM N.F.	1.10	1.11	1.09	1.08	1.17	1.24	1.21	1.15	1.41	1.35					1.12	1.21
TOTAL NORMAL FORCE TRUCK B	3779	3593	3195	3484	3277	3321	3309	3184	2781	2816					3365	3349
TOTAL ESTIMATED FORCE TRUCKS A & B	7293	6934	6567	6724	6524	6419	6366	6144	5368	5435					6533	6464
OVERALL CAR LEVER EFFICIENCY	56.4	53.5	48.1	52.9	48.4	49.3	49.2	46.8	41.3	42.0					50.7	50.9
MEASURED EFFICIENCY AT TOP ROD/LIVE LEVER PIN	64.3	67.0	59.7	61.3	57.5	58.5	53.1	56.0							60.7	59.5
MEASURED EFFICIENCY AT TRUCK LEVER/BEAM PINS	57.9	56.1	54.3	57.5	54.3	54.5	52.3	48.6	45.8	46.3					55.7	[illegible]
MEASURED EFFICIENCY AT SHOE/WHEEL INTERFACES	58.4	55.4	49.8	54.7	50.1	51.0	51.0	49.5	42.8	43.5					53.4	51.7
LOADED BRAKE RATIO	2.77	2.64	2.34	2.56	2.40	2.44	2.43	2.34	2.04	2.07					2.48	2.46
EMPTY BRAKE RATIO	12.02	11.42	10.16	11.08	10.42	10.56	10.52	10.12	8.84	8.95					10.76	10.65
L1-R1 BEAM PIN FORCE	1926	1884	1824	1942	1845	1629	1765	1601	1627	1665					1375	1376
L1 N.F. + R1 N.F.	1874	1801	1546	1702	1515	1530	1574	1507	1196	1239					1514	1572
L2-R2 BEAM PIN FORCE	1822	1759	1663	1715	1712	1721	1697	1587	1350	1333					1720	1762
L2 N.F. + R2 N.F.	1905	1791	1549	1782	1751	1751	1735	1677	1585	1578					1771	1777
DEAD LEVER - ANCHOR PIN FORCE	962	748			945	949	891	867							899	924
LIVE LEVER - TOP ROD PIN FORCE	1039	1006	957	1072	940	951	942	919							971	963
L2 INSTRUMENTED BRAKEHEAD TEMPERATURE	72	109	161	162	79	95	97	84	98	103					77	96
TEST #	57	58	44	45			75	76								
SPEED (mph)	39.8	39.8	39.7	39.7			39.8	39.8								
BRAKE CYLINDER PRESSURE (psi)	26.9	24.6	24.2	24.3			25.2	25.3								
ELAPSED TIME (sec)	240	240	240	240			240	240								
RIGGING TYPE	1	1	2	2			4	4								
WHEEL L1 NORMAL FORCE	1049	972	1034	986			855	909								
WHEEL R1 NORMAL FORCE	964	1020	1084	1029			866	848								
WHEEL L2 NORMAL FORCE	943	944	1069	1020			904	928								
WHEEL R2 NORMAL FORCE	992	964	1040	942			853	878								
MAXIMUM N.F./MINIMUM N.F.	1.11	1.08	1.05	1.09			1.06	1.09								
TOTAL NORMAL FORCE TRUCK B	3948	3900	4228	3976			3477	3563								
TOTAL ESTIMATED FORCE TRUCKS A & B	7619	7527	8159	7673			6710	6377								
OVERALL CAR LEVER EFFICIENCY	54.9	59.0	65.1	61.0			51.4	52.4								
MEASURED EFFICIENCY AT TOP ROD/LIVE LEVER PIN	61.0	67.6	74.2	71.0			59.3	60.4								
MEASURED EFFICIENCY AT TRUCK LEVER/BEAM PINS	56.2	62.0	68.6	66.7			51.0	51.1								
MEASURED EFFICIENCY AT SHOE/WHEEL INTERFACES	56.7	61.1	67.4	63.2			53.2	54.3								
LOADED BRAKE RATIO	2.90	2.86	3.10	2.92			2.55	2.61								
EMPTY BRAKE RATIO	12.55	12.40	13.44	12.64			11.05	11.33								
L1-R1 BEAM PIN FORCE	2050	2071	2260	2180			1772	1829								
L1 N.F. + R1 N.F.	2013	1992	2119	2014			1720	1757								
L2-R2 BEAM PIN FORCE	1865	1886	2042	2014			1556	1527								
L2 N.F. + R2 N.F.	1935	1908	2109	1962			1756	1806								
DEAD LEVER - ANCHOR PIN FORCE	968	1023					897	947								
LIVE LEVER - TOP ROD PIN FORCE	1060	1078	1162	1116			967	990								
L2 INSTRUMENTED BRAKEHEAD TEMPERATURE	95.2	107.5	116.6	117.1			125.7	90.6								

RIGGING TYPES:

1 - Original rigging components, west running direction (A-end leading)
2 - Same as No. 1 except live lever with more bend angle
3 - Same as No. 1 except east running direction (B-end leading)
4 - Same as No. 1 except live lever with worn pin holes
5 - Same as No. 1 except live lever with worn pin holes and 5 worn pins (2 top rod pins, 2 truck lever connector pins, and dead lever/anchor pin)
6 - Same as No. 1 except worn shoe L2 and new shoe R2
7 - Same as No. 1 except worn shoe R2 and new shoe L2
8 - Same as No. 1 except top rod [illegible]

DRAG BRAKING DATA FROM TESTING ON R.D.U. DATA COLLECTED AFTER 40 SECONDS OF DRAG BRAKING

TEST PARAMETER	RIGGING TYPE 1		2		3		4		5		6		7		8	
	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2
TEST #	61	62	48	49	67	68	79	80	91		93	94	96	99	108	109
SPEED (mph)	49.8	49.5	47.8	47.8	49.7	49.9	49.8	49.7	49.8		49.7	49.8	49.7	49.8	49.7	49.7
BRAKE CYLINDER PRESSURE (psi)	25.4	25.3	25.4	25.4	25.5	25.3	25.5	25.6	24.8		25.3	25.6	25.5	25.4	24.7	25.3
ELAPSED TIME (sec)	40	40	40	40	40	40	40	40	40		40	40	40	40	40	40
RIGGING TYPE	1	1	2	2	3	3	4	4	5		6	6	7	7	8	8
WHEEL L1 NORMAL FORCE	962	966	870	862	793	776	742	780	1014		859	867	885	781	739	756
WHEEL R1 NORMAL FORCE	834	867	849	910	765	775	705	763	905		724	727	918	699	795	795
WHEEL L2 NORMAL FORCE	831	822	907	926	870	850	809	866	1113		649	854	971	840	939	927
WHEEL R2 NORMAL FORCE	915	920	895	895	657	562	780	819	1111		804	829	906	779	905	923
MAXIMUM N.F./MINIMUM N.F.	1.10	1.12	1.06	1.07	1.14	1.11	1.15	1.13	1.23		1.19	1.19	1.10	1.29	1.27	1.27
TOTAL NORMAL FORCE TRUCK B	3442	3476	3516	3592	3145	3273	3036	3227	4143		3236	3267	3681	3099	3377	3424
TOTAL ESTIMATED FORCE TRUCKS A & B	6643	6709	6786	6933	6455	6317	5859	6229	7995		6245	6306	7104	5981	6517	6569
OVERALL CAR LEVER EFFICIENCY	50.5	51.1	51.6	57.7	46.3	48.2	44.4	47.1	62.3		47.7	47.6	55.7	45.5	51.0	50.5
MEASURED EFFICIENCY AT TOP ROD/LIVE LEVER PIN	60.0	60.8	59.7	60.9	57.7	59.7	53.9	56.0			57.1	56.1	67.9	55.4	63.3	62.8
MEASURED EFFICIENCY AT TRUCK LEVER/BEAM PINS	51.3	54.5	55.2	57.4	51.7	52.9	44.6	46.8	68.0		49.9	52.6	60.9	47.9	56.3	56.2
MEASURED EFFICIENCY AT SHOE/WHEEL INTERFACES	52.3	53.0	53.4	54.6	53.5	49.9	46.0	48.8	64.5		49.3	49.3	55.6	47.1	52.8	52.5
LOADED BRAKE RATIO	2.53	2.55	2.58	2.64	2.45	2.40	2.23	2.37	3.04		2.37	2.40	2.70	2.27	2.48	[illegible]
EMPTY BRAKE RATIO	10.94	11.05	11.18	11.42	10.64	10.41	9.65	10.26	13.17		10.29	10.39	11.70	9.85	10.74	10.82
L1-R1 BEAM PIN FORCE	1640	1857	1875	1933	1792	1737	1539	1577	2455		1627	1847	2101	1534	1776	1647
L1 N.F. + R1 N.F.	1691	1753	1719	1772	1578	1551	1447	1513	1919		1583	1594	1804	1480	1553	1555
L2-R2 BEAM PIN FORCE	1739	1720	1755	1846	1597	1738	2405	1521	1911		1648	1646	1928	1521	1874	1819
L2 N.F. + R2 N.F.	1745	1743	1797	1821	1767	1772	1569	1684	2223		1653	1673	1877	1619	1813	1851
DEAD LEVER - ANCHOR PIN FORCE	959	917	939	880	937	942	842	863			886	905	971	902	978	967
LIVE LEVER - TOP ROD PIN FORCE	986	996	981	1001	953	978	988	926			939	933	1040	912	1012	1021
L2 INSTRUMENTED BRAKEHEAD TEMPERATURE	107	98	88	92	92	106	92	93	102		81	106	84	90	112	102

TEST PARAMETER	RIGGING TYPE 1		2		3		4		5		6		7		8	
	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2
TEST #	55	56	42	43			73	74	87	88					204	205
SPEED (mph)	19.8	19.9	19.8	19.9			19.8	19.9	19.8	19.9					19.9	19.9
BRAKE CYLINDER PRESSURE (psi)	50.8	50.8	50.2	50.1			50.6	50.5	50.4	50.9					50.5	50.4
ELAPSED TIME (sec)	40	40	40	40			40	40	40	40					40	40
RIGGING TYPE	1	1	2	2			4	4	5	5					8	8
WHEEL L1 NORMAL FORCE	1567	1494	1413	1330			1560	1402	1245	1360					1612	1444
WHEEL R1 NORMAL FORCE	1446	1705	1309	1440			1674	1558	1338	1219					1707	1591
WHEEL L2 NORMAL FORCE	1874	1875	1879	1861			1998	1893	1930	1896					2135	2079
WHEEL R2 NORMAL FORCE	1961	1992	1819	1791			1981	1853	1846	1827					2102	2055
MAXIMUM N.F./MINIMUM N.F.	1.36	1.33	1.44	1.40			1.28	1.35	1.55	1.56					1.33	1.44
TOTAL NORMAL FORCE TRUCK B	6850	7064	6420	6422			7213	6707	6359	6301					7636	7170
TOTAL ESTIMATED FORCE TRUCKS A & B	13221	13633	12391	12394			13921	12915	12272	12162					14738	13637
OVERALL CAR LEVER EFFICIENCY	50.3	51.8	47.7	47.6			53.2	49.6	47.1	46.2					56.3	53.0
MEASURED EFFICIENCY AT TOP ROD/LIVE LEVER PIN	63.0	63.5	63.8	63.3			63.4	61.1							65.3	64.4
MEASURED EFFICIENCY AT TRUCK LEVER/BEAM PINS	55.8	58.1	56.0	56.4			58.9	53.5	53.2	53.3					58.2	56.7
MEASURED EFFICIENCY AT SHOE/WHEEL INTERFACES	52.1	53.7	49.4	49.3			55.1	51.3	48.8	47.8					58.3	54.9
LOADED BRAKE RATIO	5.03	5.18	4.71	4.71			5.29	4.92	4.67	4.62					5.60	5.26
EMPTY BRAKE RATIO	21.70	22.46	20.41	20.42			22.93	21.33	20.22	20.04					24.28	22.89
L1-R1 BEAM PIN FORCE	3523	3504	3459	3594			3747	3305	3296	3325					3759	3557
L1 N.F. + R1 N.F.	3013	3199	2722	2770			3234	2961	2583	2578					3319	3035
L2-R2 BEAM PIN FORCE	3705	3749	3927	3723			3964	3670	3645	3694					3874	3848
L2 N.F. + R2 N.F.	3837	3865	3698	3652			3979	3747	3775	3723					4287	4174
DEAD LEVER - ANCHOR PIN FORCE	2076	2048					2081	2016							2249	2190
LIVE LEVER - TOP ROD PIN FORCE	2067	2089	2072	2033			2076	1994							2130	2099
L2 INSTRUMENTED BRAKEHEAD TEMPERATURE	110	115	105	110			100	119	106	86					98	93

RIGGING TYPES:

1 - Original rigging components, most running direction (A-end leading)
2 - Same as No. 1 except live lever with worn bend angle
3 - Same as No. 1 except most running direction (B-end leading)
4 - Same as No. 1 except live lever with worn pin holes
5 - Same as No. 1 except live lever with worn pin holes and 5 worn pins (2 top rod pins, 2 truck lever connector pins, and dead lever/anchor pin)
6 - Same as No. 1 except worn shoe L2 and new shoe R2
7 - Same as No. 1 except worn shoe R2 and new shoe L2
8 - Same as No. 1 except top rod extended to introduce lever angularity

DRAG BRAKING DATA FROM TESTING ON R.D.U.   DATA COLLECTED AFTER 240 SECONDS OF DRAG BRAKING

TEST PARAMETER	1 TEST 1	1 TEST 2	2 TEST 1	2 TEST 2	3 TEST 1	3 TEST 2	4 TEST 1	4 TEST 2	5 TEST 1	5 TEST 2	6 TEST 1	6 TEST 2	7 TEST 1	7 TEST 2	8 TEST 1	8 TEST 2
	<----	----	----	----	----	----	RIGGING TYPE	----	----	----	---->					
TEST #	61	62	48	49	67	68	79	80	91		93	94	98	99	108	109
SPEED (mph)	49.7	49.7	49.9	49.8	49.8	49.3	49.8	49.7	49.7		49.8	49.8	49.8	49.8	49.3	49.8
BRAKE CYLINDER PRESSURE (psi)	24.7	24.6	24.7	24.7	25.1	25.0	24.8	25.2	24.9		24.9	24.9	25.1	24.9	24.6	24.6
ELAPSED TIME (sec)	240	240	240	240	240	240	240	240	240		240	240	240	240	240	240
RIGGING TYPE	1	1	2	2	3	3	4	4	5		6	6	7	7	8	8
WHEEL L1 NORMAL FORCE	969	969	1019	1024	865	857	891	934	1289		1012	981	1010	961	953	927
WHEEL R1 NORMAL FORCE	965	1029	1029	1132	887	845	870	930	1108		894	925	1017	936	1012	1094
WHEEL L2 NORMAL FORCE	953	925	1101	1130	999	976	927	1015	1215		980	1000	1095	974	1033	1067
WHEEL R2 NORMAL FORCE	1011	1003	1083	1085	1025	920	871	922	1166		753	955	1013	905	959	1041
MAXIMUM N.F./MINIMUM N.F.	1.06	1.11	1.08	1.11	1.19	1.16	1.06	1.10	1.16		1.13	1.08	1.08	1.08	1.08	1.18
TOTAL NORMAL FORCE TRUCK B	3917	3924	4232	4371	3797	3648	3579	3798	4778		3640	3860	4136	3777	3958	4130
TOTAL ESTIMATED FORCE TRUCKS A & B	7559	7573	8160	8435	7309	7041	6907	7331	9222		7411	7450	7983	7290	7639	7920
OVERALL CAR LEVER EFFICIENCY	59.1	59.4	63.8	65.9	56.2	54.4	53.9	56.1	71.7		57.5	57.8	61.4	56.5	59.9	62.7
MEASURED EFFICIENCY AT TOP ROD/LIVE LEVER PIN	68.7	69.4	72.0	74.3	65.4	[illegible]	61.4	65.2			66.3	66.8	70.4	64.1	69.2	72.3
MEASURED EFFICIENCY AT TRUCK LEVER/BEAM PINS	61.4	63.3	67.5	70.2	59.7	59.4	51.6	55.9	72.0		59.5	55.4	68.2	58.5	63.3	69.1
MEASURED EFFICIENCY AT SHOE/WHEEL INTERFACES	61.2	61.5	66.1	68.2	59.2	56.4	55.7	58.1	74.2		59.5	59.8	63.6	58.5	62.0	64.9
LOADED BRAKE RATIO	2.87	2.88	3.11	3.21	2.78	2.18	2.63	2.79	3.51		2.82	2.83	3.04	2.77	2.99	3.03
EMPTY BRAKE RATIO	12.45	12.48	13.46	13.90	12.04	11.40	11.38	12.08	15.19		12.21	12.27	13.15	12.01	12.59	13.13
L1-R1 BEAM PIN FORCE	2007	2102	2262	2262	2000	1890	1828	1961	2578		1931	2279	2292	1890	2052	2340
L1 N.F. + R1 N.F.	1954	1997	2048	2155	1764	1702	1781	1864	2397		1907	1906	2027	1997	1965	2021
L2-R2 BEAM PIN FORCE	1919	1940	2062	2237	1682	1957	1490	1694	2059		1909	1942	2148	1888	1958	2057
L2 N.F. + R2 N.F.	1963	1926	2194	2215	2024	1946	1798	1935	2381		1933	1954	2109	1880	1991	2109
DEAD LEVER - ANCHOR PIN FORCE	1045	1017	1069	1051	993	1024	933	978			1004	986	1050	999	1056	1069
LIVE LEVER - TOP ROD PIN FORCE	1099	1107	1151	1150	1063	1094	986	1065			1069	1078	1145	1033	1105	1149
L2 INSTRUMENTED BRAKEHEAD TEMPERATURE	105	106	98	103	93	115	95	101	108		94	115	95	94	117	109
TEST #	55	56	42	43			73	74	87	88					104	105
SPEED (mph)	19.9	19.9	19.9	19.9			19.9	19.9	19.9	19.9					19.9	19.9
BRAKE CYLINDER PRESSURE (psi)	50.2	50.2	49.6	49.6			50.1	50.0	50.1	50.0					50.2	49.9
ELAPSED TIME (sec)	240	240	240	240			240	240	240	240					240	240
RIGGING TYPE	1	1	2	2			4	4	5	5					8	8
WHEEL L1 NORMAL FORCE	2003	1572	1836	1631			1638	1459	1406	1782					1712	2046
WHEEL R1 NORMAL FORCE	1893	2438	2258	2255			2115	2045	1961	1651					2055	2028
WHEEL L2 NORMAL FORCE	2020	2060	2211	2059			2110	2007	2047	2052					2159	2179
WHEEL R2 NORMAL FORCE	2071	2129	2166	2123			2074	1909	1908	1971					2036	2110
MAXIMUM N.F./MINIMUM N.F.	1.09	1.55	1.23	1.38			1.29	1.41	1.46	1.24					1.26	1.07
TOTAL NORMAL FORCE TRUCK B	7986	8200	8472	8067			7937	7410	7322	7456					7962	8364
TOTAL ESTIMATED FORCE TRUCKS A & B	15412	15825	16351	15569			15319	14301	14131	14390					15367	16143
OVERALL CAR LEVER EFFICIENCY	59.3	60.9	63.7	60.6			59.1	55.3	54.5	55.6					59.7	62.5
MEASURED EFFICIENCY AT TOP ROD/LIVE LEVER PIN	67.7	70.0	72.4	70.1			67.3	64.4							67.6	68.6
MEASURED EFFICIENCY AT TRUCK LEVER/BEAM PINS	62.6	67.7	67.9	66.5			64.4	60.6	57.1	55.6					63.9	67.6
MEASURED EFFICIENCY AT SHOE/WHEEL INTERFACES	61.4	63.1	66.0	62.8			61.2	57.2	56.4	57.6					61.3	64.7
LOADED BRAKE RATIO	5.86	6.02	6.72	5.92			5.82	5.44	5.37	5.47					5.84	6.13
EMPTY BRAKE RATIO	25.39	26.07	26.94	25.65			25.24	23.56	23.28	23.71					25.32	26.59
L1-R1 BEAM PIN FORCE	4178	4649	4811	4677			4279	4082	3691	3878					4760	4649
L1 N.F. + R1 N.F.	3095	4010	4095	3885			3753	3494	3368	3433					3767	4074
L2-R2 BEAM PIN FORCE	3956	4152	3704	3924			4075	3758	3726	3834					4049	4086
L2 N.F. + R2 N.F.	4090	4189	4377	4182			4184	3916	3954	4023					4195	4290
DEAD LEVER - ANCHOR PIN FORCE	2150	2178					2150	2079							2234	2234
LIVE LEVER - TOP ROD PIN FORCE	2196	2273	2320	2252			2181	2083							2197	2216
L2 INSTRUMENTED BRAKEHEAD TEMPERATURE	116	121	114	117			104	123	111	88					99	96

RIGGING TYPES:
1 - Original rigging components, west running direction (A-end leading)
2 - Same as No. 1 except live lever with more bend angle
3 - Same as No. 1 except east running direction (B-end leading)
4 - Same as No. 1 except live lever with worn pin holes
5 - Same as No. 1 except live lever with worn pin holes and 5 worn pins (2 top rod pins, 2 truck lever connector pins, and dead lever/anchor pin)
6 - Same as No. 1 except worn shoe L2 and new shoe R2
7 - Same as No. 1 except worn shoe R2 and new shoe L2
8 - Same as No. 1 except top rod extended to introduce lever angularity

DRAG BRAKING DATA FROM TESTING ON R.D.U. DATA COLLECTED AFTER 40 SECONDS OF DRAG BRAKING

TEST PARAMETER	RIGGING TYPE 1 TEST 1	1 TEST 2	2 TEST 1	2 TEST 2	3 TEST 1	3 TEST 2	4 TEST 1	4 TEST 2	5 TEST 1	5 TEST 2	6 TEST 1	6 TEST 2	7 TEST 1	7 TEST 2	8 TEST 1	8 TEST 2
TEST #	59	60	46				77	78								
SPEED (mph)	39.8	39.8	39.8				39.8	39.8								
BRAKE CYLINDER PRESSURE (psi)	50.6	50.8	50.7				50.7	50.8								
ELAPSED TIME (sec)	40	40	40				40	40								
RIGGING TYPE	1	1	2				4	4								
WHEEL L1 NORMAL FORCE	1671	1749	1678				1600	1526								
WHEEL R1 NORMAL FORCE	1801	1946	1732				1750	1509								
WHEEL L2 NORMAL FORCE	1936	1957	1965				1908	1908								
WHEEL R2 NORMAL FORCE	1932	2018	1977				1818	1792								
MAXIMUM N.F./MINIMUM N.F.	1.16	1.15	1.18				1.19	1.26								
TOTAL NORMAL FORCE TRUCK B	7420	7650	7352				7075	6734								
TOTAL ESTIMATED FORCE TRUCKS A & B	14321	14765	14190				13655	12998								
OVERALL CAR LEVER EFFICIENCY	54.7	56.1	54.1				52.1	49.4								
MEASURED EFFICIENCY AT TOP ROD/LIVE LEVER PIN	65.2	65.1	63.5				61.4	61.7								
MEASURED EFFICIENCY AT TRUCK LEVER/BEAM PINS	60.0	61.5	59.7				55.6	53.7								
MEASURED EFFICIENCY AT SHOE/WHEEL INTERFACES	56.6	58.1	56.0				53.9	51.2								
LOADED BRAKE RATIO	5.45	5.61	5.40				5.19	4.94								
EMPTY BRAKE RATIO	23.59	24.33	23.38				22.50	21.41								
L1-R1 BEAM PIN FORCE	4024	4261	4043				3608	3435								
L1 N.F. + R1 N.F.	3552	3695	3411				3350	3035								
L2-R2 BEAM PIN FORCE	3839	3842	3793				3685	3640								
L2 N.F. + R2 N.F.	3868	3955	3942				3726	3700								
DEAD LEVER - ANCHOR PIN FORCE	2081	2075	2005				2016	2025								
LIVE LEVER - TOP ROD PIN FORCE	2134	2141	2082				2015	2039								
L2 INSTRUMENTED BRAKEHEAD TEMPERATURE	113	114	77				100	99								
TEST #	63	64	51	52	69	70	82	83	89	92	97		100	101	106	107
SPEED (mph)	49.8	49.8	49.8	49.7	49.8	49.8	49.9	49.8	49.8	49.8	49.8		49.8	49.8	49.7	49.8
BRAKE CYLINDER PRESSURE (psi)	50.6	50.9	50.8	50.8	50.4	50.8	50.3	50.6	50.3	50.5	50.8		51.0	50.7	50.1	50.3
ELAPSED TIME (sec)	40	40	40	40	40	40	40	40	40	40	40		40	40	40	40
RIGGING TYPE	1	1	2	2	3	3	4	4	5	5	6		7	7	8	8
WHEEL L1 NORMAL FORCE	1878	1833	1825	1859	1808	1764	1550	1545	1511	1609	1981		2054	1850	1849	1901
WHEEL R1 NORMAL FORCE	1993	1978	1929	1937	1755	1603	1630	1550	1575	1627	1903		2034	1752	2009	2035
WHEEL L2 NORMAL FORCE	1938	1915	2046	2006	1950	1958	1938	1907	1933	1860	2087		2155	1978	2202	2191
WHEEL R2 NORMAL FORCE	2019	2003	2001	1988	1852	1920	1838	1772	1792	1828	2106		2076	1811	2131	2154
MAXIMUM N.F./MINIMUM N.F.	1.07	1.09	1.12	1.08	1.11	1.11	1.25	1.23	1.28	1.17	1.11		1.06	1.13	1.19	1.15
TOTAL NORMAL FORCE TRUCK B	7828	7730	7801	7791	7364	7445	6996	6799	6810	5943	8077		8318	7340	8169	5281
TOTAL ESTIMATED FORCE TRUCKS A & B	15108	14919	15056	15036	14213	14369	13503	13122	13144	13399	15569		16054	14167	15596	15961
OVERALL CAR LEVER EFFICIENCY	57.7	56.7	57.3	57.2	54.5	54.7	51.9	50.1	50.5	51.3	59.3		60.8	54.0	60.9	61.3
MEASURED EFFICIENCY AT TOP ROD/LIVE LEVER PIN	66.7	65.7	65.8	64.9	65.2	65.4	63.0	62.8			67.5		68.7	64.1	70.8	69.9
MEASURED EFFICIENCY AT TRUCK LEVER/BEAM PINS	63.6	62.8	63.1	62.6	57.4	59.8	55.3	55.4	56.2	53.1	64.1		66.7	57.8	69.7	69.0
MEASURED EFFICIENCY AT SHOE/WHEEL INTERFACES	59.7	58.7	59.4	59.2	56.4	56.6	53.7	51.9	52.2	53.1	61.4		62.9	55.9	63.1	63.5
LOADED BRAKE RATIO	5.74	5.67	5.72	5.72	5.40	5.46	5.13	4.99	5.00	5.09	5.93		6.10	5.39	6.01	6.06
EMPTY BRAKE RATIO	24.39	24.58	24.90	24.77	23.41	23.67	22.24	21.62	21.65	22.07	25.68		26.45	23.34	26.04	26.33
L1-R1 BEAM PIN FORCE	4392	4412	4277	4277	3637	3748	3527	3584	3624	3261	4321		4364	3750	4816	4786
L1 N.F. + R1 N.F.	3871	3612	3754	3796	3563	3567	3220	3125	3086	3235	3884		4088	3552	3856	3936
L2-R2 BEAM PIN FORCE	3949	3853	4018	3966	3257	3919	3675	3658	3705	3660	4116		4251	3636	4231	4254
L2 N.F. + R2 N.F.	3956	3918	4047	3994	3801	3578	3776	3674	3724	3708	4193		4231	3789	4333	4344
DEAD LEVER - ANCHOR PIN FORCE	2057	2052	2016	1971	2068	2093	2038	2002			2105		2167	2073	2247	2160
LIVE LEVER - TOP ROD PIN FORCE	2164	2162	2160	2135	2126	2149	2050	2055			2220		2269	2103	2297	2277
L2 INSTRUMENTED BRAKEHEAD TEMPERATURE	100	103	89	94	102	116	107	117	116	111	101		90	97	93	100

RIGGING TYPES:

1 - Original rigging components, west running direction (A-end leading)
2 - Same as No. 1 except live lever with more bend angle
3 - Same as No. 1 except east running direction (B-end leading)
4 - Same as No. 1 except live lever with worn pin holes
5 - Same as No. 1 except live lever with worn pin holes and 5 worn pins (2 top rod pins, 2 truck lever connector pins, and dead lever/anchor pin)
6 - Same as No. 1 except worn shoe L2 and new shoe R2
7 - Same as No. 1 except worn shoe R2 and new shoe L2
8 - Same as No. 1 except top rod extended to introduce lever angularity

DRAG BRAKING DATA FROM TESTING ON R.D.U. DATA COLLECTED AFTER 240 SECONDS OF DRAG BRAKING

TEST PARAMETER	RIGGING TYPE 1 TEST 1	1 TEST 2	2 TEST 1	2 TEST 2	3 TEST 1	3 TEST 2	4 TEST 1	4 TEST 2	5 TEST 1	5 TEST 2	6 TEST 1	6 TEST 2	7 TEST 1	7 TEST 2	8 TEST 1	8 TEST 2
TEST #	59	60	46				77	79								
SPEED (mph)	39.9	39.8	39.8				39.9	39.7								
BRAKE CYLINDER PRESSURE (psi)	49.9	50.5	49.9				50.3	50.3								
ELAPSED TIME (sec)	240	240	240				240	240								
RIGGING TYPE	1	1	2				4	4								
WHEEL L1 NORMAL FORCE	2084	2183	2281				1983	1930								
WHEEL R1 NORMAL FORCE	2386	2337	2227				2674	2003								
WHEEL L2 NORMAL FORCE	2311	2151	2411				2179	2196								
WHEEL R2 NORMAL FORCE	2137	2261	2341				2066	2308								
MAXIMUM N.F./MINIMUM N.F.	1.15	1.10	1.08				1.10	1.14								
TOTAL NORMAL FORCE TRUCK B	8918	8951	9260				9103	8138								
TOTAL ESTIMATED FORCE TRUCKS A & B	17211	17276	17972				16026	15706								
OVERALL CAR LEVER EFFICIENCY	66.6	66.0	69.1				61.6	60.3								
MEASURED EFFICIENCY AT TOP ROD/LIVE LEVER PIN	76.8	72.3	75.3				71.0	69.3								
MEASURED EFFICIENCY AT TRUCK LEVER/BEAM PINS	75.4	70.1	72.6				64.7	63.1								
MEASURED EFFICIENCY AT SHOE/WHEEL INTERFACES	69.0	58.4	71.6				63.8	62.4								
LOADED BRAKE RATIO	6.54	6.57	6.80				6.09	5.97								
EMPTY BRAKE RATIO	28.35	28.46	29.44				26.40	25.87								
L1-R1 BEAM PIN FORCE	5142	4870	4633				4442	4310								
L1 N.F. + R1 N.F.	4470	4540	4508				4057	3933								
L2-R2 BEAM PIN FORCE	4606	4306	4535				3983	3915								
L2 N.F. + R2 N.F.	4448	4412	4752				4247	4294								
DEAD LEVER - ANCHOR PIN FORCE	2420	2292	2423				2291	2237								
LIVE LEVER - TOP ROD PIN FORCE	2479	2363	2433				2309	2257								
L2 INSTRUMENTED BRAKEHEAD TEMPERATURE	124	121	91				107	107								
TEST #	63	64	51	52	69	70	82	83	89	92	97		100	101	106	107
SPEED (mph)	49.8	49.9	49.8	49.8	49.8	49.8	49.8	49.7	49.8	49.9	49.8		49.8	49.8	49.9	49.8
BRAKE CYLINDER PRESSURE (psi)	50.1	50.1	50.2	50.0	50.1	50.1	50.0	49.9	50.0	50.0	50.2		50.0	50.3	49.5	49.6
ELAPSED TIME (sec)	240	240	240	240	240	240	240	240	240	240	240		240	240	240	240
RIGGING TYPE	1	1	2	2	3	3	4	4	5	5	6		7	7	8	8
WHEEL L1 NORMAL FORCE	2100	1954	2151	2216	2019	1941	1966	2022	2020	2053	1922		2248	2123	2136	2127
WHEEL R1 NORMAL FORCE	2337	2254	2403	2464	2006	1991	1977	2278	2190	1949	2038		2388	2259	2353	2554
WHEEL L2 NORMAL FORCE	2359	2144	2384	2284	2185	2252	2273	2195	2328	2149	2149		2596	2397	2509	2442
WHEEL R2 NORMAL FORCE	2300	2193	2268	2409	2180	2132	2038	1986	2086	2077	2094		2467	2199	2296	2297
MAXIMUM N.F./MINIMUM N.F.	1.12	1.15	1.12	1.11	1.09	1.16	1.16	1.15	1.15	1.10	1.12		1.16	1.14	1.17	1.20
TOTAL NORMAL FORCE TRUCK B	9095	8545	9206	9374	8390	8317	8254	8471	8623	8228	8204		9700	8888	9133	9421
TOTAL ESTIMATED FORCE TRUCKS A & B	17553	16491	17768	18091	16193	16052	15930	16349	15643	15880	15833		18721	17153	17917	18182
OVERALL CAR LEVER EFFICIENCY	67.7	63.6	68.4	69.9	62.4	62.0	61.6	63.3	64.3	61.4	60.9		72.3	65.9	69.9	70.8
MEASURED EFFICIENCY AT TOP ROD/LIVE LEVER PIN	77.3	73.5	76.7	76.0	74.3	73.9	71.0	72.6			71.0		81.5	75.7	80.5	78.7
MEASURED EFFICIENCY AT TRUCK LEVER/BEAM PINS	76.0	70.4	74.9	75.1	68.4	68.5	65.8	67.4	69.0	62.7	70.5		81.1	75.2	80.3	79.0
MEASURED EFFICIENCY AT SHOE/WHEEL INTERFACES	70.1	65.8	70.8	72.4	64.6	64.2	63.8	65.5	65.6	63.6	63.1		74.0	68.3	72.4	73.3
LOADED BRAKE RATIO	6.67	6.27	6.76	6.88	6.16	6.10	6.06	6.22	6.33	6.04	6.02		7.12	6.52	6.81	6.91
EMPTY BRAKE RATIO	28.92	27.17	29.27	29.80	26.66	26.45	26.24	26.93	27.42	26.16	26.08		30.84	28.26	29.52	29.95
L1-R1 BEAM PIN FORCE	5188	4780	5054	5176	4379	4446	4535	4585	4812	4035	4854		5468	4891	5493	5496
L1 N.F. + R1 N.F.	4437	4208	4554	4651	4026	3933	3944	4300	4209	4002	3961		4636	4382	4489	4681
L2-R2 BEAM PIN FORCE	4694	4336	4585	4594	4503	4448	3979	4124	4123	4014	4307		5039	4636	4307	4656
L2 N.F. + R2 N.F.	4658	4337	4652	4693	4364	4384	4310	4171	4414	4226	4243		5064	4506	4795	4739
DEAD LEVER - ANCHOR PIN FORCE	2443	2297	2361	2296	2309	2321	2300	2107			2180		2620	2436	2519	2452
LIVE LEVER - TOP ROD PIN FORCE	2506	2385	2476	2459	2416	2394	2296	2345			2305		2640	2461	2576	2528
L2 INSTRUMENTED BRAKEHEAD TEMPERATURE	119	116	103	109	113	124	115	123	123	118	117		100	106	106	112

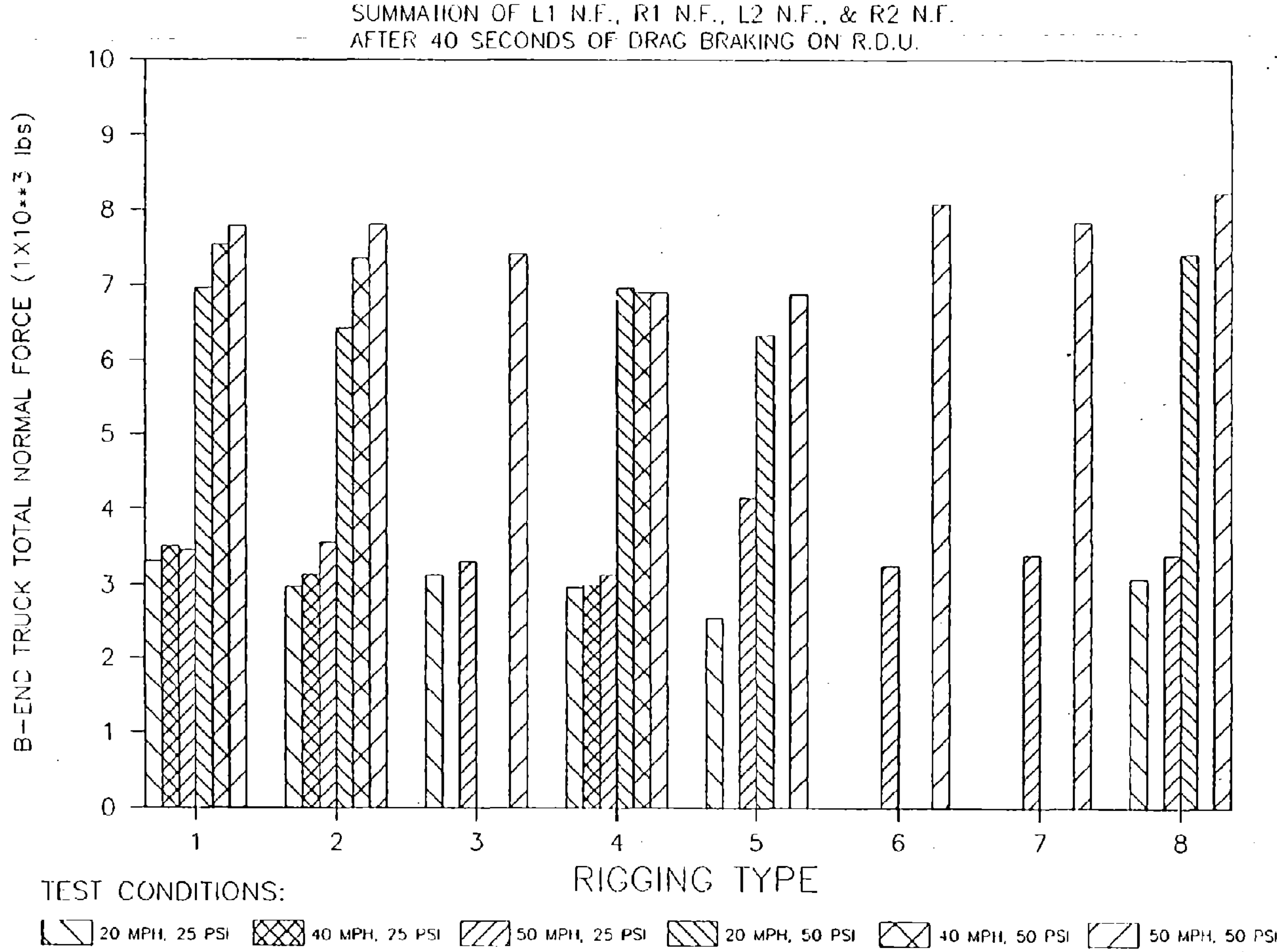
RIGGING TYPES:

1 - Original rigging components, west running direction (A-end leading)
2 - Same as No. 1 except live lever with more bend angle
3 - Same as No. 1 except east running direction (B-end leading)
4 - Same as No. 1 except live lever with worn pin holes
5 - Same as No. 1 except live lever with worn pin holes and 5 worn pins (2 top rod pins, 2 truck lever connector pins, and dead lever/anchor pin)
6 - Same as No. 1 except worn shoe L2 and new shoe R2
7 - Same as No. 1 except worn shoe R2 and new shoe L2
8 - Same as No. 1 except top rod extended to introduce lever angularity

APPENDIX B

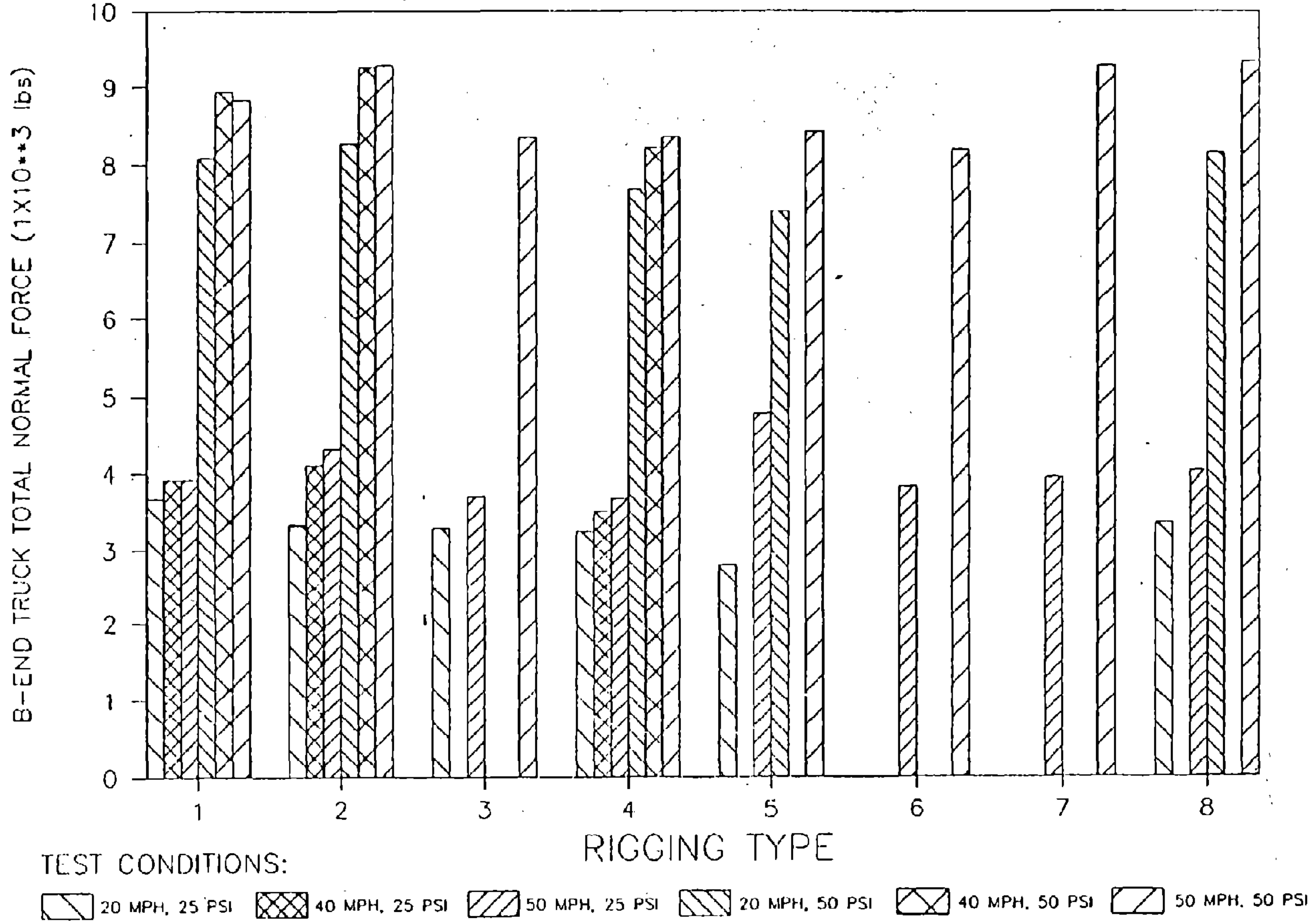
Plots of Brake Forces and
Rigging Pin Forces
From Testing on the R.D.U.

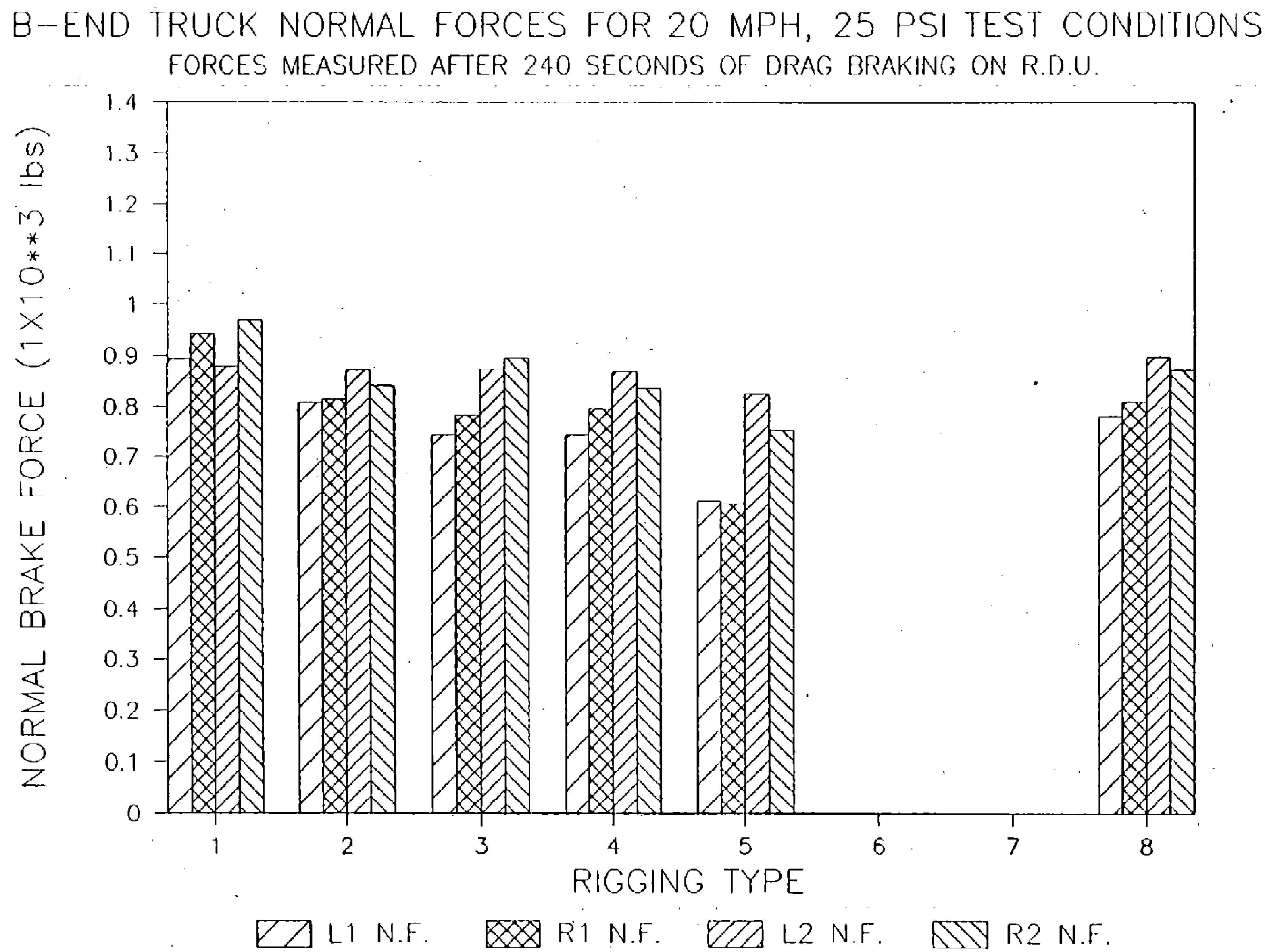
B-END TRUCK TOTAL NORMAL FORCE



B-END TRUCK TOTAL NORMAL FORCE

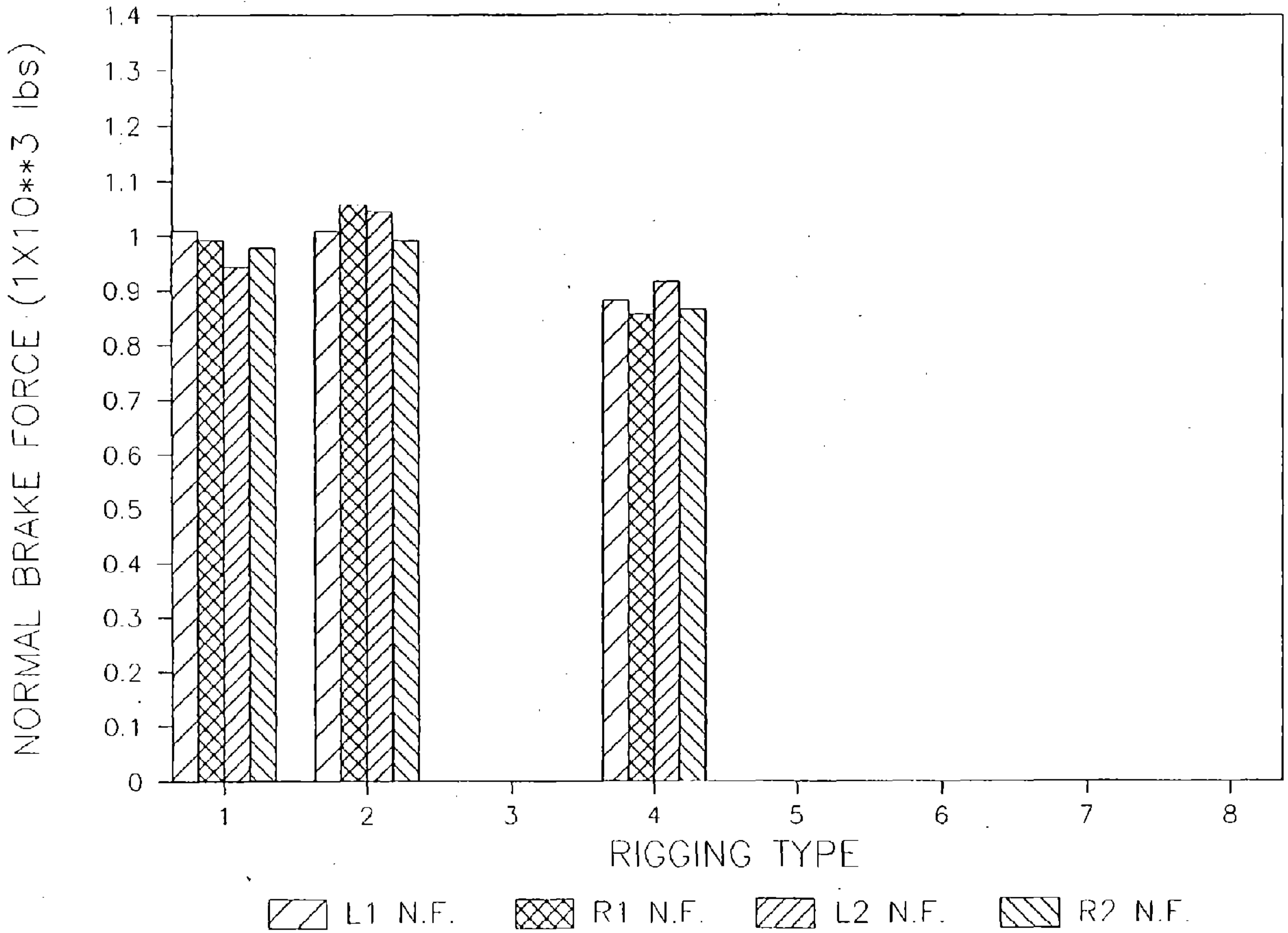
SUMMATION OF L1 N.F., R1 N.F., L2 N.F., & R2 N.F.
AFTER 240 SECONDS OF DRAG BRAKING ON R.D.U.




B-END TRUCK NORMAL FORCES FOR 20 MPH, 25 PSI TEST CONDITIONS
FORCES MEASURED AFTER 240 SECONDS OF DRAG BRAKING ON R.D.U.
NORMAL BRAKE FORCE (1X10**3 lbs)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1
2
3
4
5
6
7
8
RIGGING TYPE
L1 N.F.
R1 N.F.
L2 N.F.
R2 N.F.

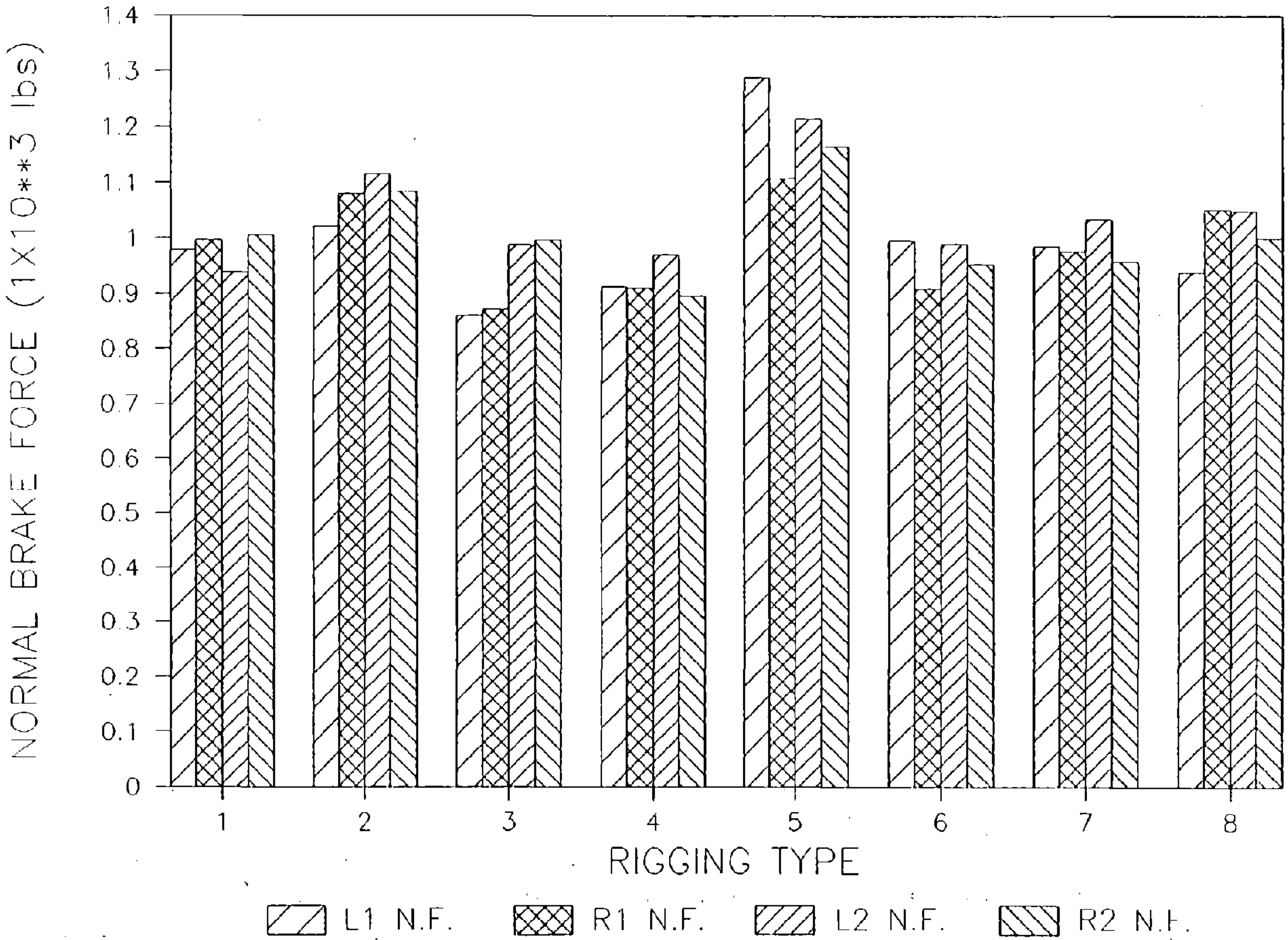
B–END TRUCK NORMAL FORCES FOR 40 MPH, 25 PSI TEST CONDITIONS

FORCES MEASURED AFTER 240 SECONDS OF DRAG BRAKING ON R.D.U.



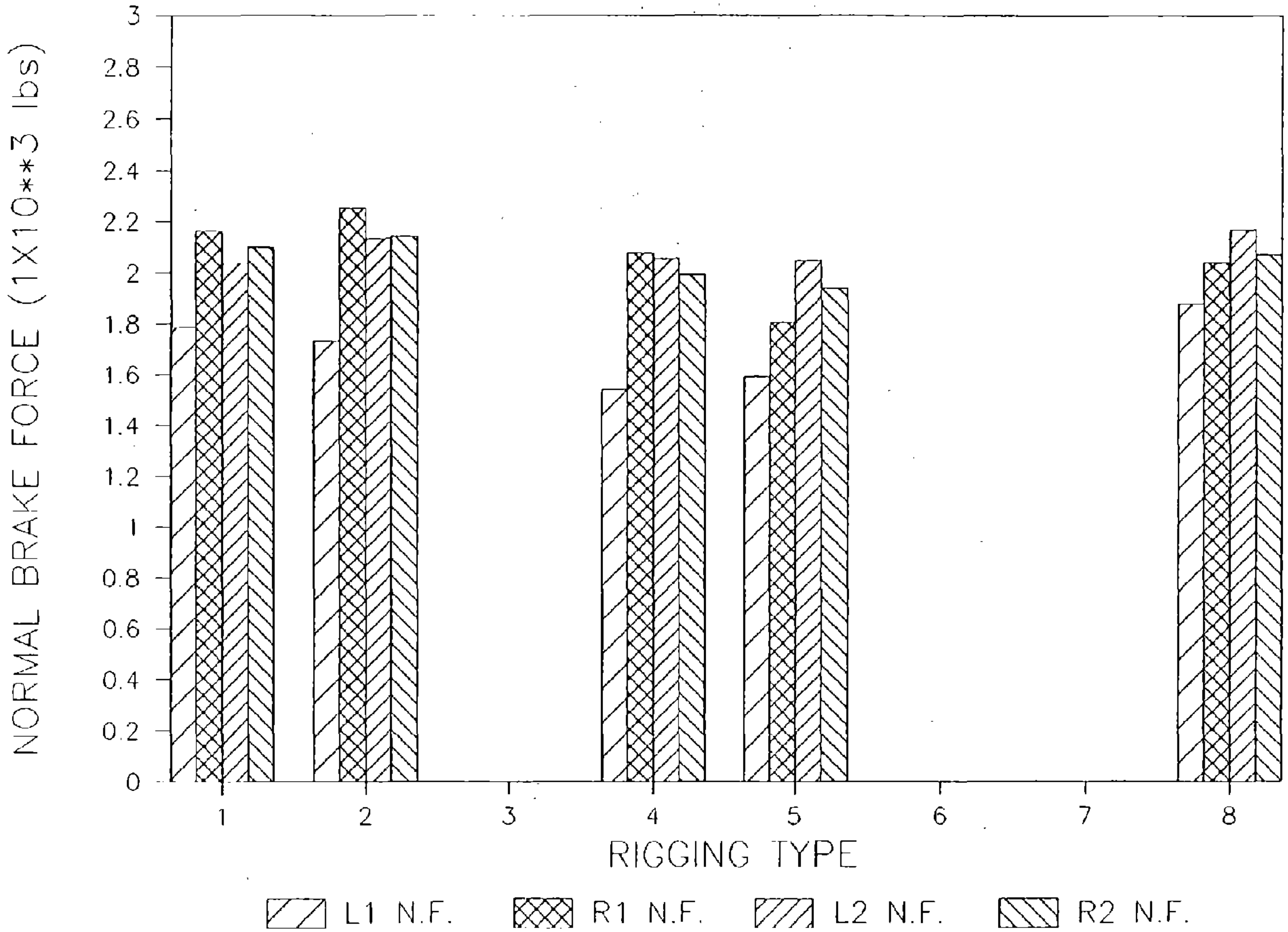
B-END TRUCK NORMAL FORCES FOR 50 MPH, 25 PSI TEST CONDITIONS

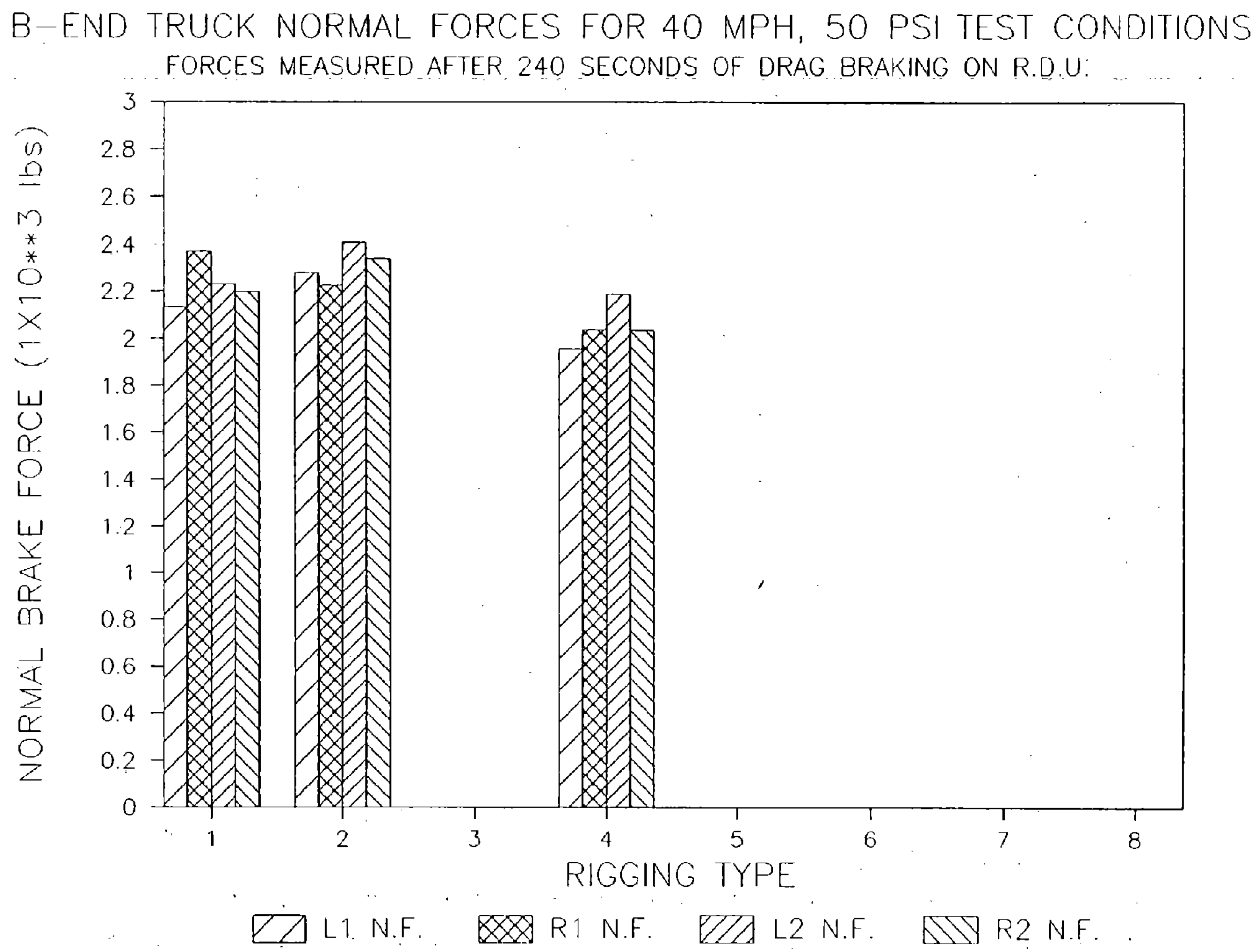
FORCES MEASURED AFTER 240 SECONDS OF DRAG BRAKING ON R.D.U.



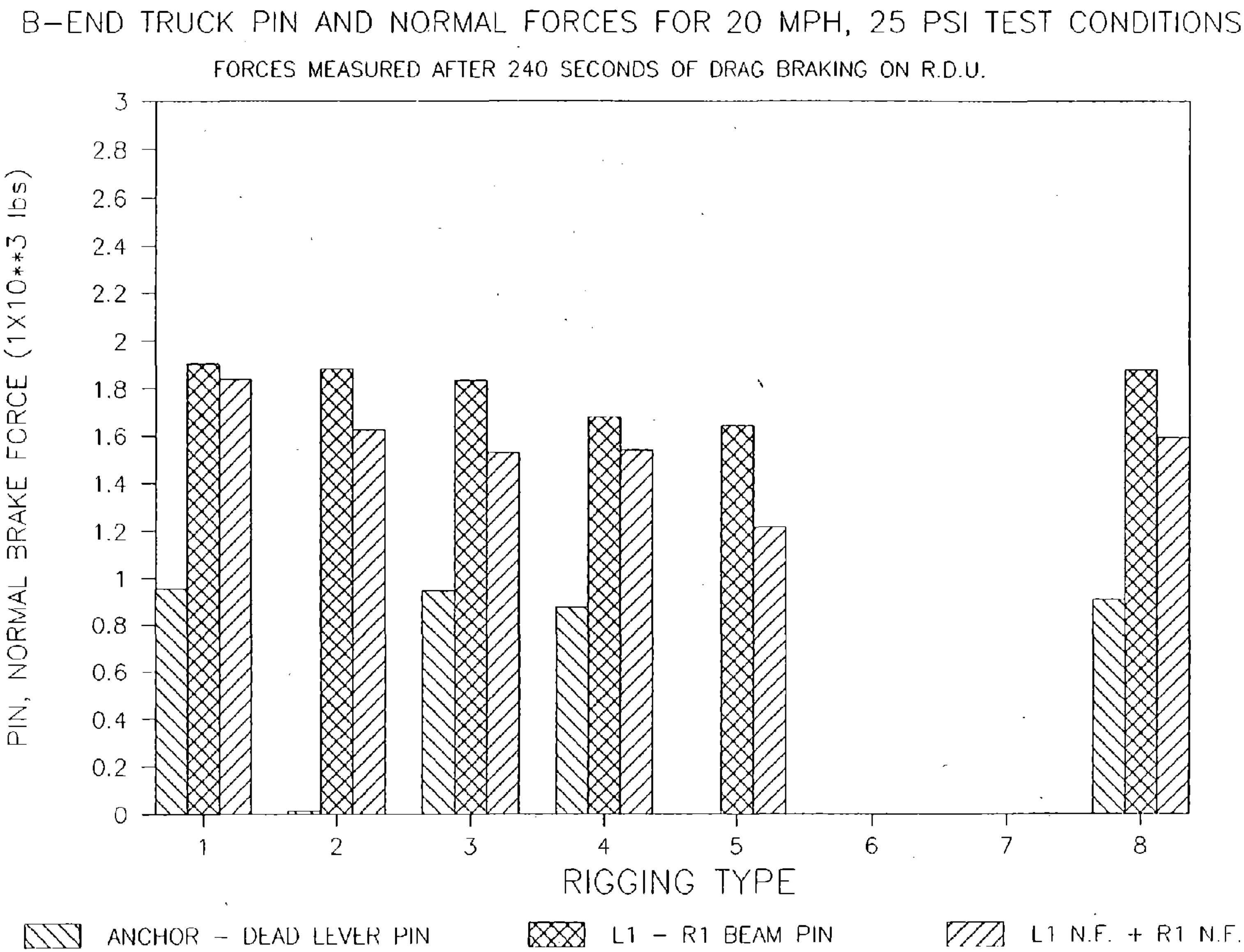
B-END TRUCK NORMAL FORCES FOR 20 MPH, 50 PSI TEST CONDITIONS

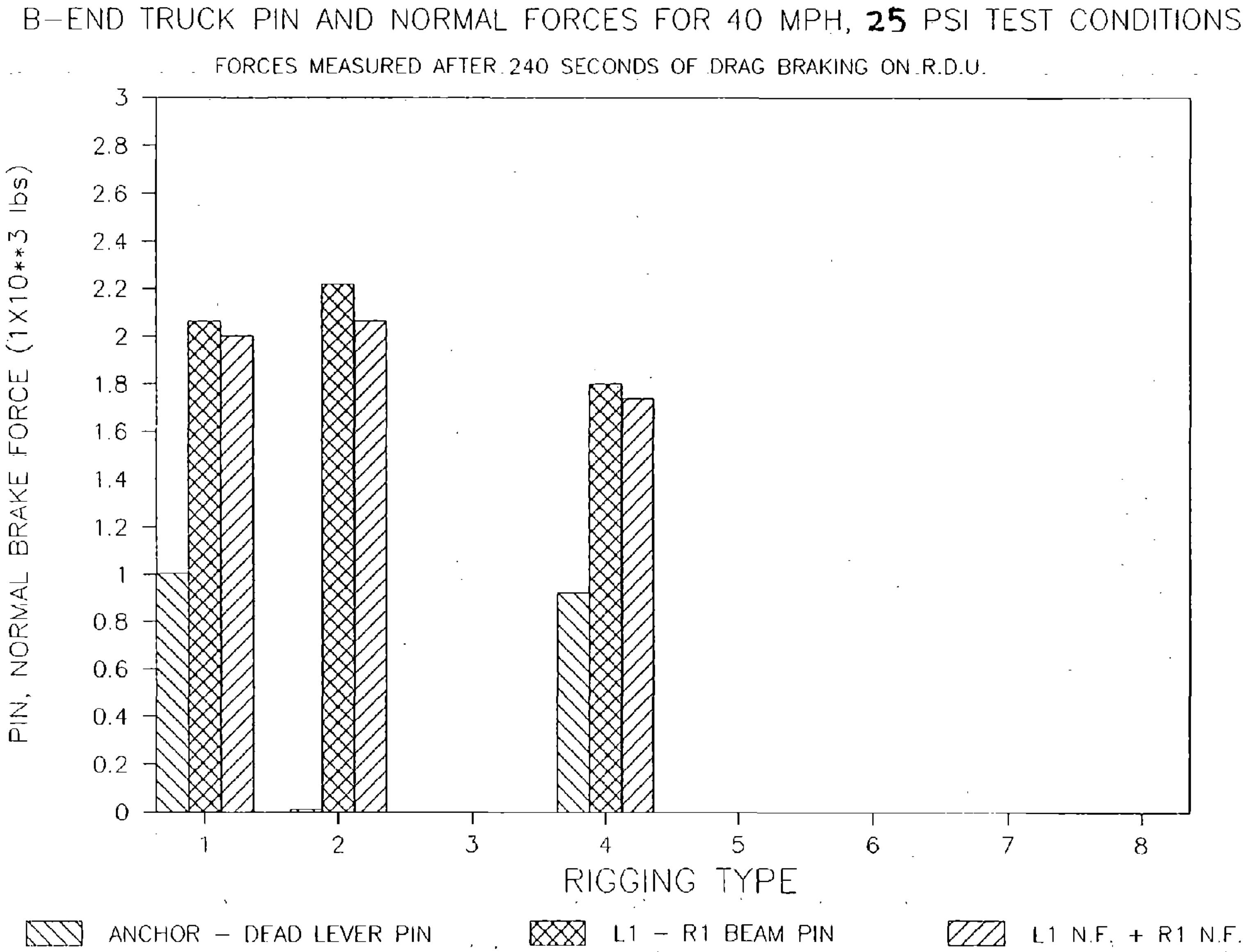
FORCES MEASURED AFTER 240 SECONDS OF DRAG BRAKING ON R.D.U.

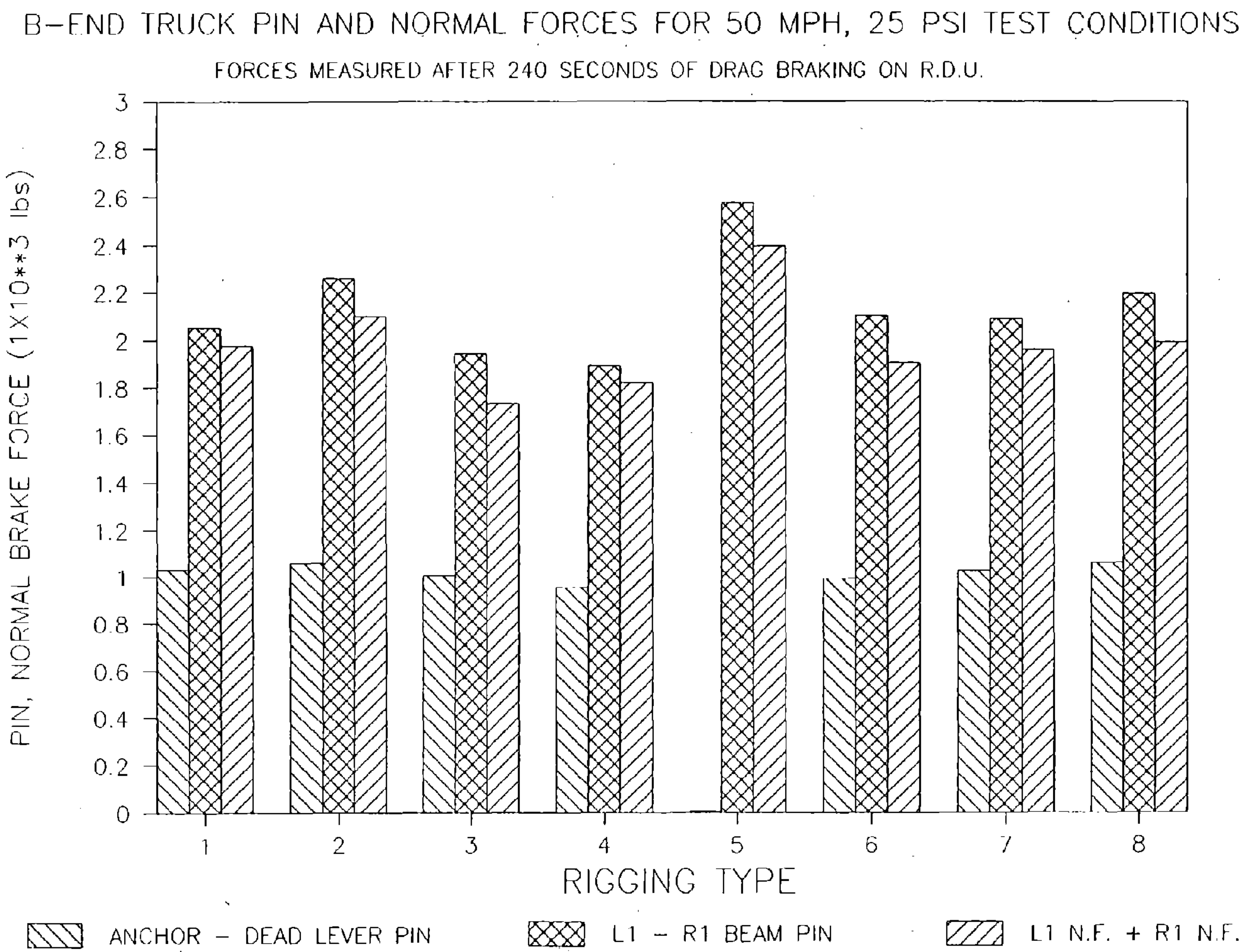


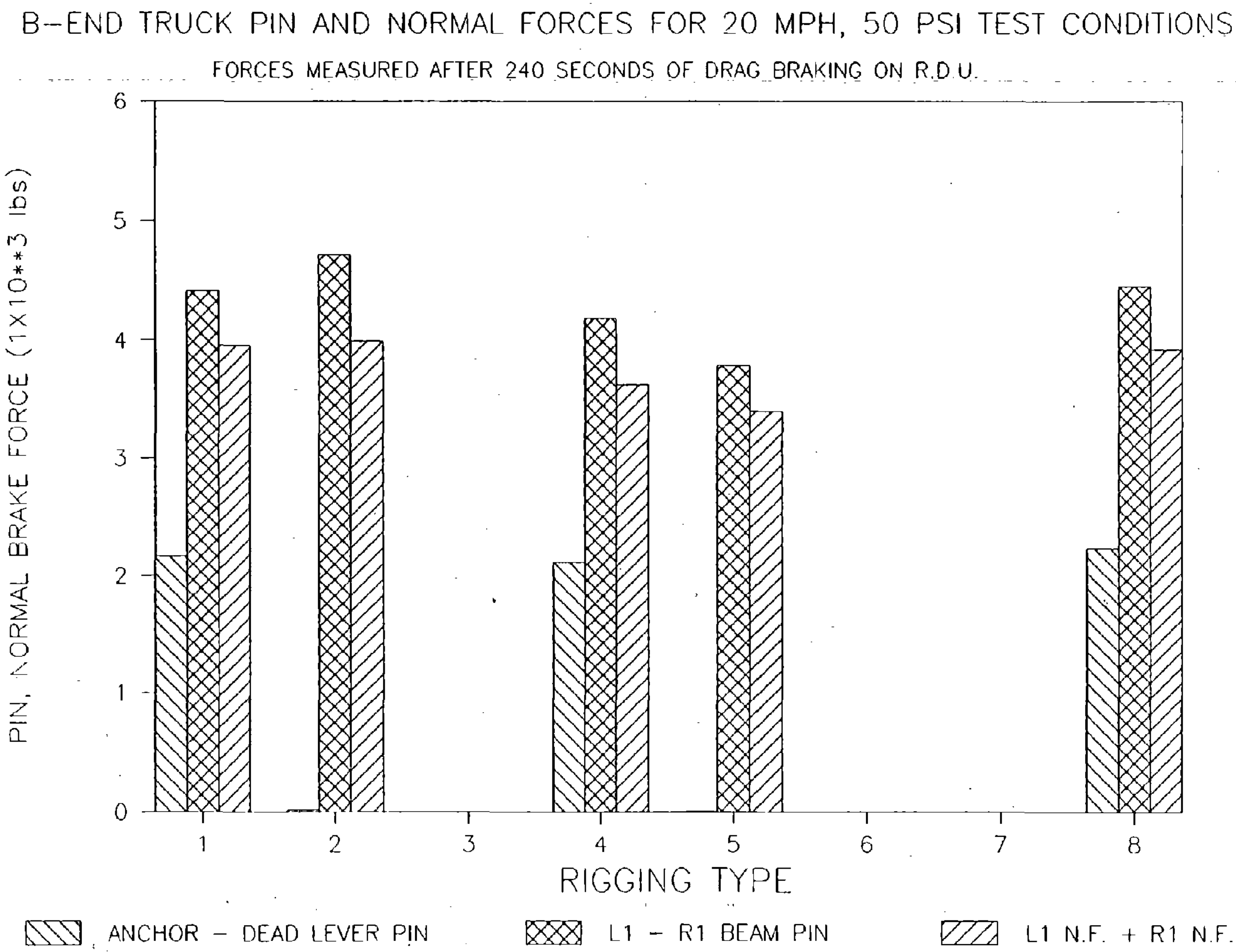


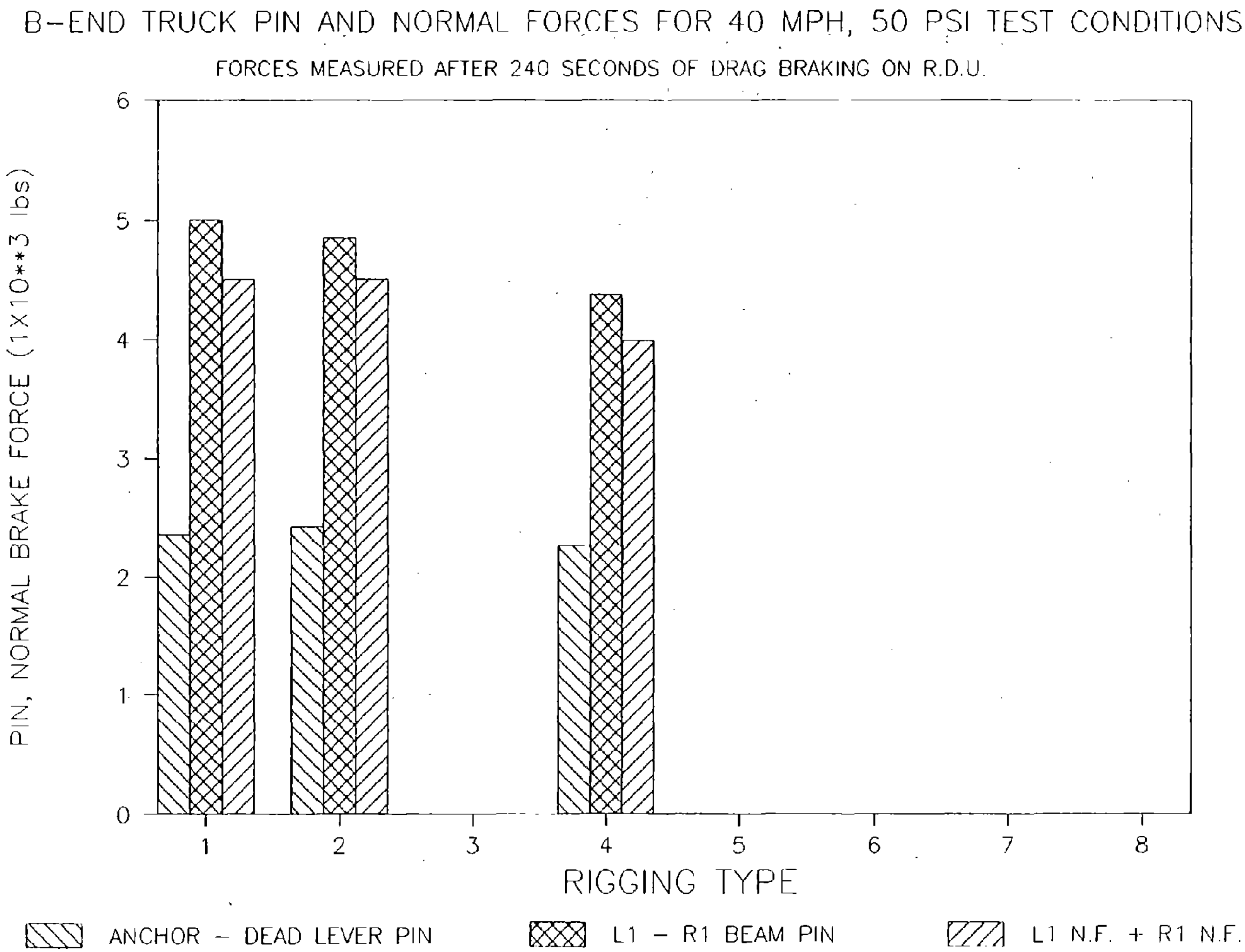
B-END TRUCK NORMAL FORCES FOR 40 MPH, 50 PSI TEST CONDITIONS
FORCES MEASURED AFTER 240 SECONDS OF DRAG BRAKING ON R.D.U.
NORMAL BRAKE FORCE (1X10**3 lbs)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
7
8
RIGGING TYPE
L1 N.F.
R1 N.F.
L2 N.F.
R2 N.F.

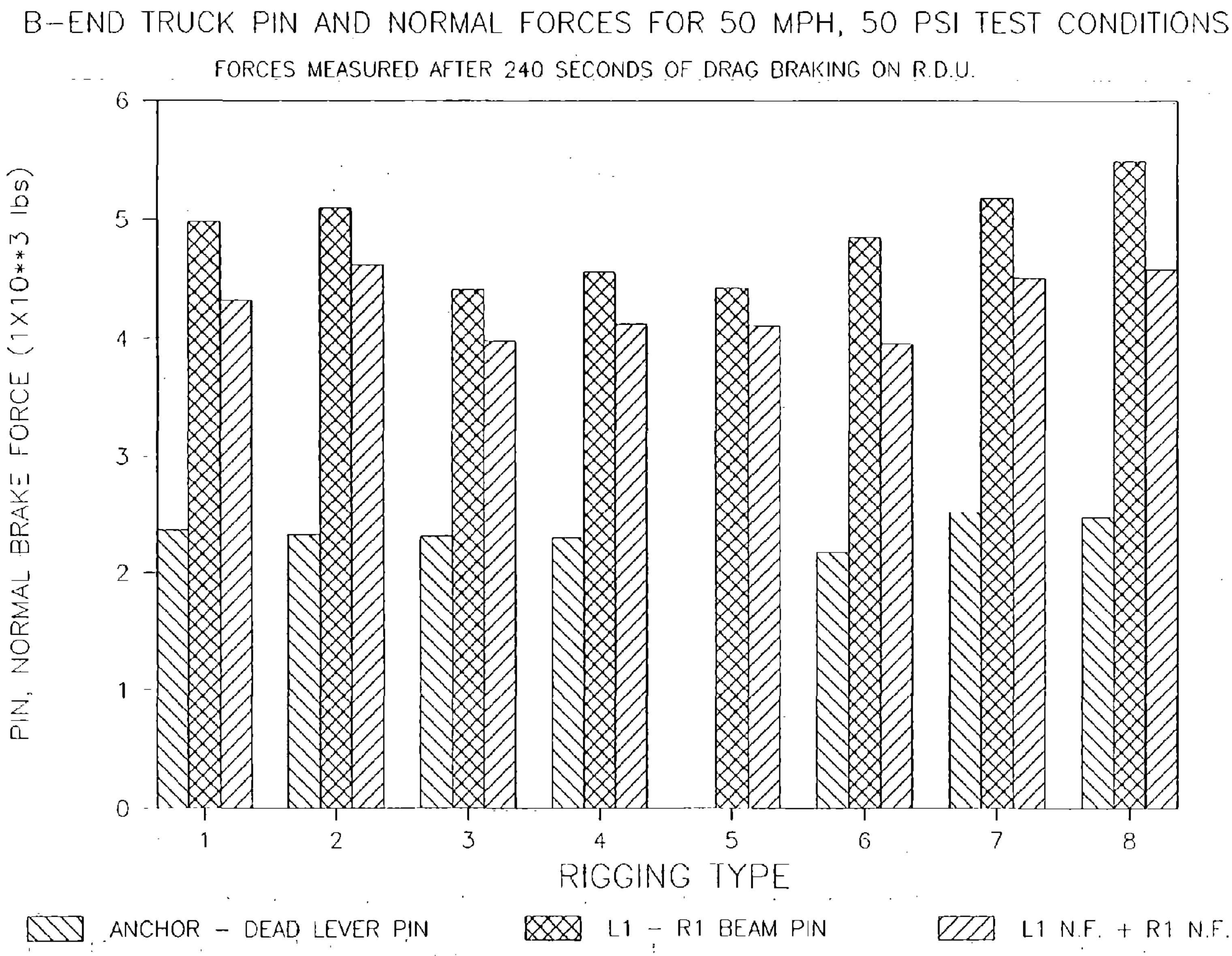

B-END TRUCK PIN AND NORMAL FORCES FOR 20 MPH, 25 PSI TEST CONDITIONS
FORCES MEASURED AFTER 240 SECONDS OF DRAG BRAKING ON R.D.U.
PIN, NORMAL BRAKE FORCE (1X10**3 lbs)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
1
2
3
4
5
6
7
8
RIGGING TYPE
ANCHOR - DEAD LEVER PIN
L1 - R1 BEAM PIN
L1 N.F. + R1 N.F.


B-END TRUCK PIN AND NORMAL FORCES FOR 40 MPH, 25 PSI TEST CONDITIONS
FORCES MEASURED AFTER 240 SECONDS OF DRAG BRAKING ON R.D.U.
PIN, NORMAL BRAKE FORCE (1X10**3 lbs)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
7
8
RIGGING TYPE
ANCHOR - DEAD LEVER PIN
L1 - R1 BEAM PIN
L1 N.F. + R1 N.F.

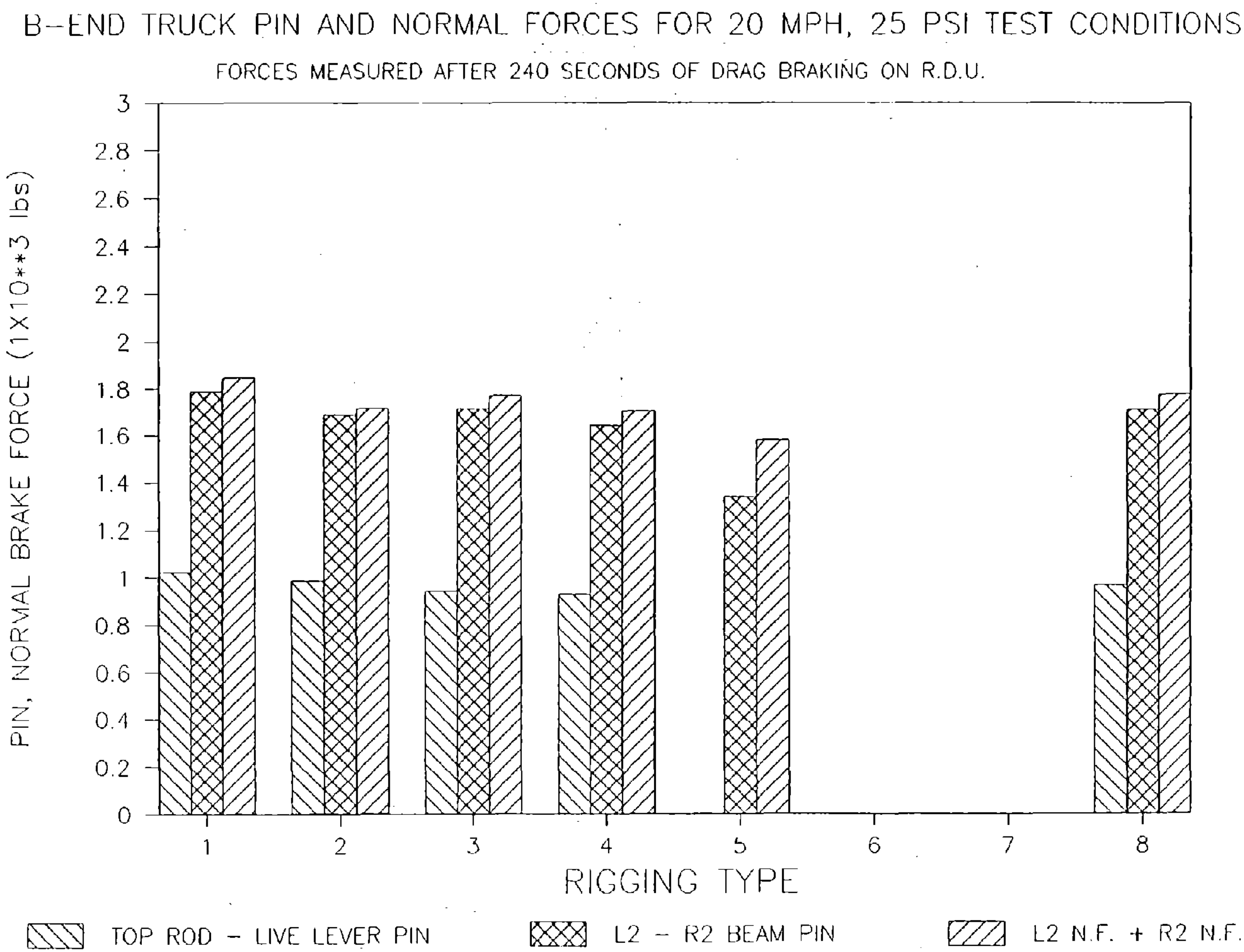

B-END TRUCK PIN AND NORMAL FORCES FOR 50 MPH, 25 PSI TEST CONDITIONS
FORCES MEASURED AFTER 240 SECONDS OF DRAG BRAKING ON R.D.U.
PIN, NORMAL BRAKE FORCE (1X10**3 lbs)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
7
8
RIGGING TYPE
ANCHOR - DEAD LEVER PIN
L1 - R1 BEAM PIN
L1 N.F. + R1 N.F.

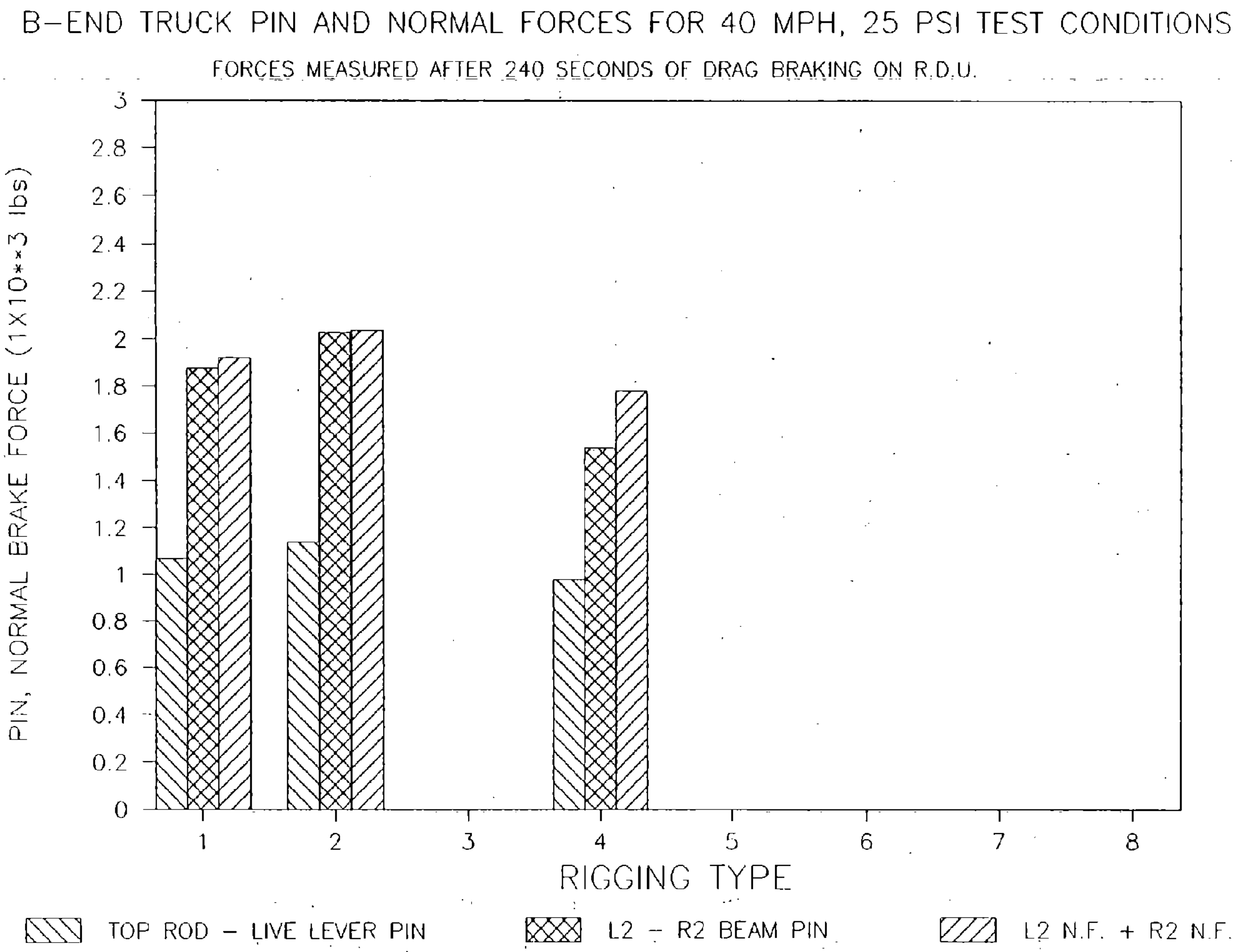

B-END TRUCK PIN AND NORMAL FORCES FOR 20 MPH, 50 PSI TEST CONDITIONS
FORCES MEASURED AFTER 240 SECONDS OF DRAG BRAKING ON R.D.U.
PIN, NORMAL BRAKE FORCE (1X10**3 lbs)
0
1
2
3
4
5
6
1
2
3
4
5
6
7
8
RIGGING TYPE
ANCHOR - DEAD LEVER PIN
L1 - R1 BEAM PIN
L1 N.F. + R1 N.F.


B-END TRUCK PIN AND NORMAL FORCES FOR 40 MPH, 50 PSI TEST CONDITIONS
FORCES MEASURED AFTER 240 SECONDS OF DRAG BRAKING ON R.D.U.
PIN, NORMAL BRAKE FORCE (1X10**3 lbs)
0
1
2
3
4
5
6
1
2
3
4
5
6
7
8
RIGGING TYPE
ANCHOR – DEAD LEVER PIN
L1 – R1 BEAM PIN
L1 N.F. + R1 N.F.



B-END TRUCK PIN AND NORMAL FORCES FOR 50 MPH, 50 PSI TEST CONDITIONS
FORCES MEASURED AFTER 240 SECONDS OF DRAG BRAKING ON R.D.U.
PIN, NORMAL BRAKE FORCE (1X10**3 lbs)
0
1
2
3
4
5
6
1
2
3
4
5
6
7
8
RIGGING TYPE
ANCHOR - DEAD LEVER PIN
L1 - R1 BEAM PIN
L1 N.F. + R1 N.F.

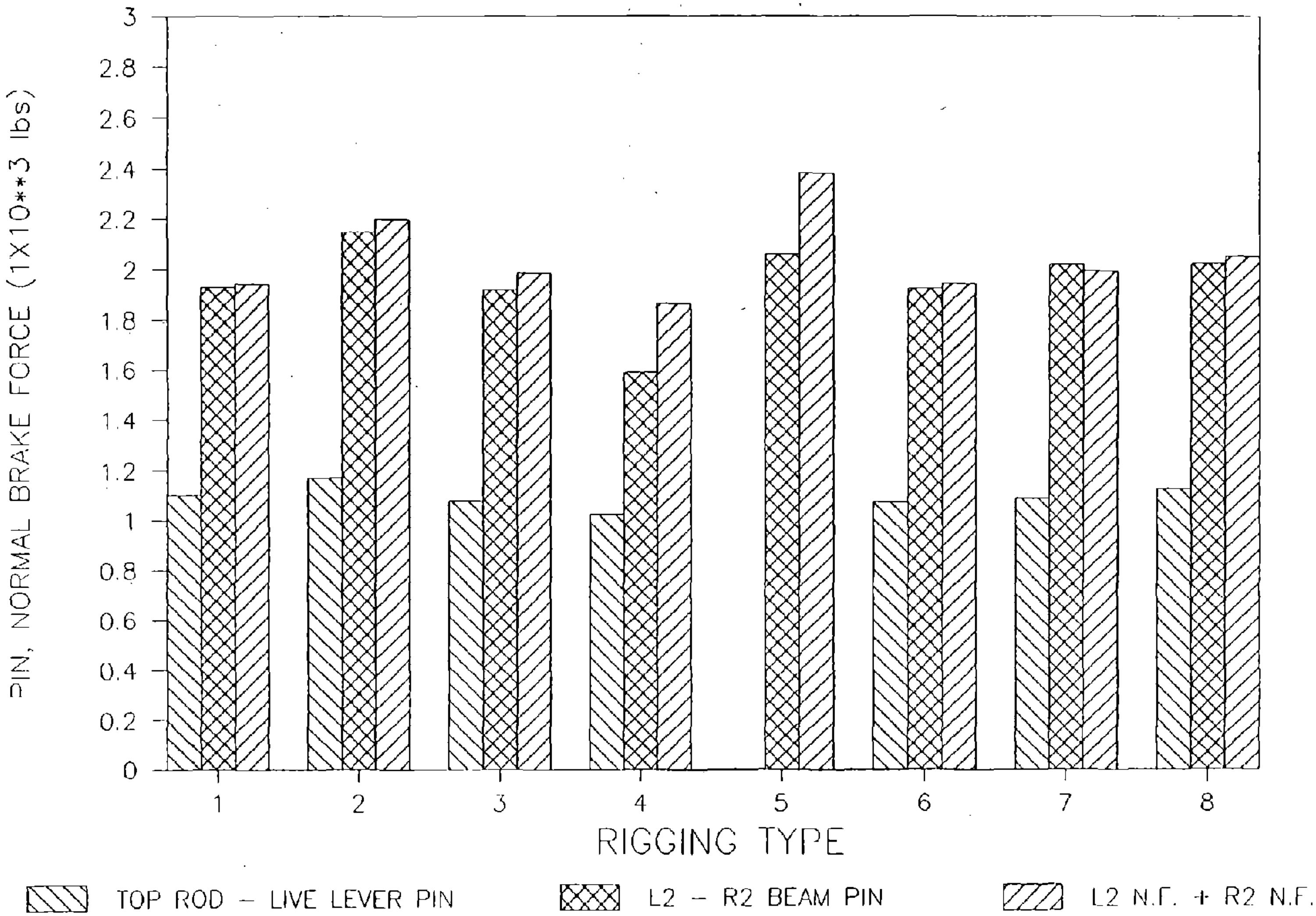

B-END TRUCK PIN AND NORMAL FORCES FOR 20 MPH, 25 PSI TEST CONDITIONS
FORCES MEASURED AFTER 240 SECONDS OF DRAG BRAKING ON R.D.U.
PIN, NORMAL BRAKE FORCE (1X10**3 lbs)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
7
8
RIGGING TYPE
TOP ROD - LIVE LEVER PIN
L2 - R2 BEAM PIN
L2 N.F. + R2 N.F.



B-END TRUCK PIN AND NORMAL FORCES FOR 40 MPH, 25 PSI TEST CONDITIONS
FORCES MEASURED AFTER 240 SECONDS OF DRAG BRAKING ON R.D.U.
PIN, NORMAL BRAKE FORCE (1X10**3 lbs)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
7
8
RIGGING TYPE
TOP ROD - LIVE LEVER PIN
L2 - R2 BEAM PIN
L2 N.F. + R2 N.F.

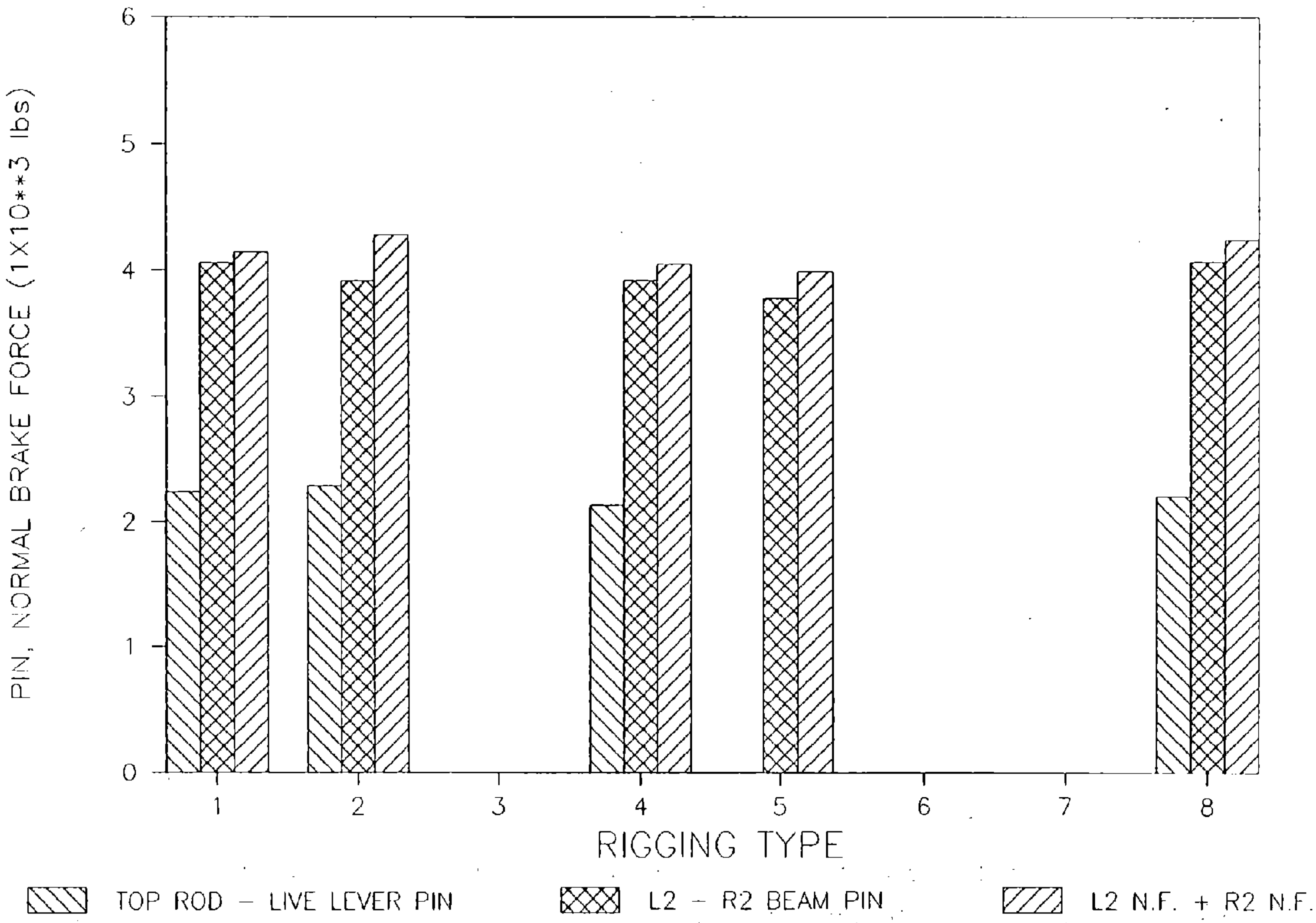
B-END TRUCK PIN AND NORMAL FORCES FOR 50 MPH, 25 PSI TEST CONDITIONS

FORCES MEASURED AFTER 240 SECONDS OF DRAG BRAKING ON R.D.U.



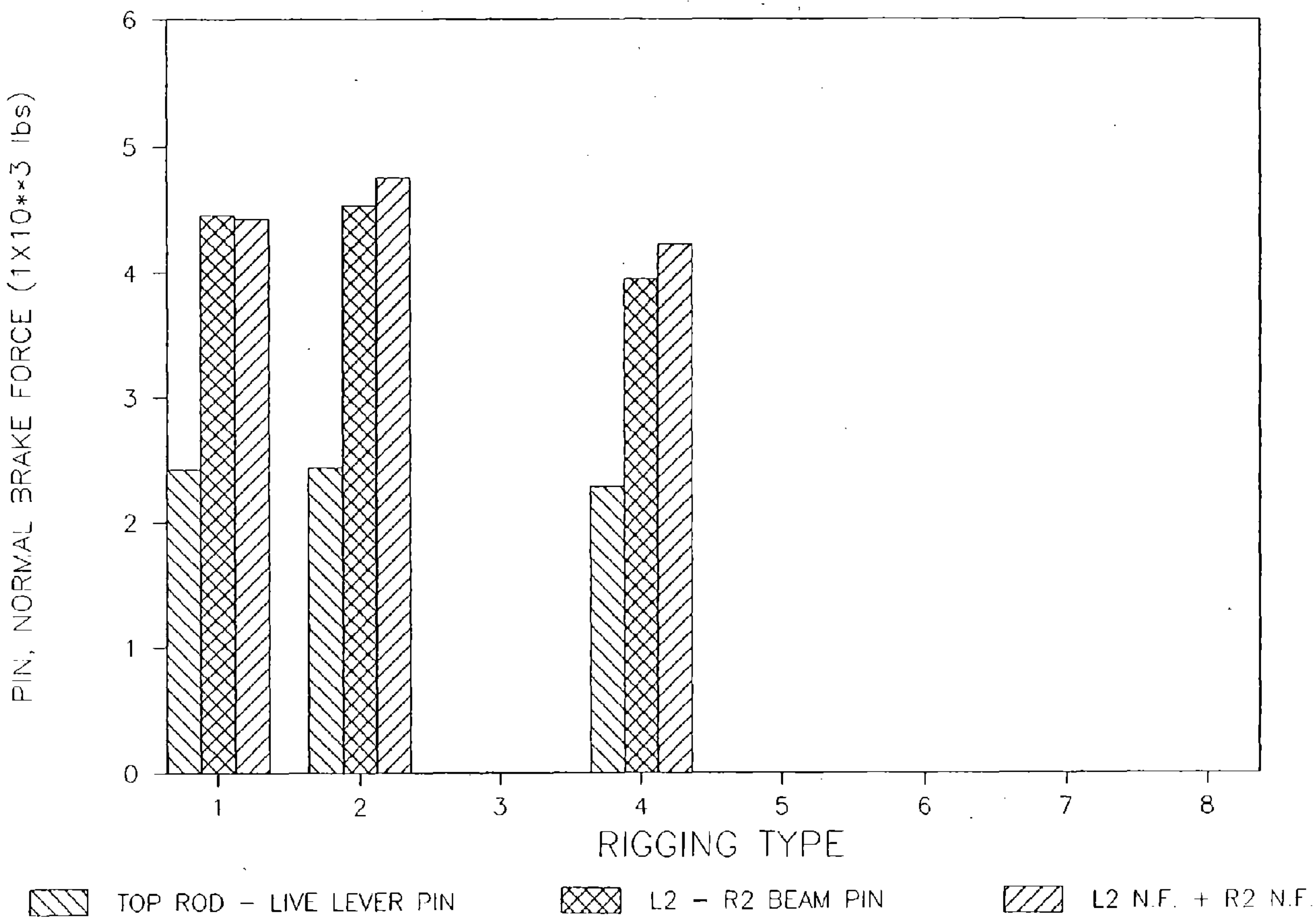
B-END TRUCK PIN AND NORMAL FORCES FOR 20 MPH, 50 PSI TEST CONDITIONS

FORCES MEASURED AFTER 240 SECONDS OF DRAG BRAKING ON R.D.U.



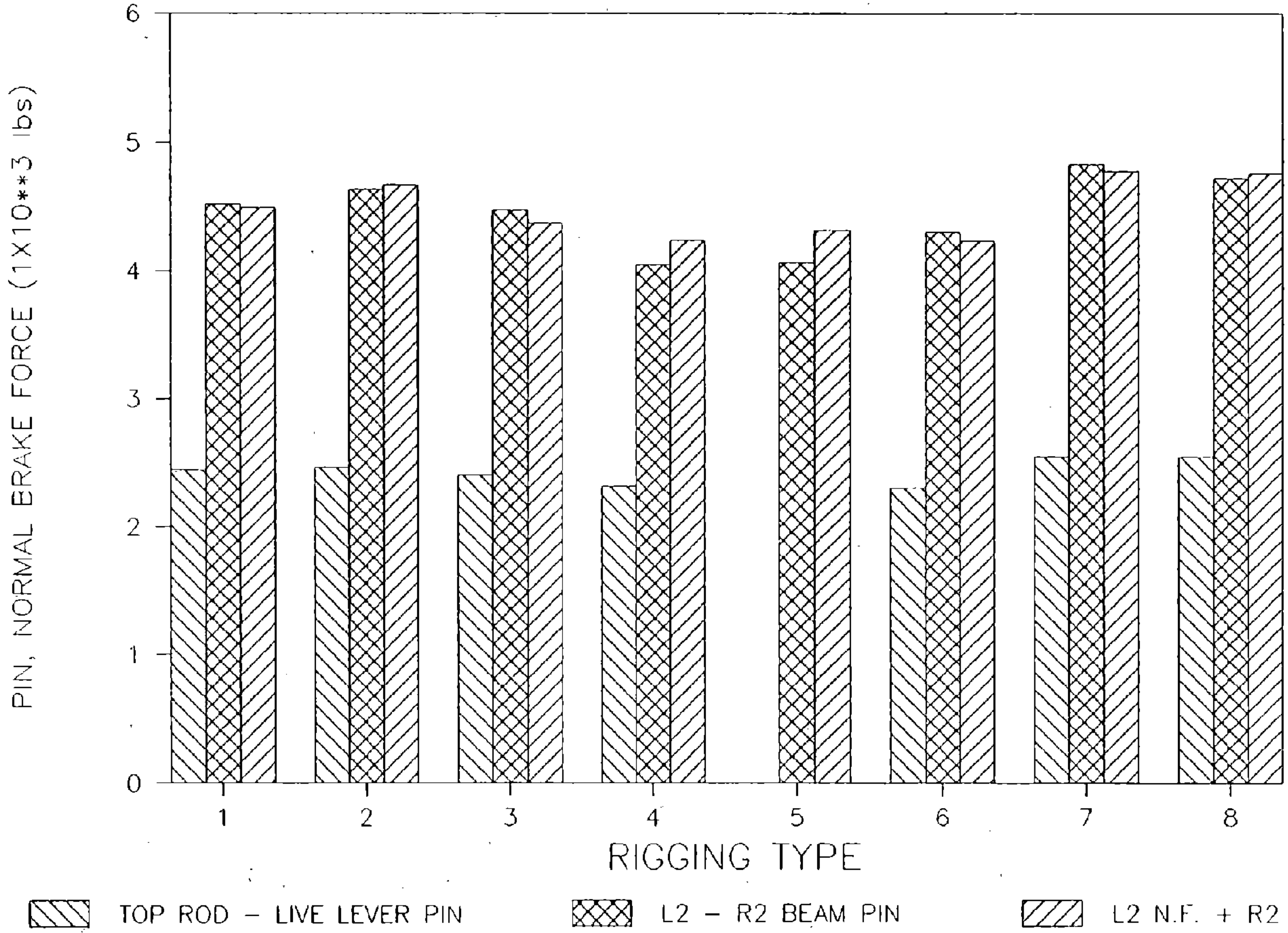
B-END TRUCK PIN AND NORMAL FORCES FOR 40 MPH, 50 PSI TEST CONDITIONS

FORCES MEASURED AFTER 240 SECONDS OF DRAG BRAKING ON R.D.U.



B-END TRUCK PIN AND NORMAL FORCES FOR 50 MPH, 50 PSI TEST CONDITIONS

FORCES MEASURED AFTER 240 SECONDS OF DRAG BRAKING ON R.D.U.



APPENDIX C

B-End Truck Rigging Efficiencies
Measured During Testing on the R.D.U.

TABLE 1. B-END TRUCK BRAKE RIGGING EFFICIENCIES MEASURED DURING TESTING ON R.D.U.

SPEED (mph)	BRAKE CYLINDER PRESSURE (psi)	ELAPSED TIME (sec)	PARAMETER	RIGGING TYPE 1		2		3		4		5		6		7		8	
				TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2
20	25	40	B-END TRUCK RIGGING EFFICIENCY	51.1	48.9	45.6	46.5	48.0	45.9	43.9	45.5	37.8	39.2					45.0	48.3
			EFFICIENCY LOSS NO. 1	41.6	42.7	44.6	42.8	44.7	46.3	46.8	46.1							44.3	42.8
			EFFICIENCY LOSS NO. 2	5.8	5.1	5.6	6.2	3.4	3.9	4.0	6.7							5.7	5.5
			EFFICIENCY LOSS NO. 3	1.5	3.3	4.3	4.6	3.9	3.9	5.3	1.7	5.5	6.6					4.9	3.4
40	25	40	B-END TRUCK RIGGING EFFICIENCY	54.1	52.3	49.2	48.7			45.6	43.9								
			EFFICIENCY LOSS NO. 1	40.7	40.8	40.9	41.4			46.4	46.6								
			EFFICIENCY LOSS NO. 2	6.0	5.5	5.3	4.6			7.5	8.3								
			EFFICIENCY LOSS NO. 3	-0.8	1.4	4.6	5.2			0.5	1.3								
50	25	40	B-END TRUCK RIGGING EFFICIENCY	52.3	53.0	53.4	54.6	50.6	49.9	46.0	48.8	64.5		49.3	49.3	55.6	47.1	52.8	52.3
			EFFICIENCY LOSS NO. 1	40.0	39.2	40.3	39.1	42.3	40.3	46.1	44.0			42.7	43.7	37.1	44.6	36.7	37.2
			EFFICIENCY LOSS NO. 2	8.6	6.2	4.5	3.4	5.0	6.7	9.3	9.2			7.4	3.6	2.0	7.5	7.1	6.6
			EFFICIENCY LOSS NO. 3	-0.9	1.6	1.7	2.8	2.2	3.1	-1.4	-2.0	3.5		0.6	3.4	5.3	0.9	3.5	3.9
20	50	40	B-END TRUCK RIGGING EFFICIENCY	52.1	53.7	49.4	49.5			55.1	51.3	48.8	47.8					58.3	54.9
			EFFICIENCY LOSS NO. 1	37.0	36.5	36.2	36.7			36.6	38.9							34.7	35.6
			EFFICIENCY LOSS NO. 2	7.2	5.4	7.8	7.0			4.6	7.6							7.1	7.6
			EFFICIENCY LOSS NO. 3	3.6	4.5	6.7	6.9			3.8	2.2	4.5	5.4					-0.2	1.8
40	50	40	B-END TRUCK RIGGING EFFICIENCY	56.6	58.1	56.0				53.9	51.2								
			EFFICIENCY LOSS NO. 1	34.8	34.9	36.5				38.6	38.3								
			EFFICIENCY LOSS NO. 2	5.2	3.6	3.8				5.9	7.9								
			EFFICIENCY LOSS NO. 3	3.4	3.4	3.7				1.7	2.6								
50	50	40	B-END TRUCK RIGGING EFFICIENCY	59.7	58.7	59.4	59.2	56.4	56.6	53.7	51.9	52.2	53.1	61.4		62.9	55.9	63.1	63.5
			EFFICIENCY LOSS NO. 1	33.3	34.3	34.2	35.1	34.8	34.6	37.0	37.2			32.5		31.3	35.9	29.2	30.1
			EFFICIENCY LOSS NO. 2	3.2	2.9	2.7	2.2	7.8	5.6	7.7	7.4			3.4		2.0	6.3	1.1	0.9
			EFFICIENCY LOSS NO. 3	3.8	4.1	3.8	3.4	1.0	3.2	1.6	3.5	4.0	-0.0	2.7		3.8	1.9	6.6	5.4

RIGGING EFFICIENCY LOSSES:
1 - EFFICIENCY LOSS BETWEEN BRAKE CYLINDER AND TOP ROD/LIVE LEVER PIN
2 - EFFICIENCY LOSS BETWEEN TOP ROD/LIVE LEVER PIN AND TRUCK LEVER BEAM PINS
3 - EFFICIENCY LOSS BETWEEN TRUCK LEVER BEAM PINS AND BRAKE SHOES

RIGGING TYPES:
1 - Original rigging components, west running direction (A-end
2 - Same as No. 1 except live lever with more bend angle
3 - Same as No. 1 except east running direction (B-end leading)
4 - Same as No. 1 except live lever with worn pin holes
5 - Same as No. 1 except live lever with worn pin holes and 5 worn pins (2 top rod pins, 2 truck lever connector pins, and dead lever/anchor pin)
6 - Same as No. 1 except worn shoe L2 and new shoe R2
7 - Same as No. 1 except worn shoe R2 and new shoe L2
8 - Same as No. 1 except top rod extended to introduce lever angularity

TABLE 2. B-END TRUCK BRAKE RIGGING EFFICIENCIES MEASURED DURING TESTING ON R.D.U.

SPEED (mph)	BRAKE CYLINDER PRESSURE (psi)	ELAPSED TIME (sec)	PARAMETER	RIGGING TYPE 1 TEST 1	1 TEST 2	2 TEST 1	2 TEST 2	3 TEST 1	3 TEST 2	4 TEST 1	4 TEST 2	5 TEST 1	5 TEST 2	6 TEST 1	6 TEST 2	7 TEST 1	7 TEST 2	8 TEST 1	8 TEST 2
20	25	240	B-END TRUCK RIGGING EFFICIENCY	58.4	55.4	49.8	54.7	50.1	51.0	51.0	48.5	42.8	43.5					52.4	51.7
			EFFICIENCY LOSS NO. 1	35.7	38.0	40.3	35.7	42.5	41.5	41.9	44.0							39.8	40.5
			EFFICIENCY LOSS NO. 2	6.3	5.9	5.4	6.8	3.2	4.0	4.8	7.5							4.5	4.3
			EFFICIENCY LOSS NO. 3	-0.5	0.8	4.5	2.7	4.2	3.5	2.3	0.1	3.0	2.8					3.2	3.5
40	25	240	B-END TRUCK RIGGING EFFICIENCY	56.7	61.1	67.4	63.2			53.2	54.3								
			EFFICIENCY LOSS NO. 1	39.0	32.4	25.8	29.0			40.7	39.6								
			EFFICIENCY LOSS NO. 2	4.7	5.6	5.6	4.3			8.3	9.2								
			EFFICIENCY LOSS NO. 3	-0.5	0.9	1.2	3.5			-2.3	-3.2								
50	25	240	B-END TRUCK RIGGING EFFICIENCY	61.2	61.5	66.1	68.2	58.2	56.4	55.7	58.1	74.2		59.5	59.8	63.6	58.5	62.0	64.9
			EFFICIENCY LOSS NO. 1	31.3	30.6	28.0	25.7	34.6	32.3	38.6	34.8			33.7	33.2	29.6	35.9	30.8	27.7
			EFFICIENCY LOSS NO. 2	7.4	6.1	4.4	4.1	5.7	8.2	9.8	9.3			6.8	1.4	2.2	5.5	5.9	3.2
			EFFICIENCY LOSS NO. 3	0.2	1.9	1.4	2.0	1.5	3.1	-4.1	-2.2	-2.2		0.0	5.6	4.7	0.0	1.3	4.2
20	50	240	B-END TRUCK RIGGING EFFICIENCY	61.4	63.1	66.0	62.8			61.2	57.2	56.4	57.6					61.3	64.7
			EFFICIENCY LOSS NO. 1	32.3	30.0	27.6	29.9			32.7	35.6							32.4	31.4
			EFFICIENCY LOSS NO. 2	5.1	2.3	4.5	3.6			2.9	3.9							3.7	1.1
			EFFICIENCY LOSS NO. 3	1.1	4.6	1.9	3.8			3.2	3.3	0.7	2.0					2.7	2.9
40	50	240	B-END TRUCK RIGGING EFFICIENCY	69.0	68.4	71.6				63.8	62.4								
			EFFICIENCY LOSS NO. 1	23.2	27.7	24.7				29.0	30.7								
			EFFICIENCY LOSS NO. 2	1.4	2.2	2.7				6.3	6.2								
			EFFICIENCY LOSS NO. 3	6.4	1.7	1.0				0.9	0.7								
50	50	240	B-END TRUCK RIGGING EFFICIENCY	70.1	65.8	70.8	72.4	64.6	64.2	63.8	65.5	66.6	63.6	63.1		74.8	68.3	72.4	73.3
			EFFICIENCY LOSS NO. 1	22.7	26.5	23.8	24.0	25.7	26.1	29.0	27.4			29.0		18.5	24.3	19.5	21.3
			EFFICIENCY LOSS NO. 2	1.2	3.2	1.3	0.9	5.9	5.3	5.2	5.2			0.5		0.5	2.5	0.1	-0.3
			EFFICIENCY LOSS NO. 3	6.0	4.6	4.1	2.8	3.8	4.5	2.0	1.8	2.4	-1.4	7.4		6.2	4.9	7.9	5.7

RIGGING EFFICIENCY LOSSES:
1 - EFFICIENCY LOSS BETWEEN BRAKE CYLINDER AND TOP ROD/LIVE LEVER PIN
2 - EFFICIENCY LOSS BETWEEN TOP ROD/LIVE LEVER PIN AND TRUCK LEVER BEAM PINS
3 - EFFICIENCY LOSS BETWEEN TRUCK LEVER BEAM PINS AND BRAKE SHOES

RIGGING TYPES:
1 - Original rigging components, west running direction (A-end
2 - Same as No. 1 except live lever with more bend angle
3 - Same as No. 1 except east running direction (B-end leading)
4 - Same as No. 1 except live lever with worn pin holes
5 - Same as No. 1 except live lever with worn pin holes and 5 worn pins (2 top rod pins, 2 truck lever connector pins, and dead lever/anchor pin)
6 - Same as No. 1 except worn shoe L2 and new shoe R2
7 - Same as No. 1 except worn shoe R2 and new shoe L2
8 - Same as No. 1 except top rod extended to introduce lever angularity

APPENDIX D

Drag Braking Data and Computed Parameters From Testing on the Track

DRAG BRAKING DATA FROM TESTING ON TRACK — DATA COLLECTED AFTER 40 SECONDS OF DRAG BRAKING

TEST PARAMETER	RIGGING TYPE 1		RIGGING TYPE 2		RIGGING TYPE 3	
	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2
TEST #	140	143	155	156	167	168
SPEED (mph)	20.5	19.7	19.5	20.7	21.3	19.0
BRAKE CYLINDER PRESSURE (psi)	25.1	24.8	25.6	25.6	24.5	25.3
ELAPSED TIME (sec)	40	40	40	40	40	40
RIGGING TYPE	1	1	2	2	3	3
WHEEL L1 NORMAL FORCE	707	787	719	650	495	502
WHEEL R1 NORMAL FORCE	549	718	630	665	260	290
WHEEL L2 NORMAL FORCE	800	897	779	735	510	512
WHEEL R2 NORMAL FORCE	766	839	700	648	520	500
MAXIMUM N.F./MINIMUM N.F.	1.46	1.25	1.24	1.13	1.94	1.76
TOTAL NORMAL FORCE TRUCK B	2532	3241	2828	2697	1792	1804
TOTAL ESTIMATED FORCE TRUCKS A & B	5447	6256	5458	5706	3459	3481
OVERALL CAR LEVER EFFICIENCY	42.0	49.8	41.2	39.3	27.3	26.5
MEASURED EFFICIENCY AT TOP ROD/LIVE LEVER PIN	51.2	54.2				
MEASURED EFFICIENCY AT TRUCK LEVER/BEAM PINS	49.9	50.5	44.1	40.8	34.7	31.0
MEASURED EFFICIENCY AT SHOE/WHEEL INTERFACES	43.5	50.5	42.6	40.7	28.2	27.5
LOADED BRAKE RATIO	2.07	2.38	2.08	1.98	1.32	1.32
EMPTY BRAKE RATIO	8.97	10.31	8.99	8.58	5.70	5.74
L1-R1 BEAM PIN FORCE	1615	1557	1281	1268	1095	1021
L1 N.F. + R1 N.F.	1257	1505	1349	1315	763	792
L2-R2 BEAM PIN FORCE	1625	1637	1645	1442	1105	1016
L2 N.F. + R2 N.F.	1566	1736	1479	1382	1029	1012
DEAD LEVER - ANCHOR PIN FORCE	794	757	697	664		
LIVE LEVER - TOP ROD PIN FORCE	829	869				
L2 INSTRUMENTED BRAKEHEAD TEMPERATURE	78.8	65.5	73.8	79.3	77.0	71.1
TEST #	144	145	157	158	169	170
SPEED (mph)	39.4	38.8	39.2	38.7	37.4	36.5
BRAKE CYLINDER PRESSURE (psi)	25.5	25.0	25.6	25.5	25.8	24.8
ELAPSED TIME (sec)	40	40	40	40	40	40
RIGGING TYPE	1	1	2	2	3	3
WHEEL L1 NORMAL FORCE	899	849	738	726	555	600
WHEEL R1 NORMAL FORCE	777	758	687	668	550	547
WHEEL L2 NORMAL FORCE	954	967	835	861	622	630
WHEEL R2 NORMAL FORCE	989	936	787	797	607	611
MAXIMUM N.F./MINIMUM N.F.	1.27	1.27	1.22	1.29	1.13	1.17
TOTAL NORMAL FORCE TRUCK B	3619	3510	3048	3052	2333	2418
TOTAL ESTIMATED FORCE TRUCKS A & B	6984	6774	5883	5891	4503	4668
OVERALL CAR LEVER EFFICIENCY	52.9	52.4	44.3	44.6	33.8	36.4
MEASURED EFFICIENCY AT TOP ROD/LIVE LEVER PIN	60.6	60.6				
MEASURED EFFICIENCY AT TRUCK LEVER/BEAM PINS	54.1	53.9	44.1	45.0	36.0	38.6
MEASURED EFFICIENCY AT SHOE/WHEEL INTERFACES	54.8	54.2	45.9	46.2	35.0	37.7
LOADED BRAKE RATIO	2.66	2.58	2.24	2.24	1.71	1.77
EMPTY BRAKE RATIO	11.51	11.16	9.69	9.71	7.47	7.69
L1-R1 BEAM PIN FORCE	1633	1626	1430	1423	1224	1224
L1 N.F. + R1 N.F.	1676	1607	1426	1394	1105	1147
L2-R2 BEAM PIN FORCE	1943	1852	1500	1550	1177	1254
L2 N.F. + R2 N.F.	1943	1907	1622	1658	1229	1271
DEAD LEVER - ANCHOR PIN FORCE	851	811	757	754		
LIVE LEVER - TOP ROD PIN FORCE	1060	980				
L2 INSTRUMENTED BRAKEHEAD TEMPERATURE	74.9	94.9	83.6	89.3	83.5	64.0

RIGGING TYPES:

1 - Original rigging components, B-end leading

2 - Same as No. 1 except live lever with more bend angle and 2 worn pins (top rod/live lever pin and live lever/truck lever connector pin)

3 - Same as No. 1 except live lever with worn pin holes and 5 worn pins (2 top rod pins, 2 truck lever connector pins, and dead lever/anchor pin)

DRAG BRAKING DATA FROM TESTING ON TRACK — DATA COLLECTED AFTER 120 SECONDS OF DRAG BRAKING

TEST PARAMETER	RIGGING TYPE 1		RIGGING TYPE 2		RIGGING TYPE 3	
	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2
TEST #	140	143	155	156	167	168
SPEED (mph)	20.2	19.1	20.3	20.3	20.5	20.1
BRAKE CYLINDER PRESSURE (psi)	24.7	25.0	25.4	25.3	24.4	25.0
ELAPSED TIME (sec)	120	120	120	120	120	120
RIGGING TYPE	1	1	2	2	3	3
WHEEL L1 NORMAL FORCE	732	861	727	729	526	552
WHEEL R1 NORMAL FORCE	662	716	696	599	290	500
WHEEL L2 NORMAL FORCE	829	900	824	804	559	589
WHEEL R2 NORMAL FORCE	865	943	688	756	547	576
MAXIMUM N.F./MINIMUM N.F.	1.31	1.32	1.20	1.34	1.93	1.18
TOTAL NORMAL FORCE TRUCK B	3089	3419	2936	2888	1923	2215
TOTAL ESTIMATED FORCE TRUCKS A & B	5962	6599	5666	5575	3711	4276
OVERALL CAR LEVER EFFICIENCY	46.6	51.0	43.1	42.5	29.4	33.1
MEASURED EFFICIENCY AT TOP ROD/LIVE LEVER PIN	55.3	59.1				
MEASURED EFFICIENCY AT TRUCK LEVER/BEAM PINS	54.7	54.4	46.0	47.0	36.6	34.8
MEASURED EFFICIENCY AT SHOE/WHEEL INTERFACES	48.2	52.8	44.6	44.0	30.4	34.2
LOADED BRAKE RATIO	2.27	2.51	2.15	2.12	1.41	1.63
EMPTY BRAKE RATIO	9.92	10.87	9.33	9.18	6.11	7.04
L1-R1 BEAM PIN FORCE	1774	1678	1398	1424	1113	1120
L1 N.F. + R1 N.F.	1393	1577	1423	1328	817	1051
L2-R2 BEAM PIN FORCE	1727	1845	1631	1663	1203	1130
L2 N.F. + R2 N.F.	1694	1842	1512	1561	1106	1164
DEAD LEVER - ANCHOR PIN FORCE	868	826	719	732		
LIVE LEVER - TOP ROD PIN FORCE	865	956				
L2 INSTRUMENTED BRAKEHEAD TEMPERATURE	80.2	67.0	74.7	79.0	77.9	71.1
TEST #	144	145	157	158	169	170
SPEED (mph)	39.4	41.4	40.3	40.2	39.2	39.7
BRAKE CYLINDER PRESSURE (psi)	25.3	25.4	25.4	25.4	25.3	24.6
ELAPSED TIME (sec)	120	120	120	120	120	120
RIGGING TYPE	1	1	2	2	3	3
WHEEL L1 NORMAL FORCE	942	860	846	854	654	668
WHEEL R1 NORMAL FORCE	884	827	819	786	502	502
WHEEL L2 NORMAL FORCE	1038	989	985	969	706	715
WHEEL R2 NORMAL FORCE	1054	973	926	938	726	709
MAXIMUM N.F./MINIMUM N.F.	1.19	1.20	1.20	1.23	1.45	1.42
TOTAL NORMAL FORCE TRUCK B	3917	3670	3575	3547	2587	2594
TOTAL ESTIMATED FORCE TRUCKS A & B	7561	7083	6900	6847	4993	5007
OVERALL CAR LEVER EFFICIENCY	57.7	53.9	52.4	52.1	38.1	39.3
MEASURED EFFICIENCY AT TOP ROD/LIVE LEVER PIN	63.6	62.3				
MEASURED EFFICIENCY AT TRUCK LEVER/BEAM PINS	59.4	56.3	51.3	53.5	40.3	40.7
MEASURED EFFICIENCY AT SHOE/WHEEL INTERFACES	59.7	55.8	54.3	53.9	39.4	40.7
LOADED BRAKE RATIO	2.87	2.69	2.62	2.60	1.90	1.90
EMPTY BRAKE RATIO	12.45	11.67	11.37	11.28	8.23	8.25
L1-R1 BEAM PIN FORCE	1634	1714	1609	1687	1271	1222
L1 N.F. + R1 N.F.	1826	1707	1665	1640	1155	1170
L2-R2 BEAM PIN FORCE	2064	1992	1769	1832	1373	1375
L2 N.F. + R2 N.F.	2091	1963	1910	1907	1432	1424
DEAD LEVER - ANCHOR PIN FORCE	911	846	948	861		
LIVE LEVER - TOP ROD PIN FORCE	1043	1024				
L2 INSTRUMENTED BRAKEHEAD TEMPERATURE	79.1	98.5	92.0	88.9	85.4	67.1

RIGGING TYPES:

1 - Original rigging components, B-end leading
2 - Same as No. 1 except live lever with zero band angle and 2 worn pins (top rod/live lever pin and live lever/truck lever connector pin)
3 - Same as No. 1 except live lever with worn pin holes and 5 worn pins
[illegible]

DRAG BRAKING DATA FROM TESTING ON TRACK — DATA COLLECTED AFTER 40 SECONDS OF DRAG BRAKING

TEST PARAMETER	RIGGING TYPE 1 TEST 1	RIGGING TYPE 1 TEST 2	RIGGING TYPE 2 TEST 1	RIGGING TYPE 2 TEST 2	RIGGING TYPE 3 TEST 1	RIGGING TYPE 3 TEST 2
TEST #	146	147	159	160	171	172
SPEED (mph)	51.0	49.3	48.9	47.6	48.0	48.9
BRAKE CYLINDER PRESSURE (psi)	25.5	25.3	25.6	25.7	25.1	25.8
ELAPSED TIME (sec)	40	40	40	40	40	40
RIGGING TYPE	1	1	2	2	3	3
WHEEL L1 NORMAL FORCE	959	862	789	693	619	595
WHEEL R1 NORMAL FORCE	831	892	721	625	457	308
WHEEL L2 NORMAL FORCE	936	974	915	796	658	644
WHEEL R2 NORMAL FORCE	952	937	846	725	647	643
MAXIMUM N.F./MINIMUM N.F.	1.24	1.13	1.27	1.27	1.44	1.66
TOTAL NORMAL FORCE TRUCK B	3370	3565	3270	2939	2381	2269
TOTAL ESTIMATED FORCE TRUCKS A & B	6495	7075	6311	5479	4595	4390
OVERALL CAR LEVER EFFICIENCY	52.3	54.1	47.5	41.3	35.4	32.8
MEASURED EFFICIENCY AT TOP ROD/LIVE LEVER PIN	66.6	65.4				
MEASURED EFFICIENCY AT TRUCK LEVER/BEAM PINS	51.8	52.8	45.2	42.5	37.0	35.6
MEASURED EFFICIENCY AT SHOE/WHEEL INTERFACES	54.2	56.0	49.3	42.7	36.7	34.0
LOADED BRAKE RATIO	2.83	2.69	2.40	2.08	1.75	1.67
EMPTY BRAKE RATIO	11.38	11.65	10.40	9.03	7.57	7.22
L1-R1 BEAM PIN FORCE	1542	1528	1474	1296	1091	1194
L1 N.F. + R1 N.F.	1590	1754	1510	1318	1076	902
L2-R2 BEAM PIN FORCE	1575	1927	1577	1538	1307	1277
L2 N.F. + R2 N.F.	1869	1911	1761	1521	1305	1287
DEAD LEVER - ANCHOR PIN FORCE	803	830	780	724		
LIVE LEVER - TOP ROD PIN FORCE	1600	1636				
L2 INSTRUMENTED BRAKEHEAD TEMPERATURE	85.5	93.5	89.8	87.9	82.7	94.9
TEST #	148	149	161	162		
SPEED (mph)	19.9	20.0	18.9	19.3		
BRAKE CYLINDER PRESSURE (psi)	50.5	50.1	50.7	50.2		
ELAPSED TIME (sec)	40	40	40	40		
RIGGING TYPE	1	1	2	2		
WHEEL L1 NORMAL FORCE	1641	1663	1633	1613		
WHEEL R1 NORMAL FORCE	1579	1579	1716	1648		
WHEEL L2 NORMAL FORCE	1902	1797	1758	1749		
WHEEL R2 NORMAL FORCE	1751	1763	1666	1643		
MAXIMUM N.F./MINIMUM N.F.	1.14	1.14	1.08	1.08		
TOTAL NORMAL FORCE TRUCK B	6812	6802	6773	6653		
TOTAL ESTIMATED FORCE TRUCKS A & B	13148	13128	13071	12841		
OVERALL CAR LEVER EFFICIENCY	50.3	50.6	49.8	49.5		
MEASURED EFFICIENCY AT TOP ROD/LIVE LEVER PIN	61.3	63.4				
MEASURED EFFICIENCY AT TRUCK LEVER/BEAM PINS	55.4	57.0	51.7	52.0		
MEASURED EFFICIENCY AT SHOE/WHEEL INTERFACES	52.1	52.4	51.6	51.2		
LOADED BRAKE RATIO	5.00	4.99	4.97	4.88		
EMPTY BRAKE RATIO	21.66	21.63	21.53	21.15		
L1-R1 BEAM PIN FORCE	3652	3697	3401	3441		
L1 N.F. + R1 N.F.	3220	3242	3349	3261		
L2-R2 BEAM PIN FORCE	3601	3700	3382	3309		
L2 N.F. + R2 N.F.	3593	3560	3424	3392		
DEAD LEVER - ANCHOR PIN FORCE	1761	1801	1693	1709		
LIVE LEVER - TOP ROD PIN FORCE	2019	2057				
L2 INSTRUMENTED BRAKEHEAD TEMPERATURE	92.2	94.7	154.5	85.3		

RIGGING TYPES:

1 - Original rigging components, B-end leading

2 - Same as No. 1 except live lever with more bend angle and 2 worn pins (top rod/live lever pin and live lever/truck lever connector pin)

3 - Same as No. 1 except live lever with worn pin holes and 5 worn pins ([illegible], 1 truck lever connector pins, and dead lever/anchor pin)

DRAG BRAKING DATA FROM TESTING ON TRACK . DATA COLLECTED AFTER 120 SECONDS OF DRAG BRAKING

TEST PARAMETER	RIGGING TYPE 1		RIGGING TYPE 2		RIGGING TYPE 3	
	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2
TEST #	145	147	159	160	171	172
SPEED (mph)	51.8	51.1	50.9	51.5	49.5	48.8
BRAKE CYLINDER PRESSURE (psi)	25.2	25.1	25.5	25.6	25.4	25.4
ELAPSED TIME (sec)	120	120	120	120	120	120
RIGGING TYPE	1	1	2	2	3	3
WHEEL L1 NORMAL FORCE	914	854	899	766	717	707
WHEEL R1 NORMAL FORCE	927	912	853	698	568	573
WHEEL L2 NORMAL FORCE	1048	1019	1088	911	781	780
WHEEL R2 NORMAL FORCE	1031	944	948	810	740	756
MAXIMUM N.F./MINIMUM N.F.	1.15	1.19	1.28	1.30	1.38	1.36
TOTAL NORMAL FORCE TRUCK B	3920	3729	3787	3185	2807	2817
TOTAL ESTIMATED FORCE TRUCKS A & B	7565	7196	7309	6148	5417	5436
OVERALL CAR LEVER EFFICIENCY	58.0	55.3	55.5	46.5	41.2	41.3
MEASURED EFFICIENCY AT TOP ROD/LIVE LEVER PIN	65.5	63.3				
MEASURED EFFICIENCY AT TRUCK LEVER/BEAM PINS	61.9	58.5	58.3	48.9	44.9	45.0
MEASURED EFFICIENCY AT SHOE/WHEEL INTERFACES	60.1	57.3	57.4	48.1	42.7	42.8
LOADED BRAKE RATIO	2.88	2.74	2.78	2.34	2.06	2.07
EMPTY BRAKE RATIO	12.45	11.86	12.04	10.13	8.92	8.96
L1-R1 BEAM PIN FORCE	1961	1808	1860	1600	1421	1425
L1 N.F. + R1 N.F.	1840	1766	1751	1465	1285	1281
L2-R2 BEAM PIN FORCE	2082	2002	1985	1636	1531	1538
L2 N.F. + R2 N.F.	2079	1963	2036	1721	1521	1536
DEAD LEVER - ANCHOR PIN FORCE	896	855	917	803		
LIVE LEVER - TOP ROD PIN FORCE	1067	1029				
L2 INSTRUMENTED BRAKEHEAD TEMPERATURE	93.4	104.7	99.6	87.2	87.2	98.4
TEST #	148	149	161	162		
SPEED (mph)	20.5	20.4	20.3	20.9		
BRAKE CYLINDER PRESSURE (psi)	49.9	50.1	50.7	49.8		
ELAPSED TIME (sec)	120	120	120	120		
RIGGING TYPE	1	1	2	2		
WHEEL L1 NORMAL FORCE	1755	1754	1629	1658		
WHEEL R1 NORMAL FORCE	1658	1673	1715	1647		
WHEEL L2 NORMAL FORCE	2062	1990	1870	1881		
WHEEL R2 NORMAL FORCE	1877	1923	1681	1740		
MAXIMUM N.F./MINIMUM N.F.	1.26	1.19	1.15	1.14		
TOTAL NORMAL FORCE TRUCK B	7372	7340	6895	6926		
TOTAL ESTIMATED FORCE TRUCKS A & B	14227	14167	13308	13366		
OVERALL CAR LEVER EFFICIENCY	55.1	54.6	51.2	51.9		
MEASURED EFFICIENCY AT TOP ROD/LIVE LEVER PIN	67.8	67.6				
MEASURED EFFICIENCY AT TRUCK LEVER/BEAM PINS	61.9	62.2	53.0	53.8		
MEASURED EFFICIENCY AT SHOE/WHEEL INTERFACES	57.1	56.5	53.9	53.7		
LOADED BRAKE RATIO	5.41	5.39	5.06	5.08		
EMPTY BRAKE RATIO	23.44	23.34	21.92	22.02		
L1-R1 BEAM PIN FORCE	4170	4121	3538	3584		
L1 N.F. + R1 N.F.	3412	3427	3344	3305		
L2-R2 BEAM PIN FORCE	3871	3958	3356	3346		
L2 N.F. + R2 N.F.	3939	3913	3552	3621		
DEAD LEVER - ANCHOR PIN FORCE	1883	1881	1657	1702		
LIVE LEVER - TOP ROD PIN FORCE	2189	2197				
L2 INSTRUMENTED BRAKEHEAD TEMPERATURE	92.2	96.3	148.5	87.6		

RIGGING TYPES:

1 - Original rigging components, B-end leading
2 - Same as No. 1 except live lever with more bend angle and 2 worn pins (top rod/live lever pin and live lever/truck lever connector pin)
3 - Same as No. 1 except live lever with worn pin holes and 5 worn pins (2 top rod pins, 2 truck lever connector pins, and dead lever/anchor pin)

DRAG BRAKING DATA FROM TESTING ON TRACK   DATA COLLECTED AFTER 40 SECONDS OF DRAG BRAKING

TEST PARAMETER	RIGGING TYPE 1 TEST 1	RIGGING TYPE 1 TEST 2	RIGGING TYPE 2 TEST 1	RIGGING TYPE 2 TEST 2	RIGGING TYPE 3 TEST 1	RIGGING TYPE 3 TEST 2
TEST #	150	151	153	164		
SPEED (mph)	38.0	38.1	38.1	38.4		
BRAKE CYLINDER PRESSURE (psi)	50.1	50.3	50.2	49.9		
ELAPSED TIME (sec)	40	40	40	40		
RIGGING TYPE	1	1	2	2		
WHEEL L1 NORMAL FORCE	1704	1647	1569	1485		
WHEEL R1 NORMAL FORCE	1754	1759	1530	1401		
WHEEL L2 NORMAL FORCE	1903	1882	1803	1709		
WHEEL R2 NORMAL FORCE	1825	1776	1590	1508		
MAXIMUM N.F./MINIMUM N.F.	1.12	1.14	1.18	1.22		
TOTAL NORMAL FORCE TRUCK B	7386	7064	6492	6103		
TOTAL ESTIMATED FORCE TRUCKS A & B	13868	13633	12530	11779		
OVERALL CAR LEVER EFFICIENCY	53.5	52.4	48.2	45.7		
MEASURED EFFICIENCY AT TOP ROD/LIVE LEVER PIN	64.8	63.5				
MEASURED EFFICIENCY AT TRUCK LEVER/BEAM PINS	58.8	57.1	50.6	52.3		
MEASURED EFFICIENCY AT SHOE/WHEEL INTERFACES	55.4	54.3	49.9	47.3		
LOADED BRAKE RATIO	5.27	5.18	4.76	4.48		
EMPTY BRAKE RATIO	22.95	22.46	20.64	19.40		
L1-R1 BEAM PIN FORCE	3623	3733	3450	3505		
L1 N.F. + R1 N.F.	3458	3406	3099	2886		
L2-R2 BEAM PIN FORCE	3610	3695	3122	3250		
L2 N.F. + R2 N.F.	3728	3658	3393	3217		
DEAD LEVER - ANCHOR PIN FORCE	1759	1713	1658	1635		
LIVE LEVER - TOP ROD PIN FORCE	2103	2065				
L2 INSTRUMENTED BRAKEHEAD TEMPERATURE	105.4	111.7	97.5	103.4		
TEST #	152	154	165	166		
SPEED (mph)	46.9	46.6	49.4	49.3		
BRAKE CYLINDER PRESSURE (psi)	50.7	50.5	49.8	49.6		
ELAPSED TIME (sec)	40	40	40	40		
RIGGING TYPE	1	1	2	2		
WHEEL L1 NORMAL FORCE	1827	1703	1562	1586		
WHEEL R1 NORMAL FORCE	1914	1704	1636	1540		
WHEEL L2 NORMAL FORCE	2042	1923	1758	1793		
WHEEL R2 NORMAL FORCE	1872	1826	1595	1846		
MAXIMUM N.F./MINIMUM N.F.	1.12	1.13	1.13	1.16		
TOTAL NORMAL FORCE TRUCK B	7655	7157	6552	6564		
TOTAL ESTIMATED FORCE TRUCKS A & B	14774	13813	12645	12669		
OVERALL CAR LEVER EFFICIENCY	56.3	52.8	49.1	49.3		
MEASURED EFFICIENCY AT TOP ROD/LIVE LEVER PIN	64.6	62.0				
MEASURED EFFICIENCY AT TRUCK LEVER/BEAM PINS	56.0	55.7	52.4	51.7		
MEASURED EFFICIENCY AT SHOE/WHEEL INTERFACES	58.3	54.7	50.8	51.1		
LOADED BRAKE RATIO	5.62	5.25	4.81	4.82		
EMPTY BRAKE RATIO	24.34	22.76	20.83	20.87		
L1-R1 BEAM PIN FORCE	3549	3721	3454	3403		
L1 N.F. + R1 N.F.	3740	3407	3198	3126		
L2-R2 BEAM PIN FORCE	3774	3575	3301	3249		
L2 N.F. + R2 N.F.	3914	3750	3353	3439		
DEAD LEVER - ANCHOR PIN FORCE	1885	1642	1681	1702		
LIVE LEVER - TOP ROD PIN FORCE	2120	2027				
L2 INSTRUMENTED BRAKEHEAD TEMPERATURE	67.2	87.0	99.1	107.7		

RIGGING TYPES:

1 - Original rigging components. B-end leading

2 - Same as No. 1 except live lever with more bend angle and 2 worn pins (top rod/live lever pin and live lever/truck lever connector pin)

3 - Same as No. 1 except live lever with worn pin holes and 5 worn pins (2 top rod pins, 2 truck lever connector pins, and dead lever/anchor pin)

DRAG BRAKING DATA FROM TESTING ON TRACK — DATA COLLECTED AFTER 120 SECONDS OF DRAG BRAKING

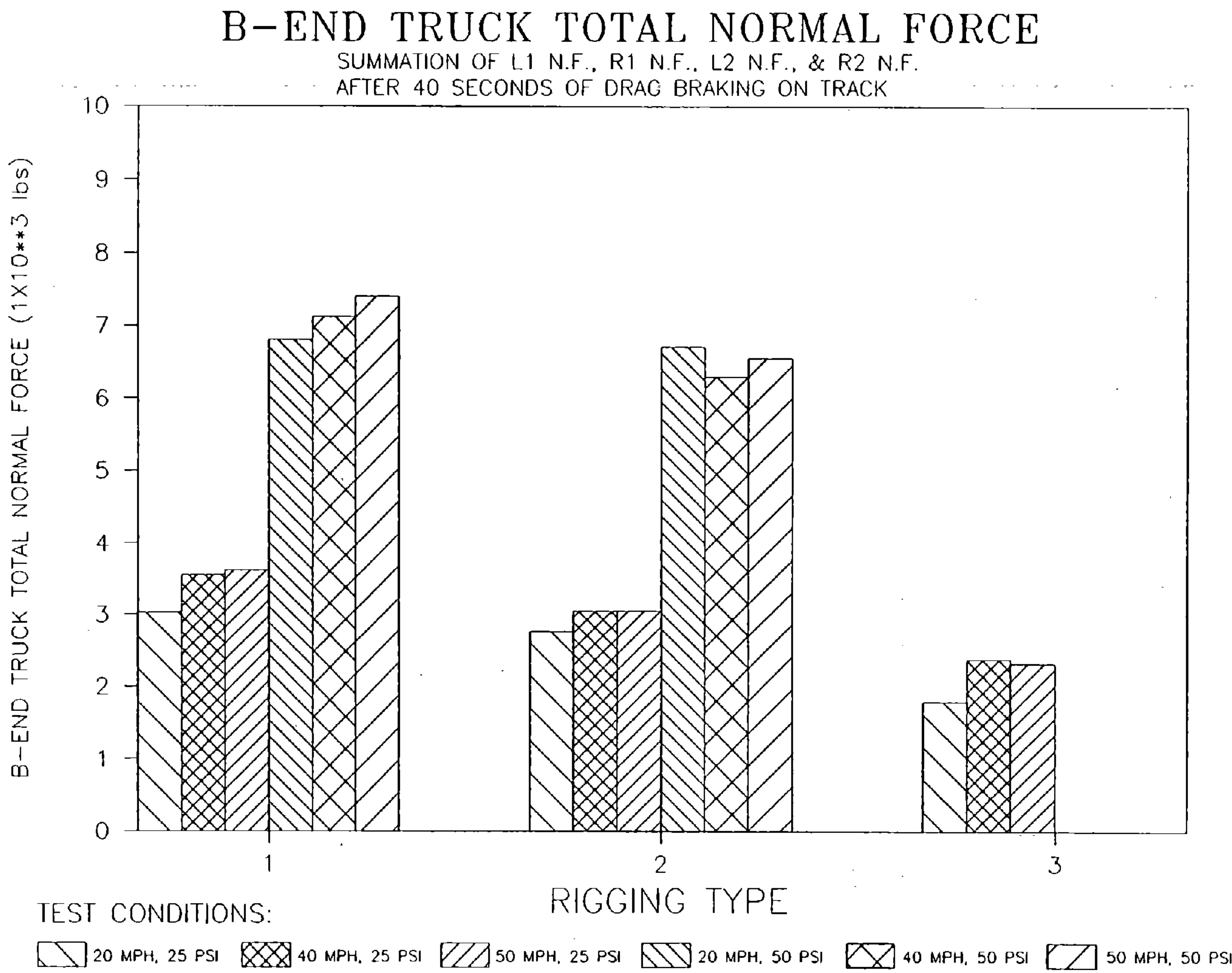
TEST PARAMETER	RIGGING TYPE 1		RIGGING TYPE 2		RIGGING TYPE 3	
	TEST 1	TEST 2	TEST 1	TEST 2	TEST 1	TEST 2
TEST #	150	151	163	164		
SPEED (mph)	40.1	41.2	41.2	41.1		
BRAKE CYLINDER PRESSURE (psi)	50.0	50.1	49.9	49.7		
ELAPSED TIME (sec)	120	120	120	120		
RIGGING TYPE	1	1	2	2		
WHEEL L1 NORMAL FORCE	1905	1829	1757	1650		
WHEEL R1 NORMAL FORCE	2086	1887	1652	1628		
WHEEL L2 NORMAL FORCE	2272	2268	1966	1889		
WHEEL R2 NORMAL FORCE	2012	1954	1901	1707		
MAXIMUM N.F./MINIMUM N.F.	1.17	1.24	1.19	1.16		
TOTAL NORMAL FORCE TRUCK B	8255	7937	7276	6874		
TOTAL ESTIMATED FORCE TRUCKS A & B	15932	15319	14045	13267		
OVERALL CAR LEVER EFFICIENCY	61.6	59.1	54.4	51.5		
MEASURED EFFICIENCY AT TOP ROD/LIVE LEVER PIN	74.0	70.9				
MEASURED EFFICIENCY AT TRUCK LEVER/BEAM PINS	68.0	65.5	58.5	55.9		
MEASURED EFFICIENCY AT SHOE/WHEEL INTERFACES	63.8	61.2	56.3	53.4		
LOADED BRAKE RATIO	6.06	5.82	5.34	5.04		
EMPTY BRAKE RATIO	26.25	25.24	23.13	21.86		
L1-R1 BEAM PIN FORCE	4403	4307	3941	3597		
L1 N.F. + R1 N.F.	3991	3716	3409	3278		
L2-R2 BEAM PIN FORCE	4397	4191	3626	3601		
L2 N.F. + R2 N.F.	4264	4221	3867	3596		
DEAD LEVER - ANCHOR PIN FORCE	2046	1948	1921	1827		
LIVE LEVER - TOP ROD PIN FORCE	2394	2298				
L2 INSTRUMENTED BRAKEHEAD TEMPERATURE	116.7	120.2	103.9	111.0		
TEST #	152	154	165	166		
SPEED (mph)	51.1	52.1	51.1	50.8		
BRAKE CYLINDER PRESSURE (psi)	50.2	50.3	49.6	49.6		
ELAPSED TIME (sec)	120	120	120	120		
RIGGING TYPE	1	1	2	2		
WHEEL L1 NORMAL FORCE	2035	1927	1793	1750		
WHEEL R1 NORMAL FORCE	2087	1914	1765	1739		
WHEEL L2 NORMAL FORCE	2215	2171	2034	2051		
WHEEL R2 NORMAL FORCE	2253	2053	1845	1860		
MAXIMUM N.F./MINIMUM N.F.	1.11	1.13	1.15	1.18		
TOTAL NORMAL FORCE TRUCK B	8589	8065	7437	7399		
TOTAL ESTIMATED FORCE TRUCKS A & B	16577	15565	14353	14281		
OVERALL CAR LEVER EFFICIENCY	63.8	59.8	55.9	55.7		
MEASURED EFFICIENCY AT TOP ROD/LIVE LEVER PIN	72.4	69.2				
MEASURED EFFICIENCY AT TRUCK LEVER/BEAM PINS	67.6	64.0	62.9	58.8		
MEASURED EFFICIENCY AT SHOE/WHEEL INTERFACES	66.1	61.9	57.9	57.6		
LOADED BRAKE RATIO	6.30	5.92	5.46	5.43		
EMPTY BRAKE RATIO	27.31	25.64	23.65	23.53		
L1-R1 BEAM PIN FORCE	4464	4239	4073	3974		
L1 N.F. + R1 N.F.	4121	3841	3558	3489		
L2-R2 BEAM PIN FORCE	4322	4109	4005	3579		
L2 N.F. + R2 N.F.	4468	4224	3879	3910		
DEAD LEVER - ANCHOR PIN FORCE	2111	2048	1922	1912		
LIVE LEVER - TOP ROD PIN FORCE	2350	2252				
L2 INSTRUMENTED BRAKEHEAD TEMPERATURE	77.1	96.9	107.4	118.0		

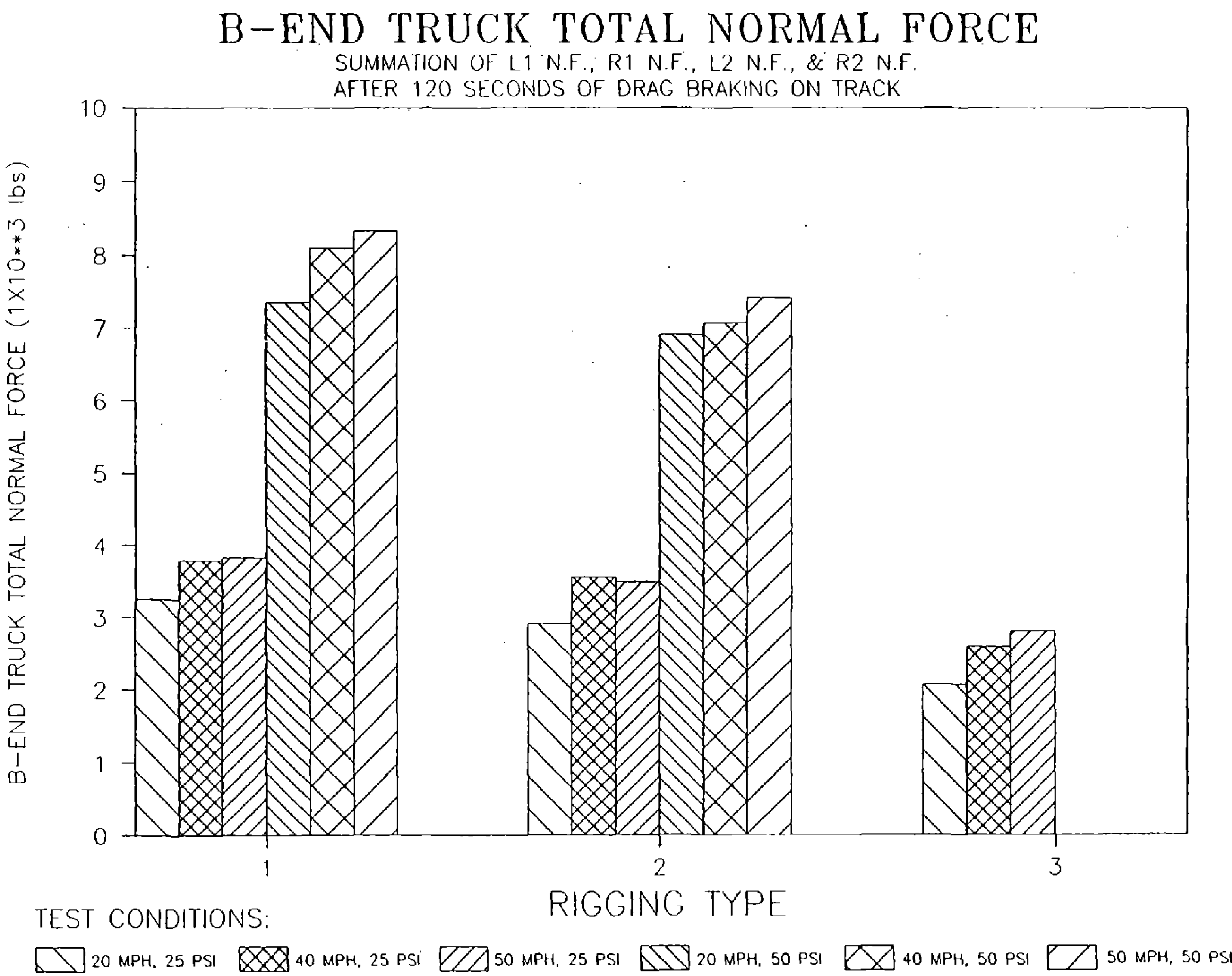
RIGGING TYPES:

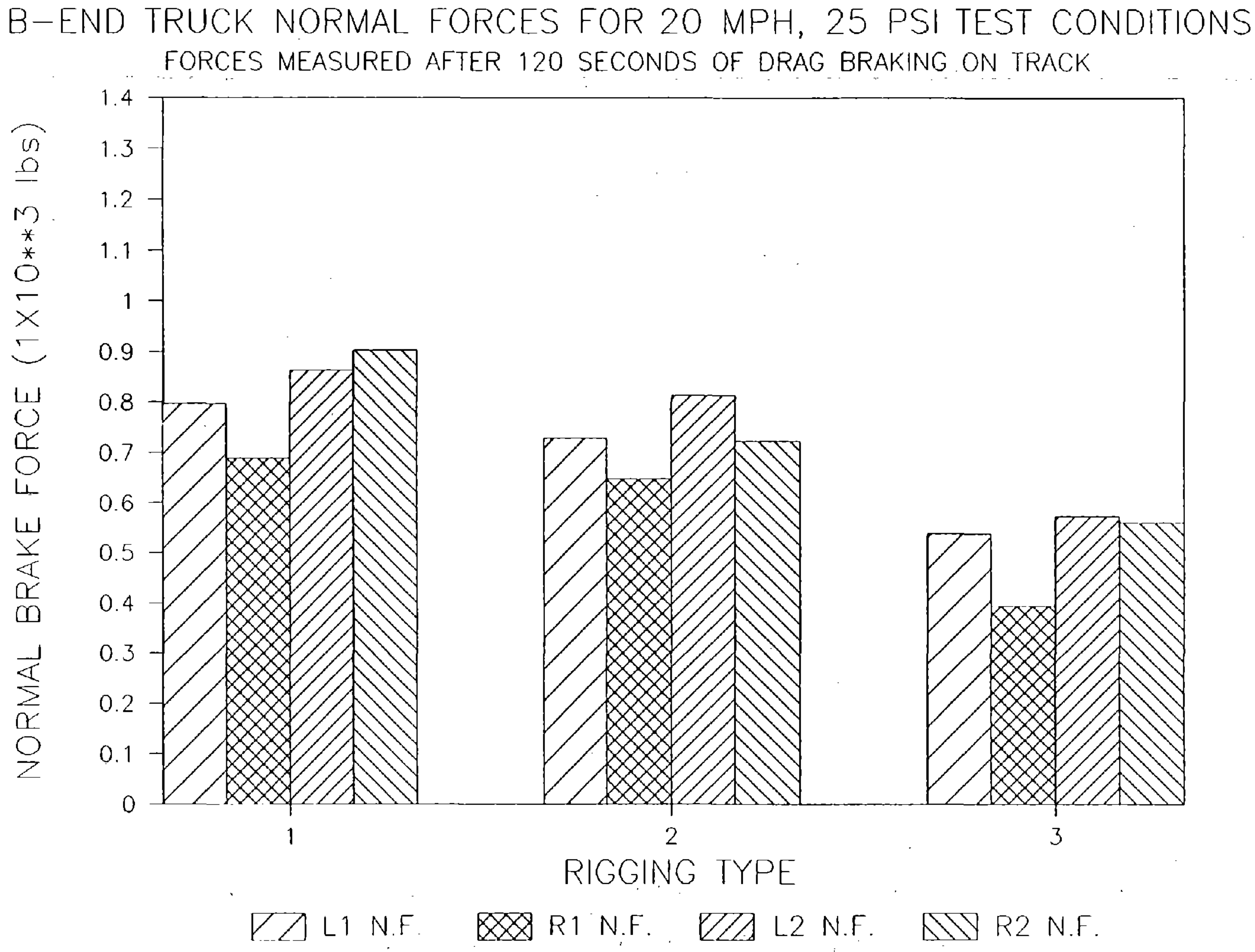
1 - Original rigging components, B end leading
2 - Same as No. 1 except live lever with more bend angle and 2 worn pins (top rod/live lever pin and live lever/truck lever connector pin)
3 - Same as No. 1 except live lever with worn pin holes and 5 worn pins (2 top rod pins, 2 truck lever connector pins, and dead lever/anchor pin)

APPENDIX E

Plots of Brake Forces and Rigging
Pin Forces From Testing on the Track

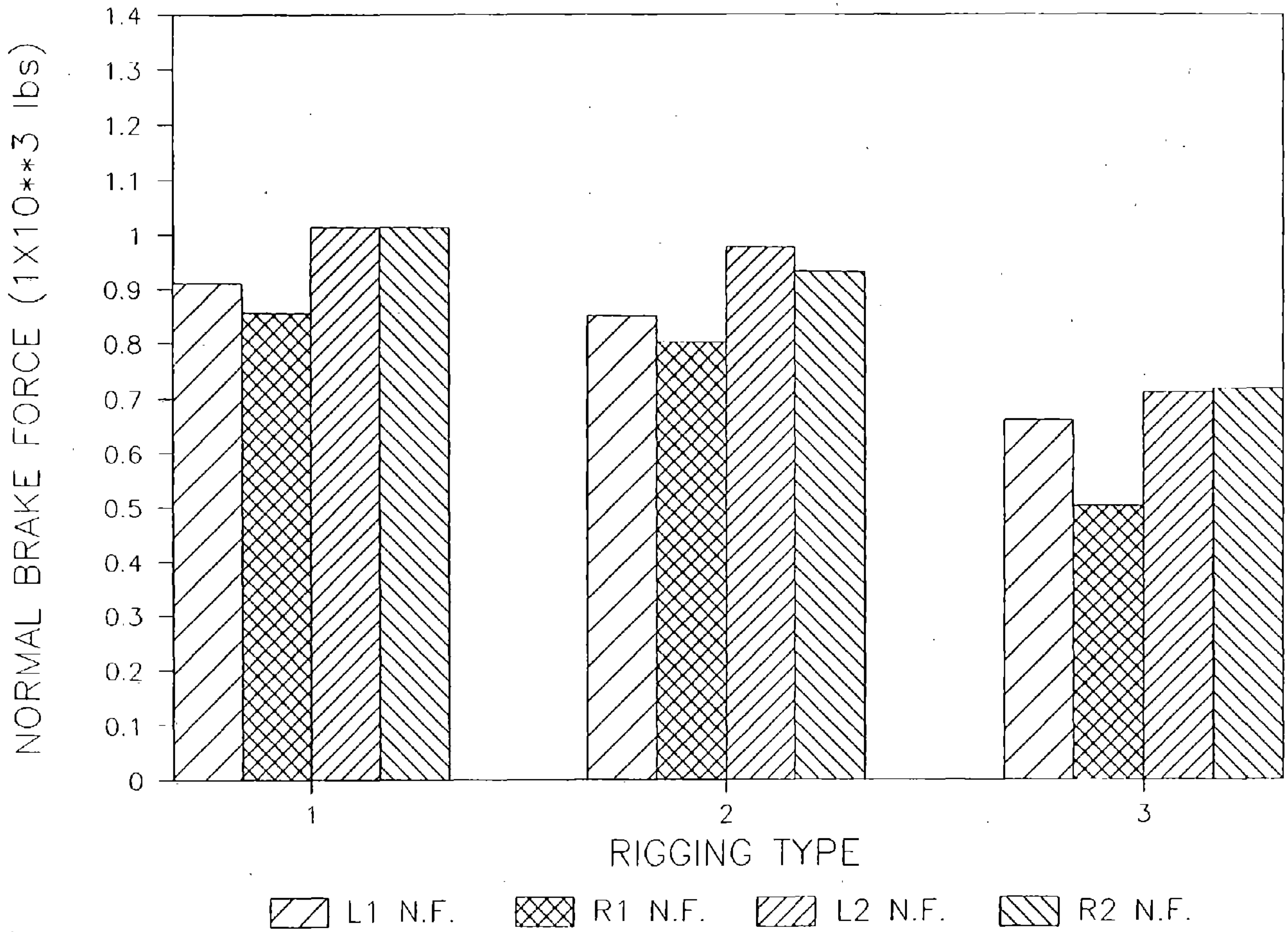

B-END TRUCK TOTAL NORMAL FORCE
SUMMATION OF L1 N.F., R1 N.F., L2 N.F., & R2 N.F.
AFTER 40 SECONDS OF DRAG BRAKING ON TRACK
B-END TRUCK TOTAL NORMAL FORCE (1X10**3 lbs)
0
1
2
3
4
5
6
7
8
9
10
1
2
3
RIGGING TYPE
TEST CONDITIONS:
20 MPH, 25 PSI
40 MPH, 25 PSI
50 MPH, 25 PSI
20 MPH, 50 PSI
40 MPH, 50 PSI
50 MPH, 50 PSI

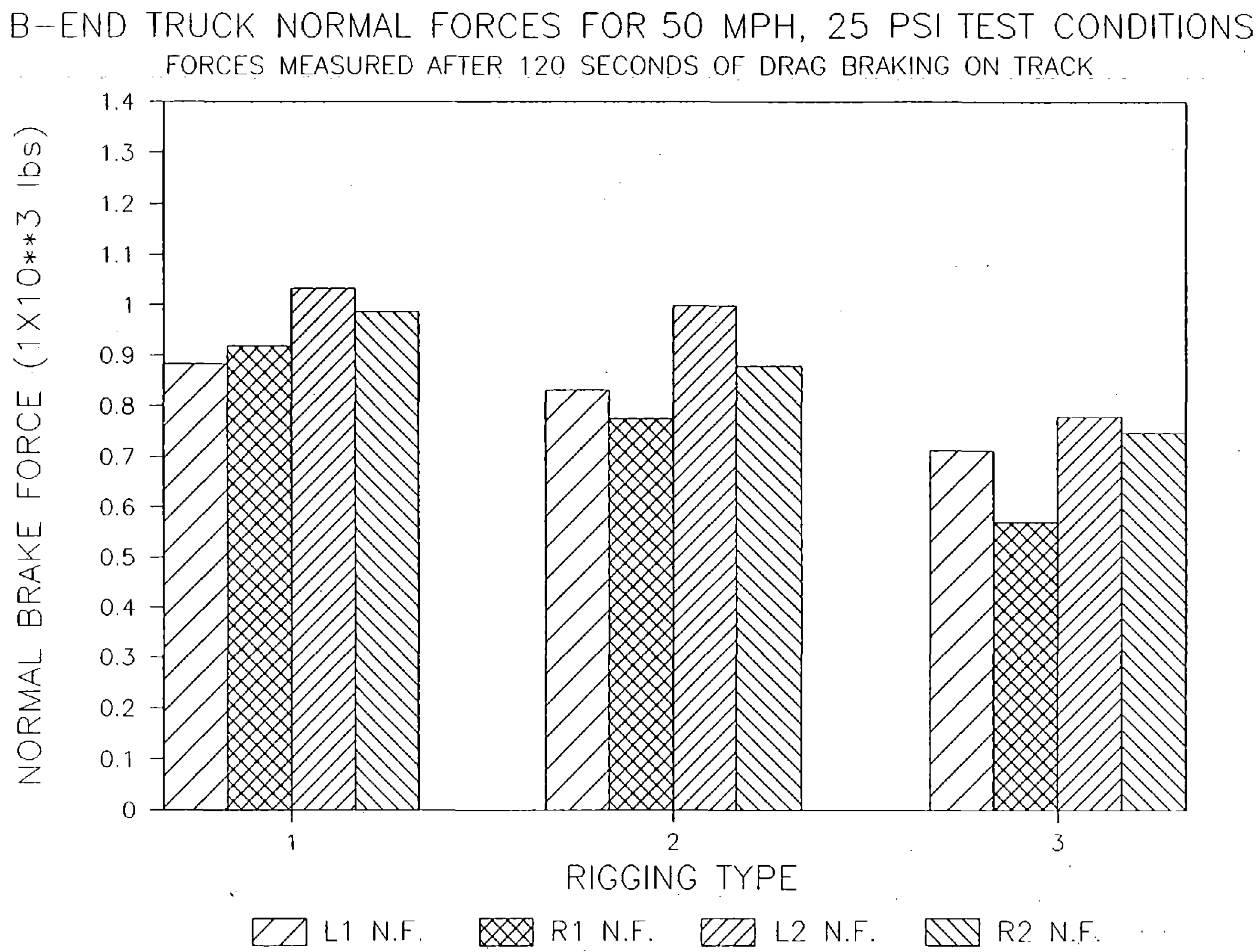

B-END TRUCK TOTAL NORMAL FORCE
SUMMATION OF L1 N.F., R1 N.F., L2 N.F., & R2 N.F.
AFTER 120 SECONDS OF DRAG BRAKING ON TRACK
B-END TRUCK TOTAL NORMAL FORCE (1X10**3 lbs)
0
1
2
3
4
5
6
7
8
9
10
1
2
3
RIGGING TYPE
TEST CONDITIONS:
20 MPH, 25 PSI
40 MPH, 25 PSI
50 MPH, 25 PSI
20 MPH, 50 PSI
40 MPH, 50 PSI
50 MPH, 50 PSI

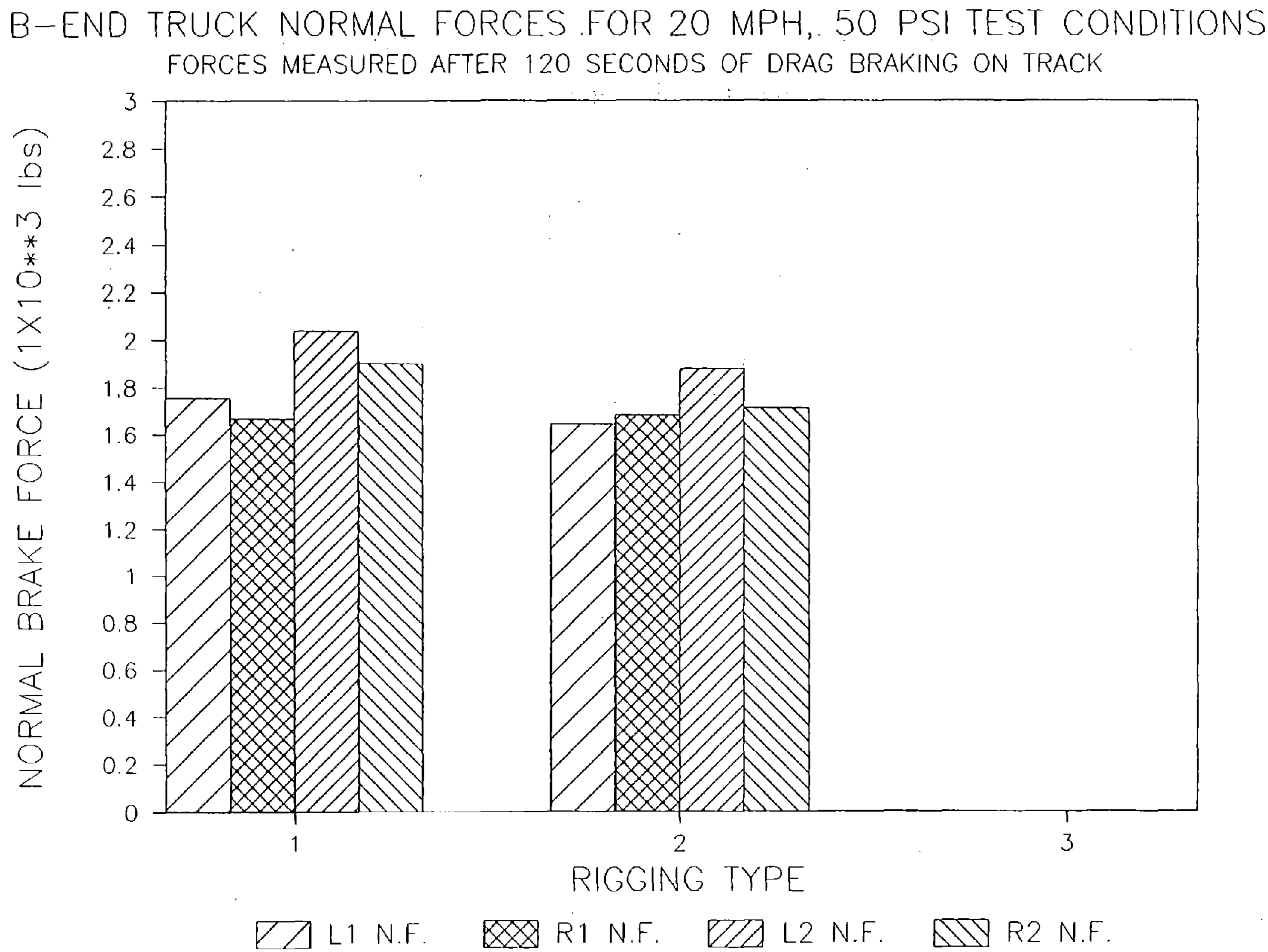

B-END TRUCK NORMAL FORCES FOR 20 MPH, 25 PSI TEST CONDITIONS
FORCES MEASURED AFTER 120 SECONDS OF DRAG BRAKING ON TRACK
NORMAL BRAKE FORCE (1X10**3 lbs)
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
RIGGING TYPE
L1 N.F.
R1 N.F.
L2 N.F.
R2 N.F.

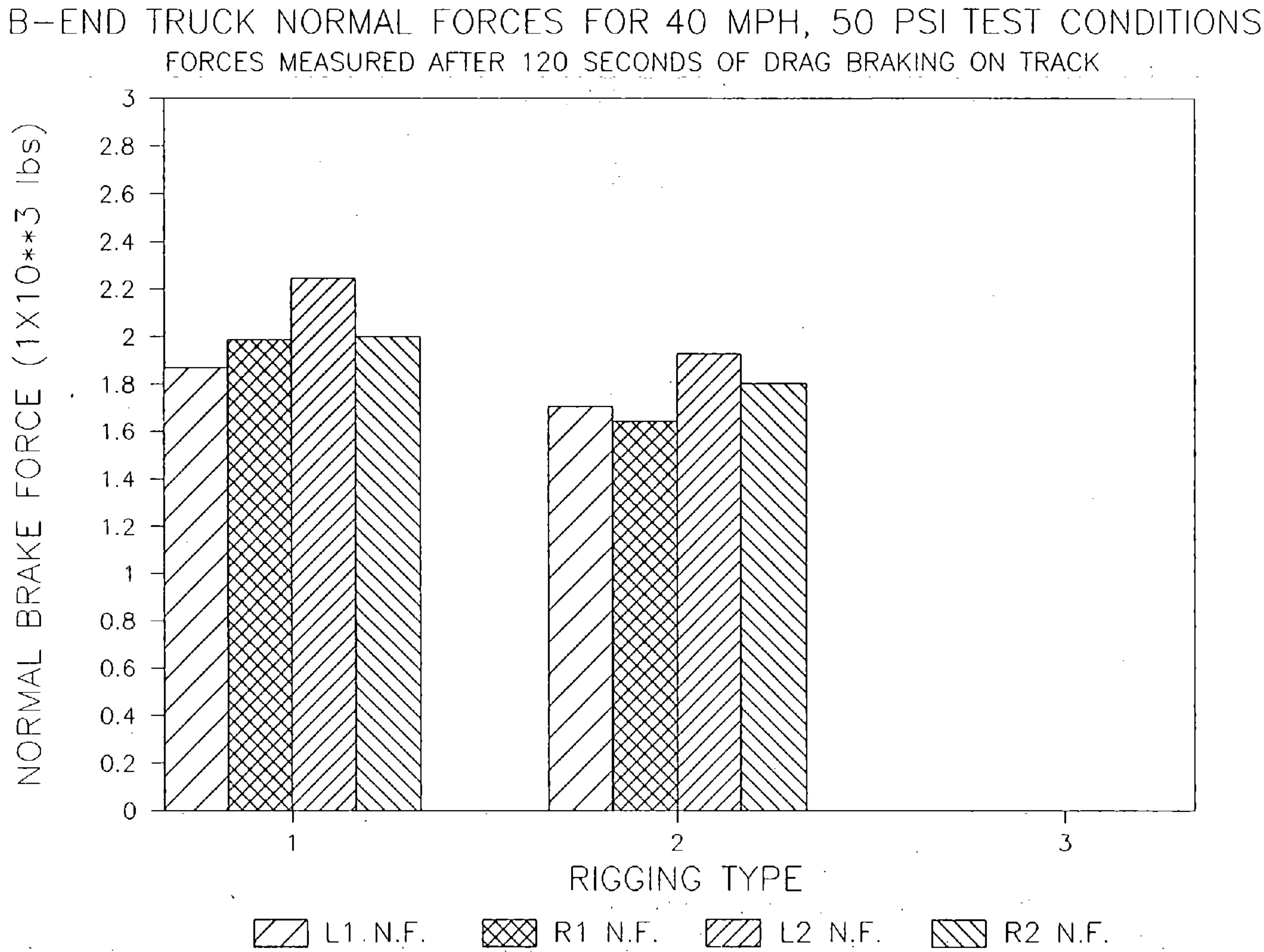
B-END TRUCK NORMAL FORCES FOR 40 MPH, 25 PSI TEST CONDITIONS

FORCES MEASURED AFTER 120 SECONDS OF DRAG BRAKING ON TRACK




B–END TRUCK NORMAL FORCES FOR 50 MPH, 25 PSI TEST CONDITIONS
FORCES MEASURED AFTER 120 SECONDS OF DRAG BRAKING ON TRACK
NORMAL BRAKE FORCE (1X10**3 lbs)
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
RIGGING TYPE
L1 N.F.
R1 N.F.
L2 N.F.
R2 N.F.

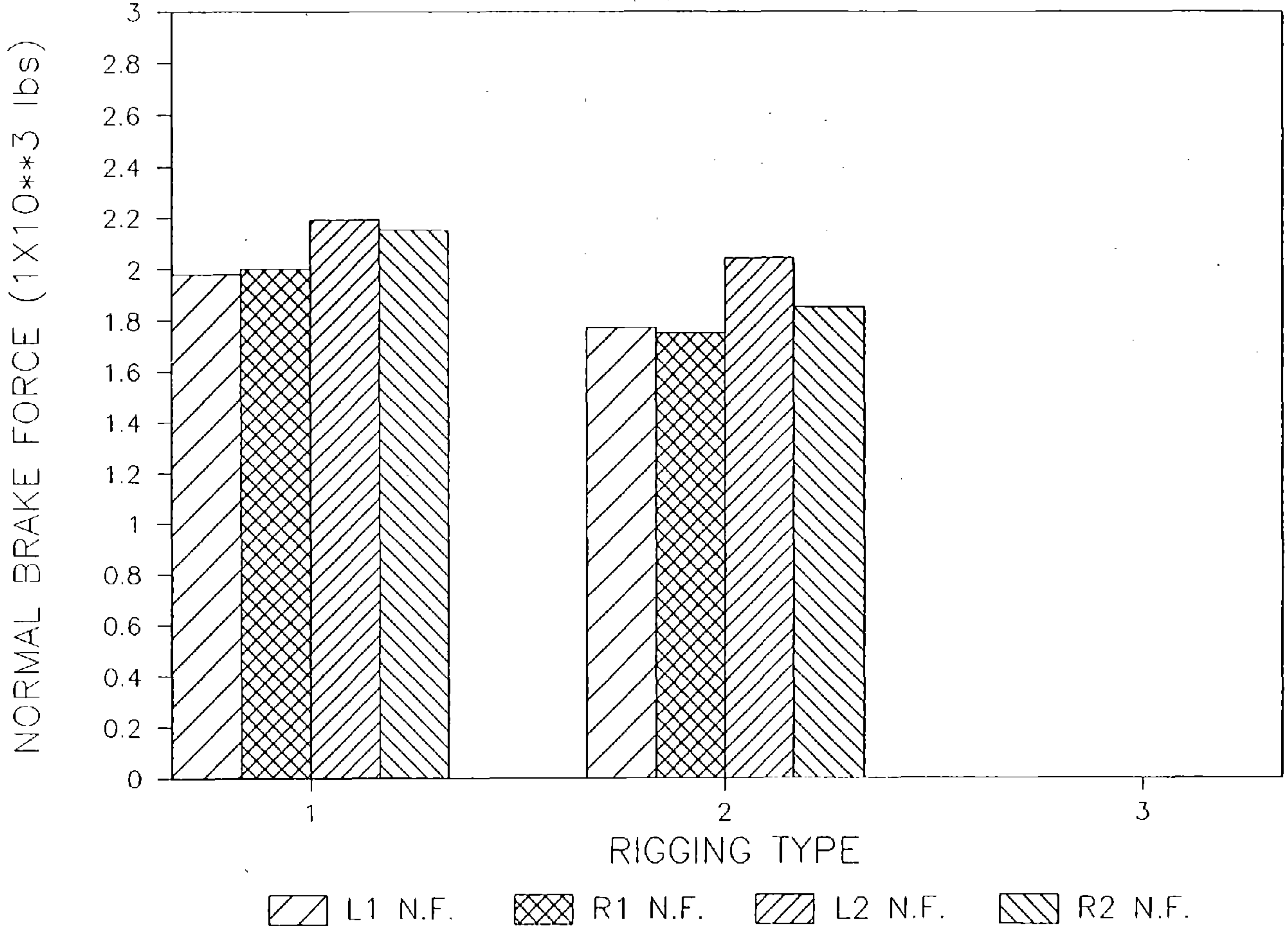

B-END TRUCK NORMAL FORCES FOR 20 MPH, 50 PSI TEST CONDITIONS
FORCES MEASURED AFTER 120 SECONDS OF DRAG BRAKING ON TRACK
NORMAL BRAKE FORCE (1X10**3 lbs)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
RIGGING TYPE
L1 N.F.
R1 N.F.
L2 N.F.
R2 N.F.

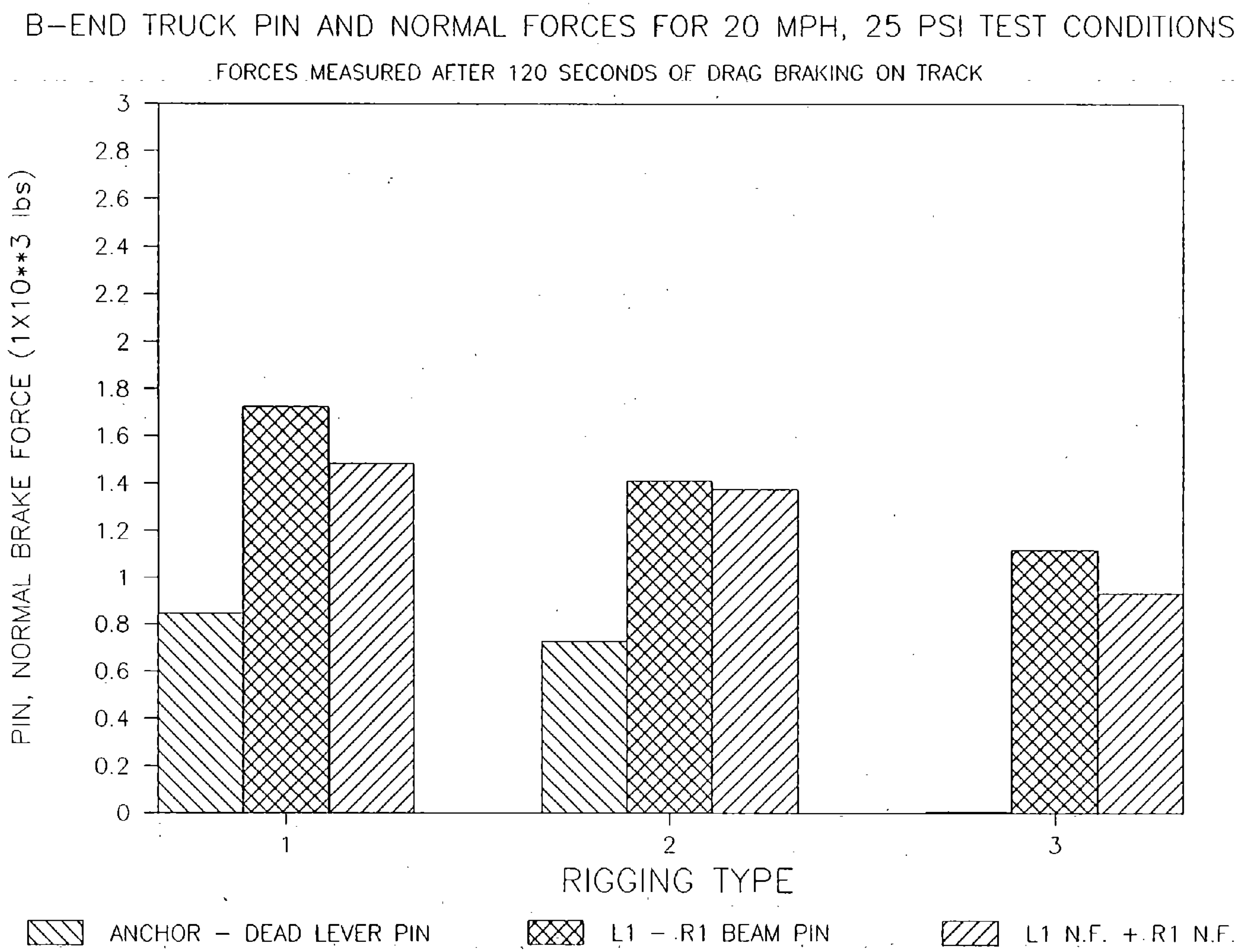


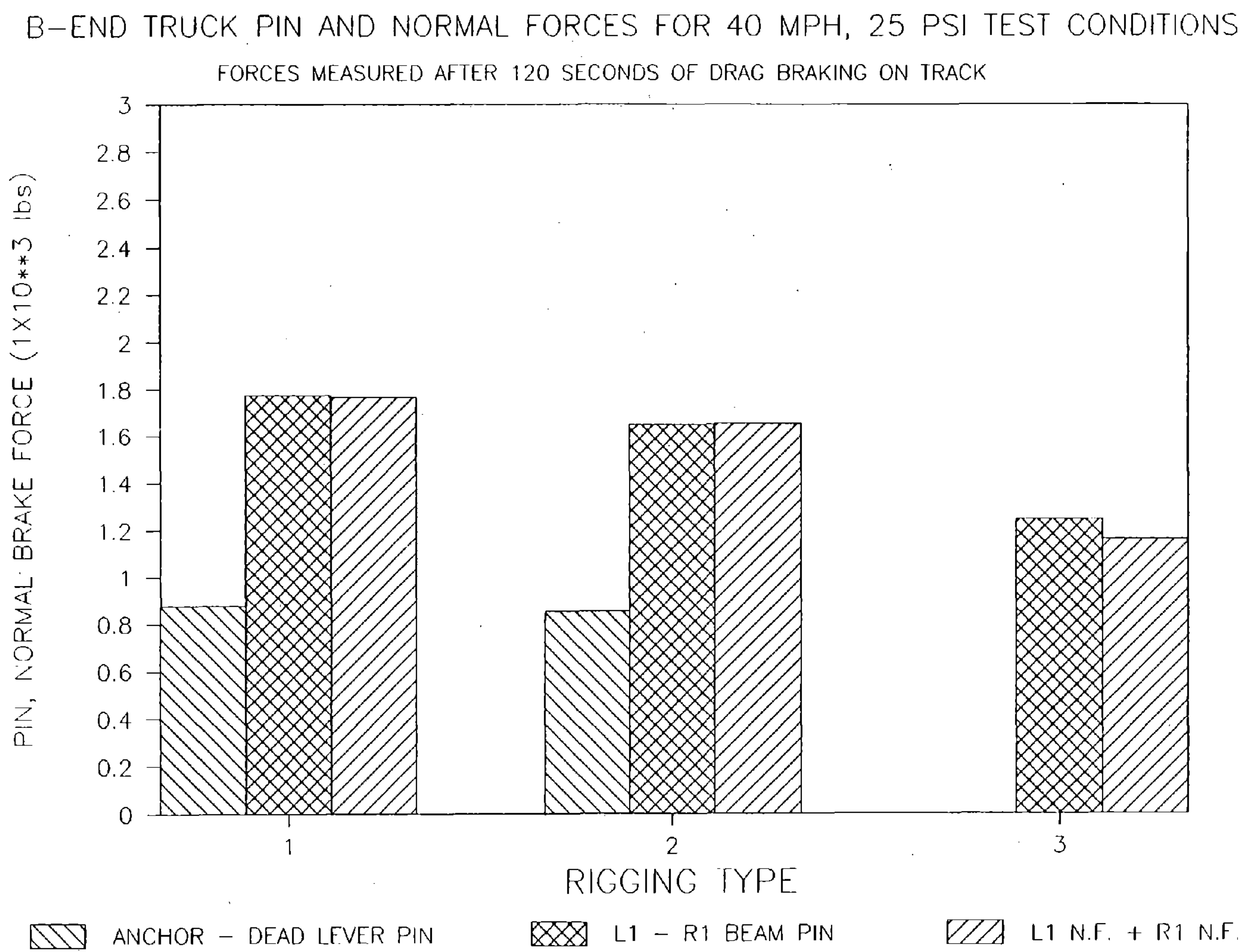
B-END TRUCK NORMAL FORCES FOR 40 MPH, 50 PSI TEST CONDITIONS
FORCES MEASURED AFTER 120 SECONDS OF DRAG BRAKING ON TRACK
NORMAL BRAKE FORCE (1X10**3 lbs)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
RIGGING TYPE
L1 N.F.
R1 N.F.
L2 N.F.
R2 N.F.

B-END TRUCK NORMAL FORCES FOR 50 MPH, 50 PSI TEST CONDITIONS

FORCES MEASURED AFTER 120 SECONDS OF DRAG BRAKING ON TRACK

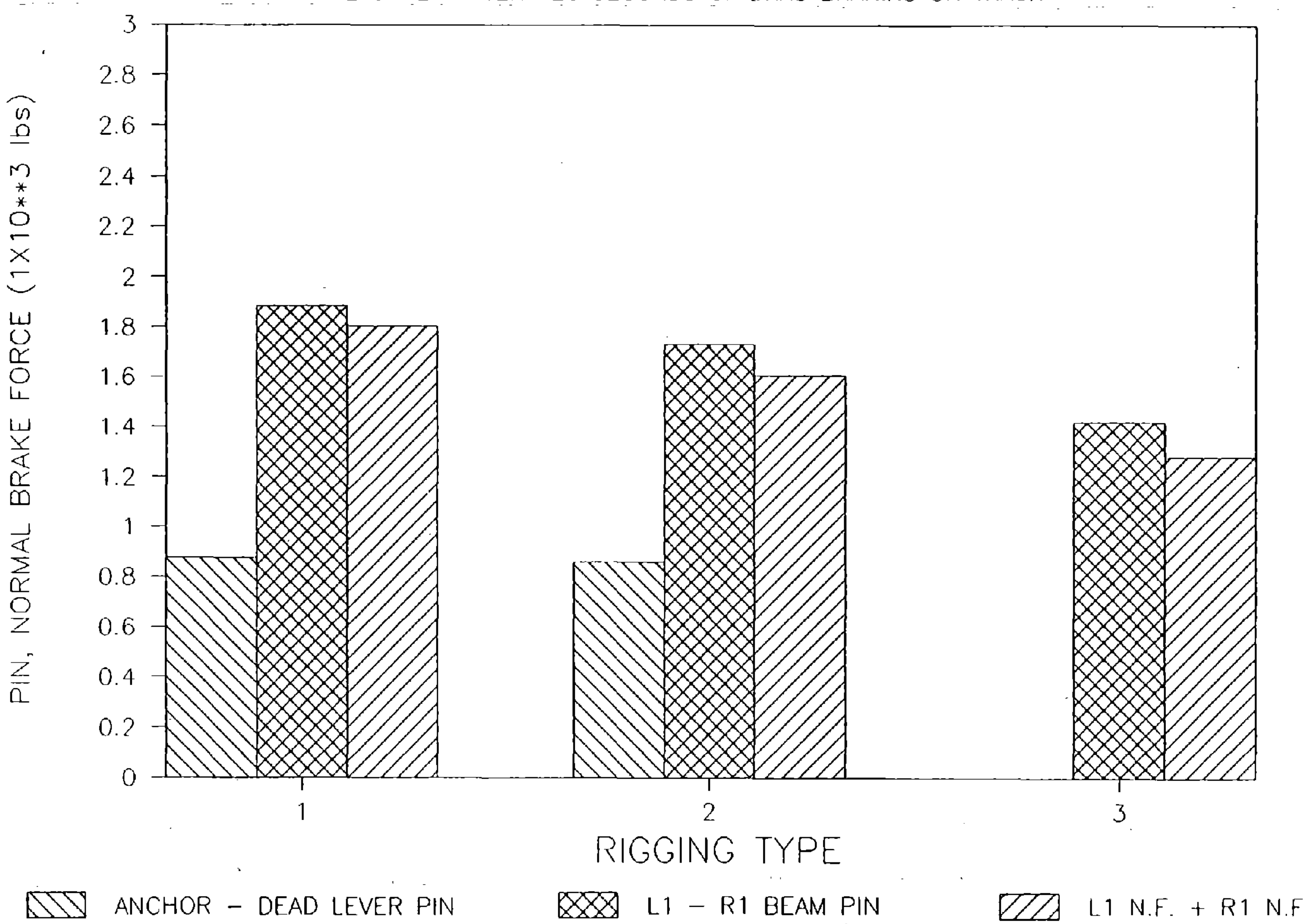


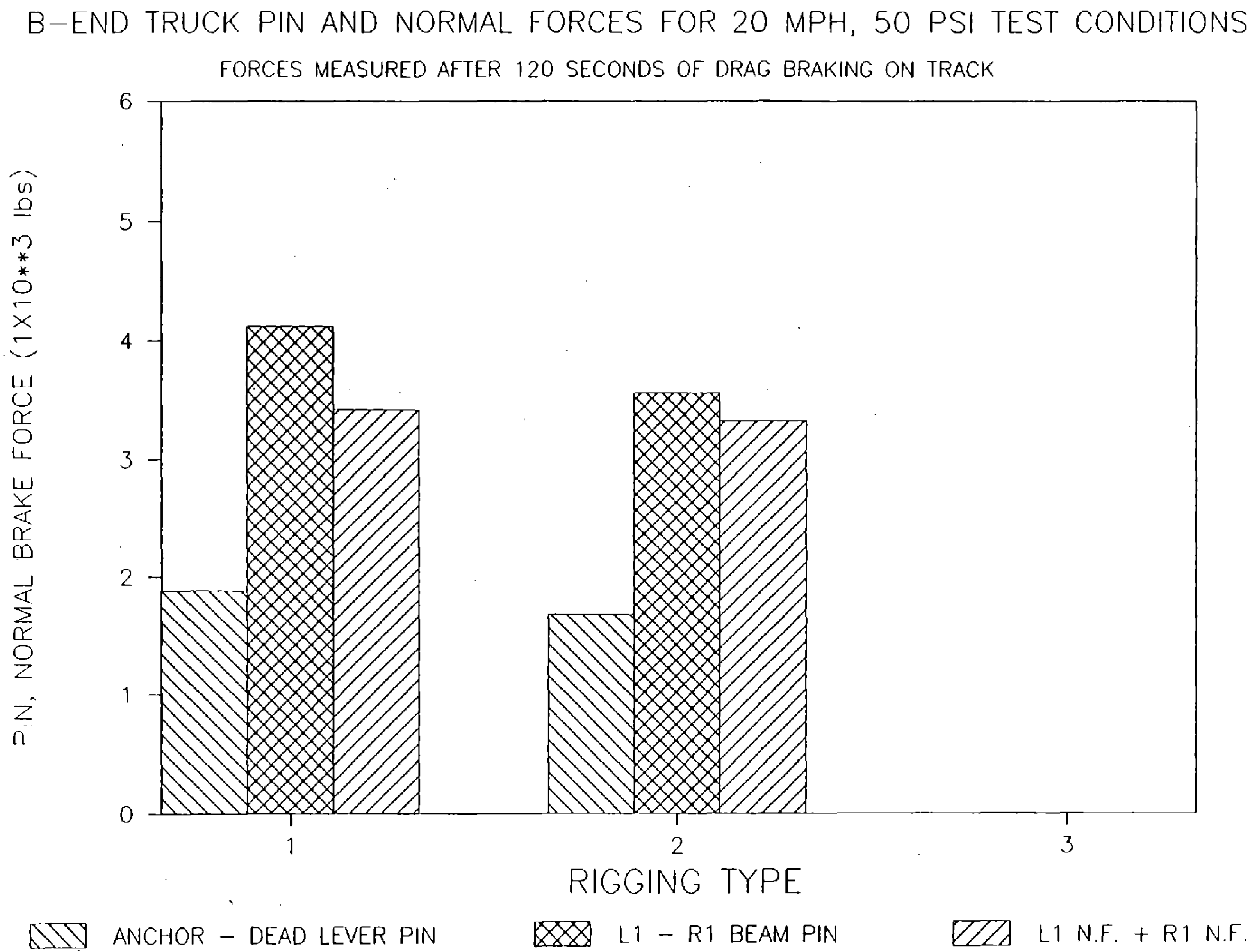

B–END TRUCK PIN AND NORMAL FORCES FOR 20 MPH, 25 PSI TEST CONDITIONS
FORCES MEASURED AFTER 120 SECONDS OF DRAG BRAKING ON TRACK
PIN, NORMAL BRAKE FORCE (1X10**3 lbs)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
RIGGING TYPE
ANCHOR – DEAD LEVER PIN
L1 – R1 BEAM PIN
L1 N.F. + R1 N.F.


B-END TRUCK PIN AND NORMAL FORCES FOR 40 MPH, 25 PSI TEST CONDITIONS
FORCES MEASURED AFTER 120 SECONDS OF DRAG BRAKING ON TRACK
PIN, NORMAL BRAKE FORCE (1X10**3 lbs)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
RIGGING TYPE
ANCHOR - DEAD LEVER PIN
L1 - R1 BEAM PIN
L1 N.F. + R1 N.F.

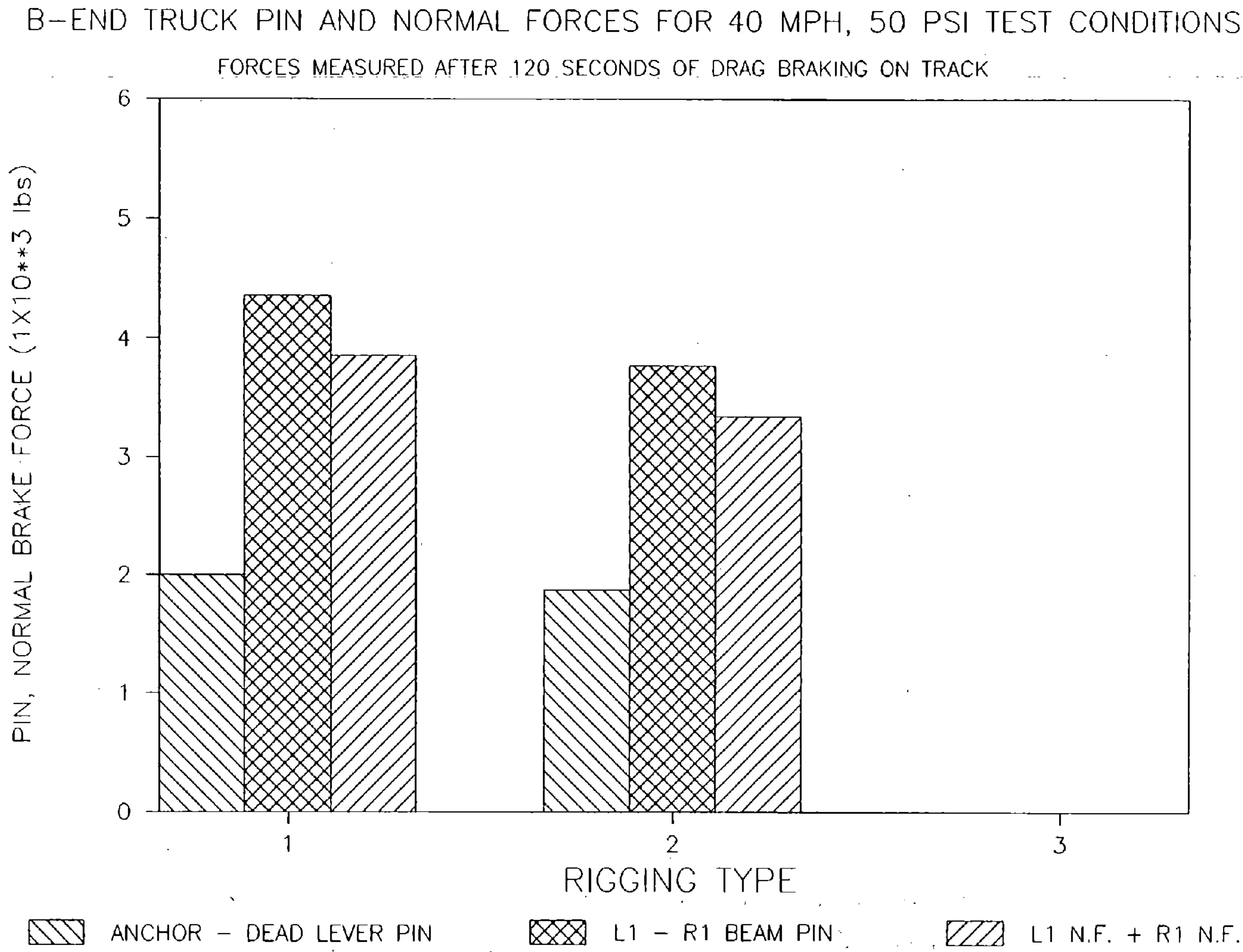
B-END TRUCK PIN AND NORMAL FORCES FOR 50 MPH, 25 PSI TEST CONDITIONS

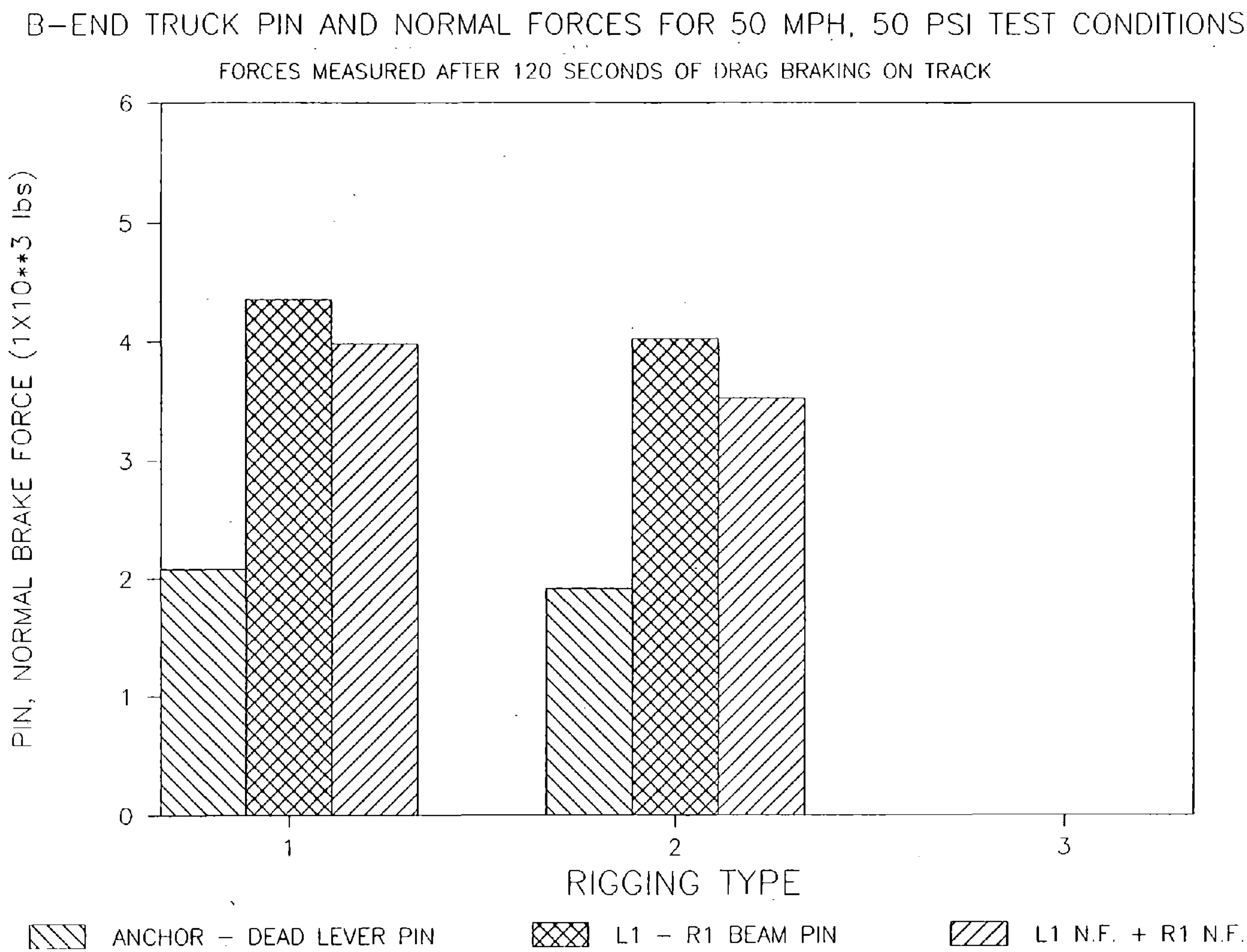
FORCES MEASURED AFTER 120 SECONDS OF DRAG BRAKING ON TRACK

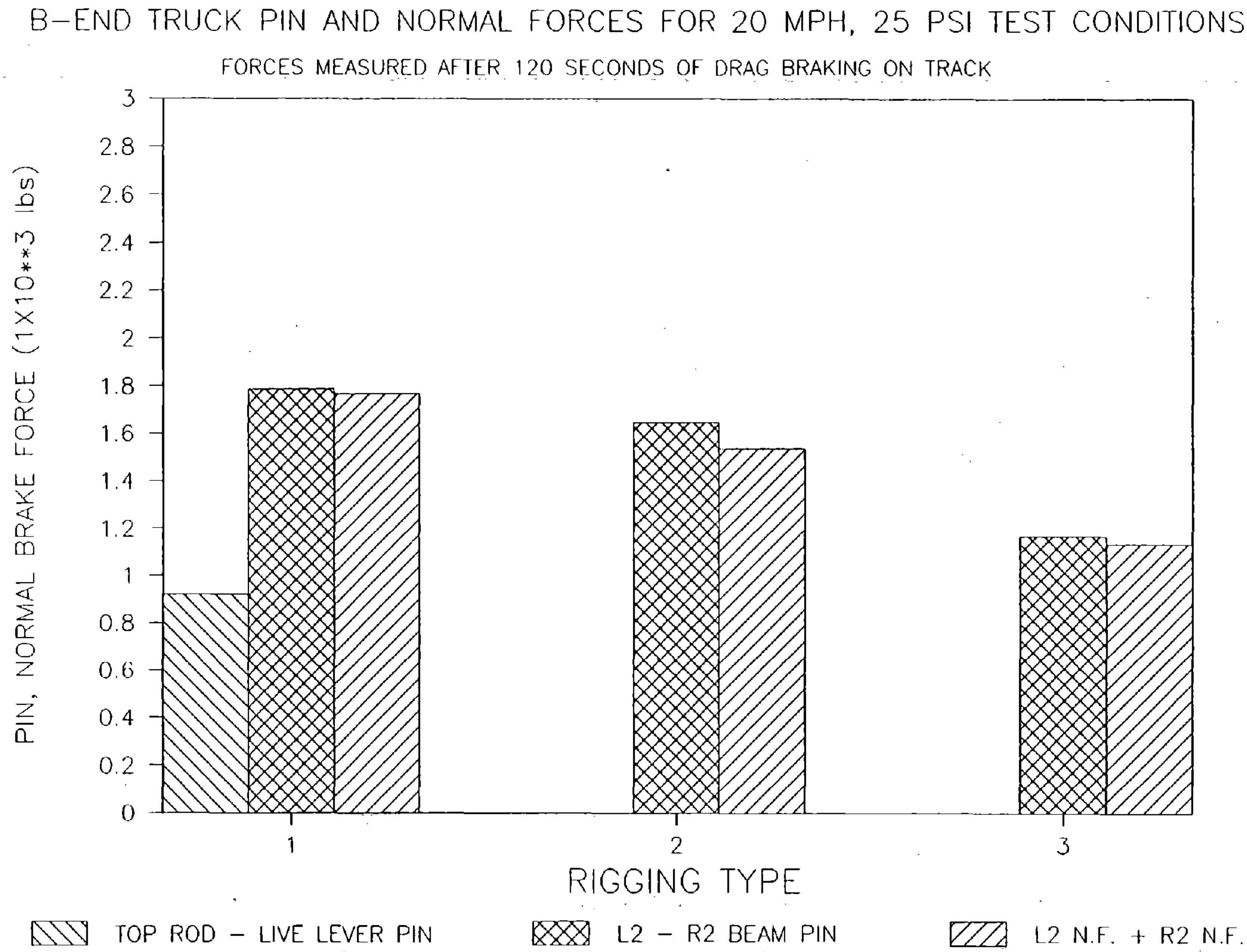


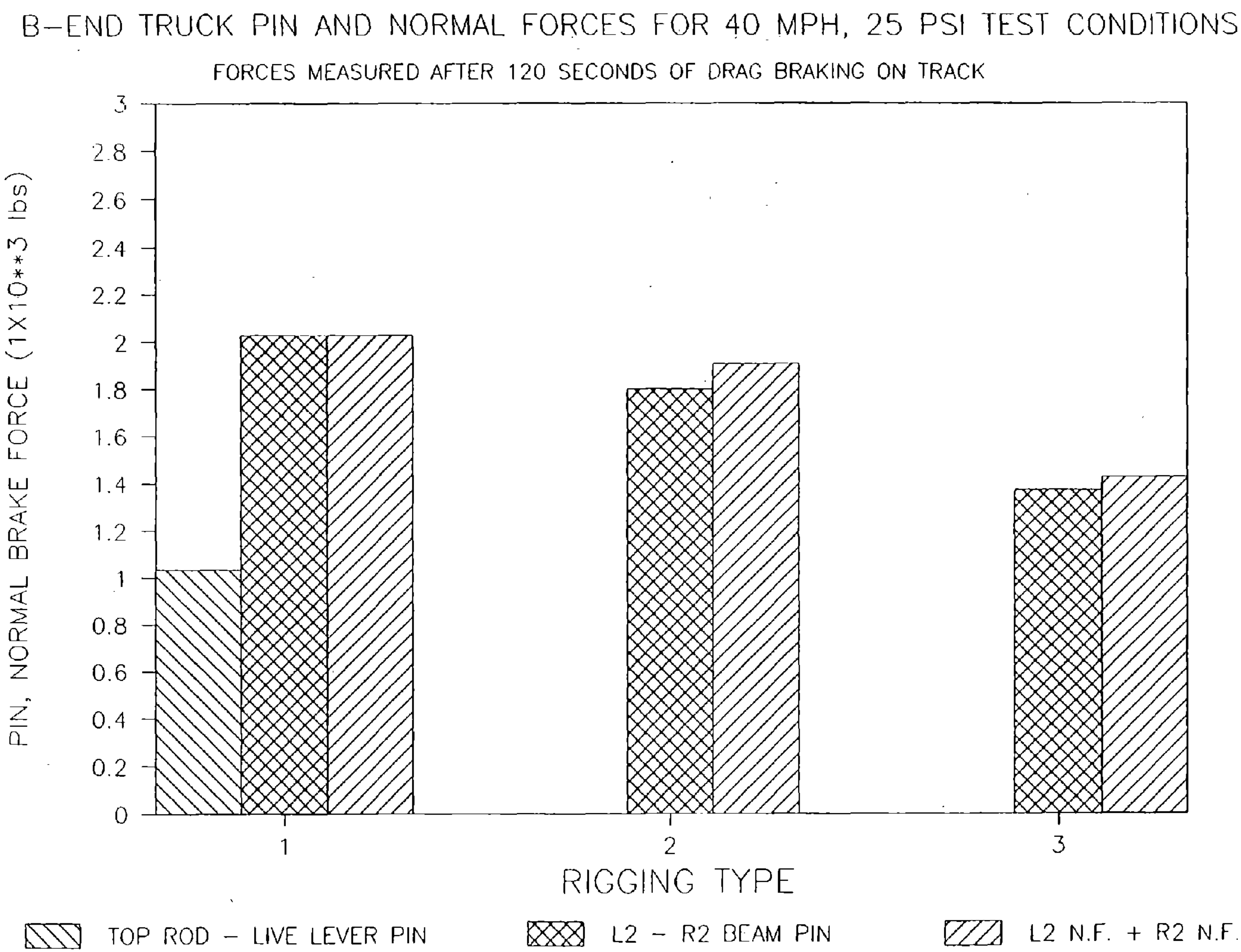


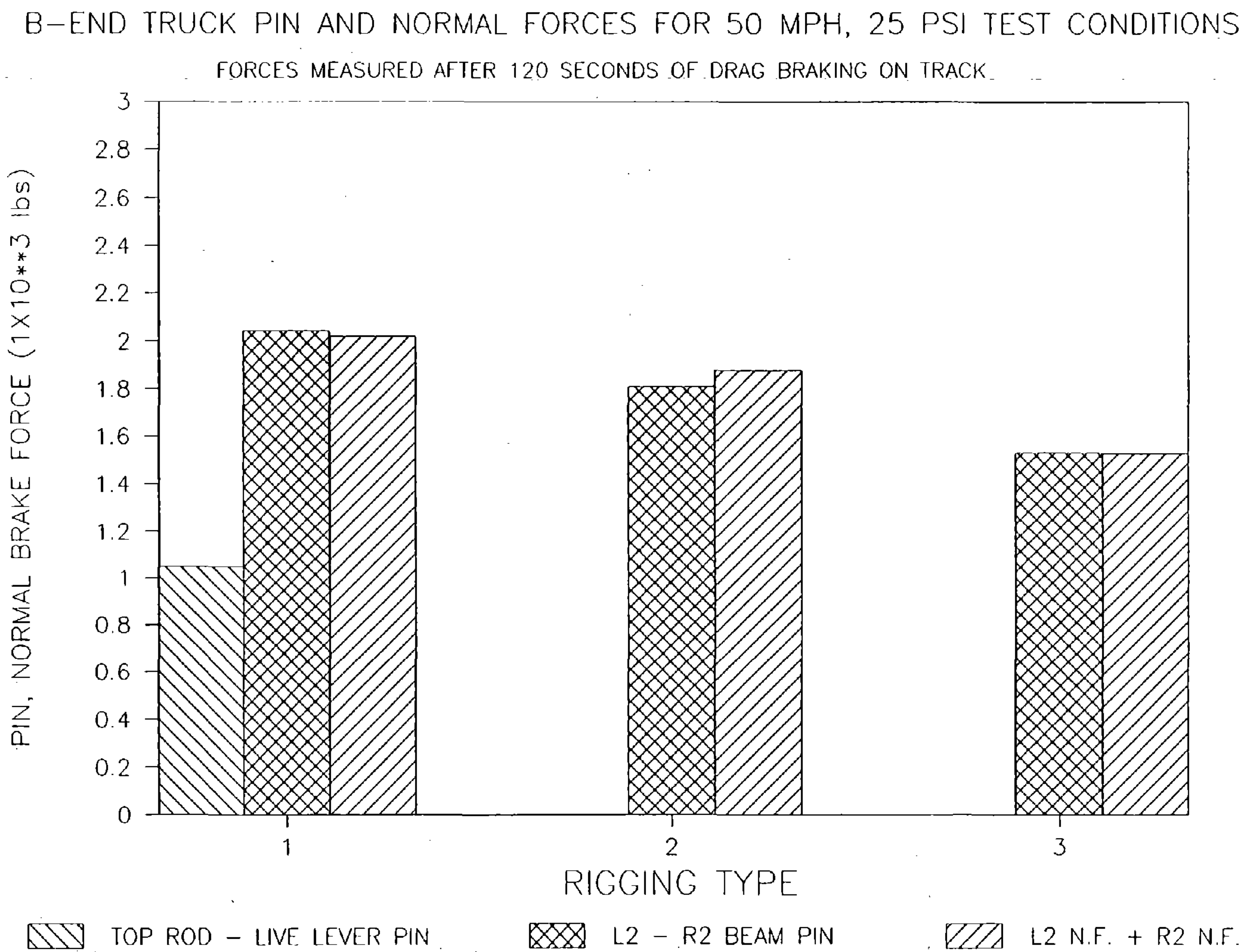
B–END TRUCK PIN AND NORMAL FORCES FOR 20 MPH, 50 PSI TEST CONDITIONS
FORCES MEASURED AFTER 120 SECONDS OF DRAG BRAKING ON TRACK
P,N, NORMAL BRAKE FORCE (1X10**3 lbs)
0
1
2
3
4
5
6
1
2
3
RIGGING TYPE
ANCHOR – DEAD LEVER PIN
L1 – R1 BEAM PIN
L1 N.F. + R1 N.F.

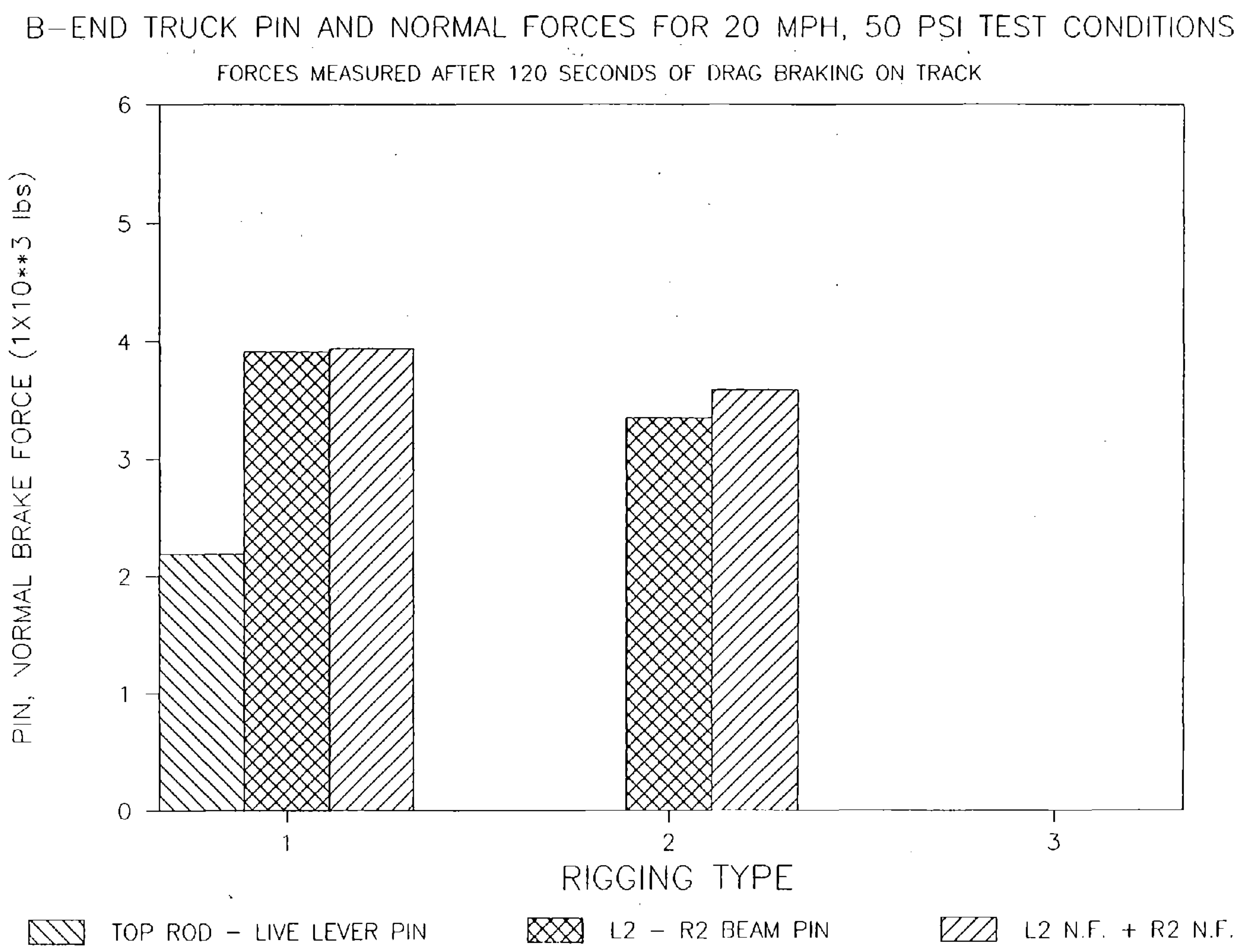

B-END TRUCK PIN AND NORMAL FORCES FOR 40 MPH, 50 PSI TEST CONDITIONS
FORCES MEASURED AFTER 120 SECONDS OF DRAG BRAKING ON TRACK
PIN, NORMAL BRAKE FORCE (1X10**3 lbs)
0
1
2
3
4
5
6
1
2
3
RIGGING TYPE
ANCHOR - DEAD LEVER PIN
L1 - R1 BEAM PIN
L1 N.F. + R1 N.F.

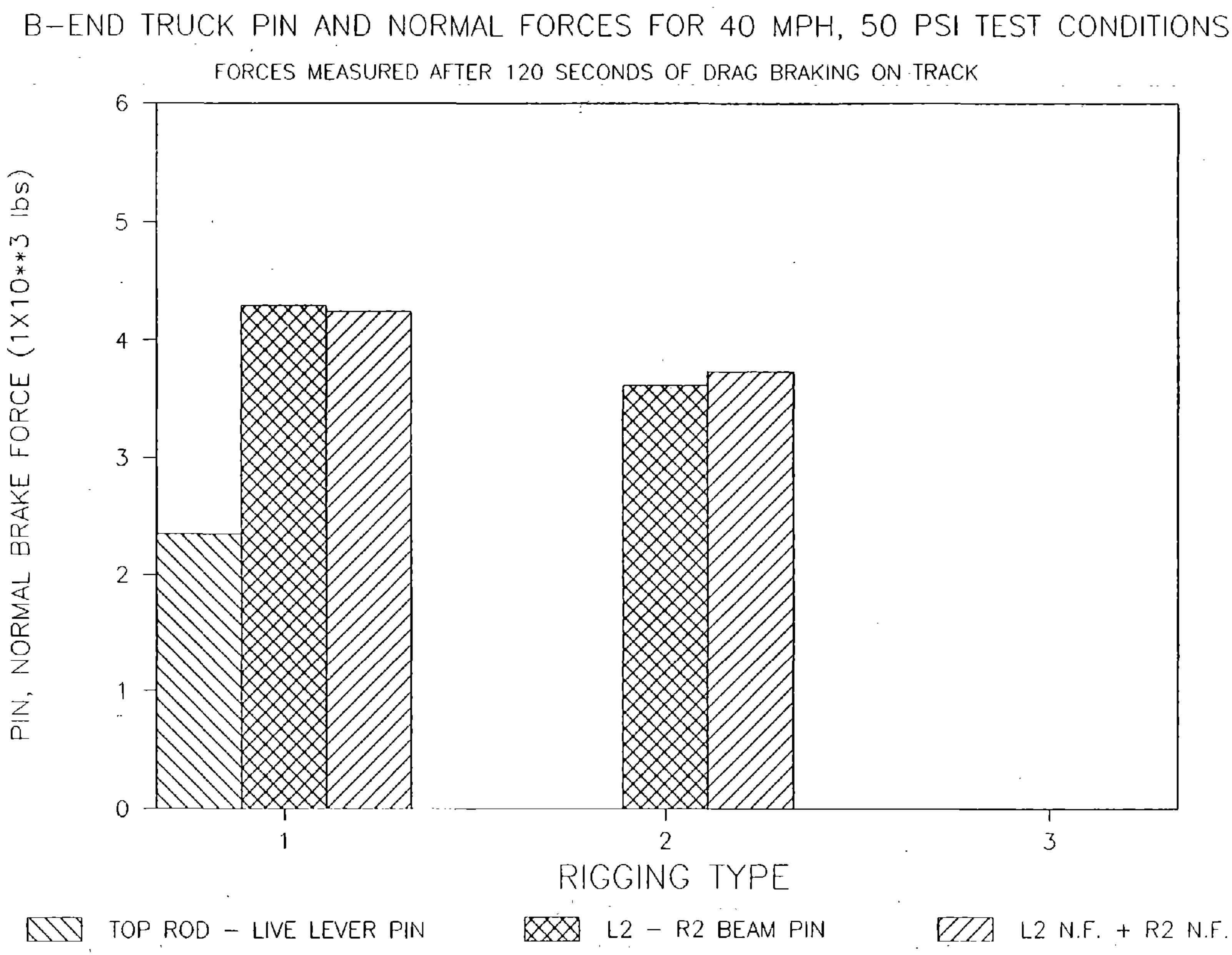

B-END TRUCK PIN AND NORMAL FORCES FOR 50 MPH, 50 PSI TEST CONDITIONS
FORCES MEASURED AFTER 120 SECONDS OF DRAG BRAKING ON TRACK
PIN, NORMAL BRAKE FORCE (1X10**3 lbs)
6
5
4
3
2
1
0
1
2
3
RIGGING TYPE
ANCHOR - DEAD LEVER PIN
L1 - R1 BEAM PIN
L1 N.F. + R1 N.F.

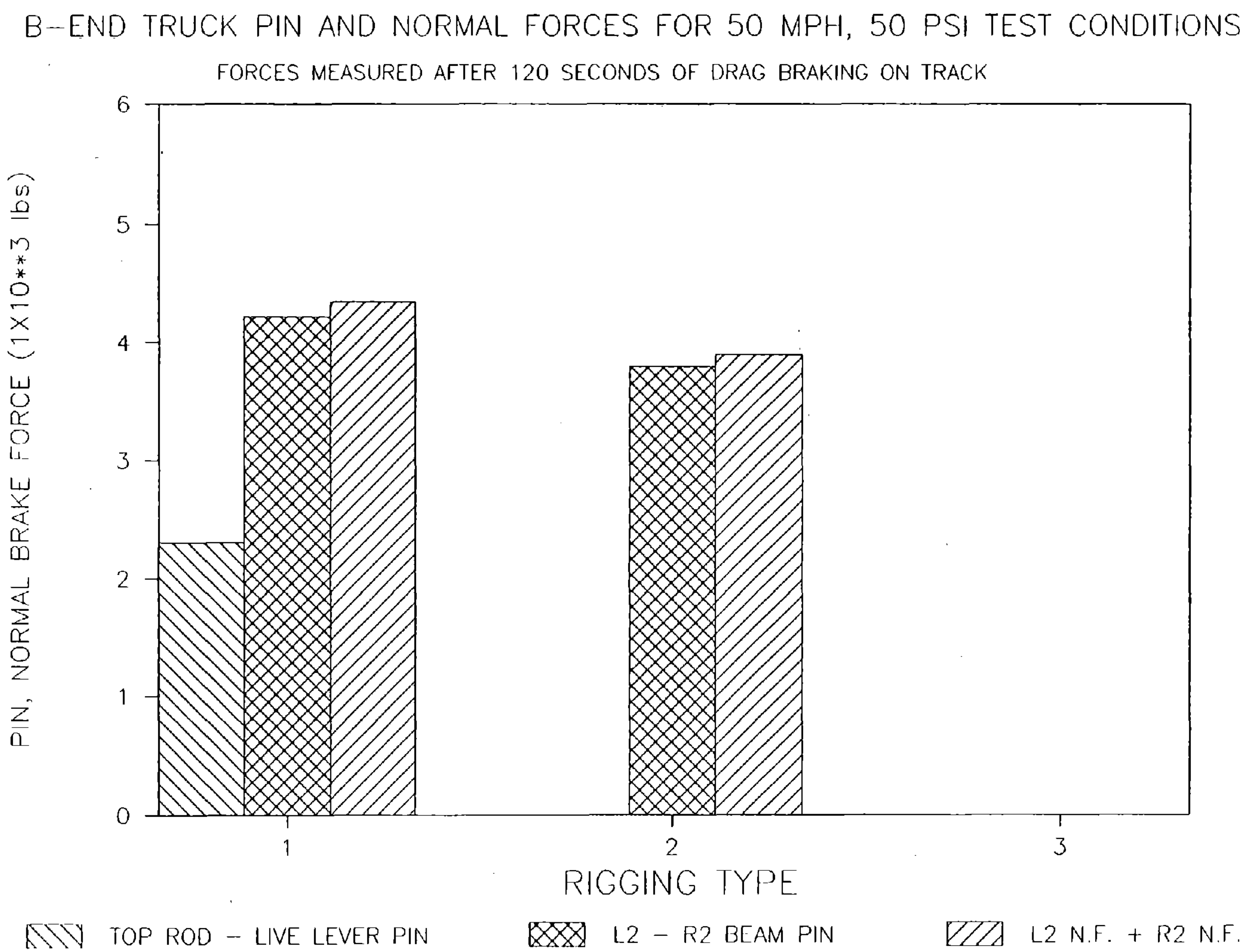

B-END TRUCK PIN AND NORMAL FORCES FOR 20 MPH, 25 PSI TEST CONDITIONS
FORCES MEASURED AFTER 120 SECONDS OF DRAG BRAKING ON TRACK
PIN, NORMAL BRAKE FORCE (1X10**3 lbs)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
RIGGING TYPE
TOP ROD - LIVE LEVER PIN
L2 - R2 BEAM PIN
L2 N.F. + R2 N.F.


B-END TRUCK PIN AND NORMAL FORCES FOR 40 MPH, 25 PSI TEST CONDITIONS
FORCES MEASURED AFTER 120 SECONDS OF DRAG BRAKING ON TRACK
PIN, NORMAL BRAKE FORCE (1X10**3 lbs)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
1
2
3
RIGGING TYPE
TOP ROD - LIVE LEVER PIN
L2 - R2 BEAM PIN
L2 N.F. + R2 N.F.


B-END TRUCK PIN AND NORMAL FORCES FOR 50 MPH, 25 PSI TEST CONDITIONS
FORCES MEASURED AFTER 120 SECONDS OF DRAG BRAKING ON TRACK
PIN, NORMAL BRAKE FORCE (1X10**3 lbs)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
RIGGING TYPE
TOP ROD - LIVE LEVER PIN
L2 - R2 BEAM PIN
L2 N.F. + R2 N.F.


B-END TRUCK PIN AND NORMAL FORCES FOR 20 MPH, 50 PSI TEST CONDITIONS
FORCES MEASURED AFTER 120 SECONDS OF DRAG BRAKING ON TRACK
PIN, NORMAL BRAKE FORCE (1X10**3 lbs)
0
1
2
3
4
5
6
1
2
3
RIGGING TYPE
TOP ROD - LIVE LEVER PIN
L2 - R2 BEAM PIN
L2 N.F. + R2 N.F.


B-END TRUCK PIN AND NORMAL FORCES FOR 40 MPH, 50 PSI TEST CONDITIONS
FORCES MEASURED AFTER 120 SECONDS OF DRAG BRAKING ON TRACK
PIN, NORMAL BRAKE FORCE (1X10**3 lbs)
0
1
2
3
4
5
6
1
2
3
RIGGING TYPE
TOP ROD - LIVE LEVER PIN
L2 - R2 BEAM PIN
L2 N.F. + R2 N.F.


B–END TRUCK PIN AND NORMAL FORCES FOR 50 MPH, 50 PSI TEST CONDITIONS
FORCES MEASURED AFTER 120 SECONDS OF DRAG BRAKING ON TRACK
PIN, NORMAL BRAKE FORCE (1X10**3 lbs)
0
1
2
3
4
5
6
1
2
3
RIGGING TYPE
TOP ROD – LIVE LEVER PIN
L2 – R2 BEAM PIN
L2 N.F. + R2 N.F.

APPENDIX F

B-End Truck Rigging Efficiencies
Measured During Testing on the Track

TABLE 1. B-END TRUCK BRAKE RIGGING EFFICIENCIES MEASURED DURING TESTING ON TRACK

SPEED (mph)	BRAKE CYLINDER PRESSURE (psi)	ELAPSED TIME (sec)	PARAMETER	RIGGING TYPE 1 TEST 1	RIGGING TYPE 1 TEST 2	RIGGING TYPE 2 TEST 1	RIGGING TYPE 2 TEST 2	RIGGING TYPE 3 TEST 1	RIGGING TYPE 3 TEST 2
20	25	40	B-END TRUCK RIGGING EFFICIENCY	43.5	50.5	42.6	40.7	28.2	27.5
			EFFICIENCY LOSS NO. 1	48.8	45.8				
			EFFICIENCY LOSS NO. 2	1.2	3.7				
			EFFICIENCY LOSS NO. 3	6.4	0.0	1.5	0.2	6.4	3.6
40	25	40	B-END TRUCK RIGGING EFFICIENCY	54.8	54.2	45.9	46.2	35.0	37.7
			EFFICIENCY LOSS NO. 1	39.4	39.4				
			EFFICIENCY LOSS NO. 2	6.4	6.7				
			EFFICIENCY LOSS NO. 3	-0.6	-0.3	-1.8	-1.2	1.0	0.9
50	25	40	B-END TRUCK RIGGING EFFICIENCY	54.2	56.0	49.3	42.7	36.7	34.0
			EFFICIENCY LOSS NO. 1	39.4	36.6				
			EFFICIENCY LOSS NO. 2	8.9	10.6				
			EFFICIENCY LOSS NO. 3	-2.4	-3.2	-4.1	-0.2	0.3	1.7
20	50	40	B-END TRUCK RIGGING EFFICIENCY	52.1	52.4	51.6	51.2		
			EFFICIENCY LOSS NO. 1	38.2	36.6				
			EFFICIENCY LOSS NO. 2	6.3	6.4				
			EFFICIENCY LOSS NO. 3	3.4	4.6	0.1	0.7		
40	50	40	B-END TRUCK RIGGING EFFICIENCY	55.4	54.3	49.9	47.3		
			EFFICIENCY LOSS NO. 1	35.2	36.5				
			EFFICIENCY LOSS NO. 2	6.0	6.4				
			EFFICIENCY LOSS NO. 3	3.4	2.8	0.6	5.1		
50	50	40	B-END TRUCK RIGGING EFFICIENCY	58.3	54.7	50.8	51.1		
			EFFICIENCY LOSS NO. 1	35.4	38.0				
			EFFICIENCY LOSS NO. 2	6.6	6.3				
			EFFICIENCY LOSS NO. 3	-0.2	1.1	1.6	0.7		

RIGGING EFFICIENCY LOSSES: 1 - EFFICIENCY LOSS BETWEEN BRAKE CYLINDER AND TOP ROD/LIVE LEVER PIN
2 - EFFICIENCY LOSS BETWEEN TOP ROD/LIVE LEVER PIN AND TRUCK LEVER BEAM PINS
3 - EFFICIENCY LOSS BETWEEN TRUCK LEVER BEAM PINS AND BRAKE SHOES

RIGGING TYPES: 1 - Original rigging components, B-end leading
2 - Same as No. 1 except live lever with more bend angle and 2 worn pins (top rod/live lever pin and live lever/truck lever connector pin)
3 - Same as No. 1 except live lever with worn pin holes and 5 worn pins (2 top rod pins, 2 truck lever connector pins, and dead lever/anchor pin)

TABLE 2. B-END TRUCK BRAKE RIGGING EFFICIENCIES MEASURED DURING TESTING ON TRACK

SPEED (mph)	BRAKE CYLINDER PRESSURE (psi)	ELAPSED TIME (sec)	PARAMETER	RIGGING TYPE 1 TEST 1	RIGGING TYPE 1 TEST 2	RIGGING TYPE 2 TEST 1	RIGGING TYPE 2 TEST 2	RIGGING TYPE 3 TEST 1	RIGGING TYPE 3 TEST 2
20	25	120	B-END TRUCK RIGGING EFFICIENCY	48.2	52.8	44.6	44.0	30.4	34.2
			EFFICIENCY LOSS NO. 1	44.7	40.9				
			EFFICIENCY LOSS NO. 2	0.7	4.7				
			EFFICIENCY LOSS NO. 3	6.4	1.6	1.4	3.0	6.2	0.5
40	25	120	B-END TRUCK RIGGING EFFICIENCY	59.7	55.8	54.3	53.9	39.4	40.7
			EFFICIENCY LOSS NO. 1	36.4	37.7				
			EFFICIENCY LOSS NO. 2	4.2	5.9				
			EFFICIENCY LOSS NO. 3	-0.3	0.6	-3.0	-0.4	0.9	0.1
50	25	120	B-END TRUCK RIGGING EFFICIENCY	60.1	57.3	57.4	48.1	42.7	42.8
			EFFICIENCY LOSS NO. 1	34.5	36.7				
			EFFICIENCY LOSS NO. 2	3.5	4.8				
			EFFICIENCY LOSS NO. 3	1.9	1.2	0.9	0.8	2.2	2.2
20	50	120	B-END TRUCK RIGGING EFFICIENCY	57.1	56.5	53.0	53.7		
			EFFICIENCY LOSS NO. 1	32.2	32.4				
			EFFICIENCY LOSS NO. 2	6.0	5.4				
			EFFICIENCY LOSS NO. 3	4.8	5.7	-0.0	0.0		
40	50	120	B-END TRUCK RIGGING EFFICIENCY	63.8	61.2	56.3	53.4		
			EFFICIENCY LOSS NO. 1	26.0	29.1				
			EFFICIENCY LOSS NO. 2	6.1	5.4				
			EFFICIENCY LOSS NO. 3	4.2	4.3	2.3	2.5		
50	50	120	B-END TRUCK RIGGING EFFICIENCY	66.1	61.9	57.9	57.6		
			EFFICIENCY LOSS NO. 1	27.6	30.8				
			EFFICIENCY LOSS NO. 2	4.8	5.1				
			EFFICIENCY LOSS NO. 3	1.5	2.2	5.0	1.2		

RIGGING EFFICIENCY LOSSES:
1 - EFFICIENCY LOSS BETWEEN BRAKE CYLINDER AND TOP ROD/LIVE LEVER PIN
2 - EFFICIENCY LOSS BETWEEN TOP ROD/LIVE LEVER PIN AND TRUCK LEVER BEAM PINS
3 - EFFICIENCY LOSS BETWEEN TRUCK LEVER BEAM PINS AND BRAKE SHOES

RIGGING TYPES:
1 - Original rigging components, B-end leading
2 - Same as No. 1 except live lever with more bend angle and 2 worn pins (top rod/live lever pin and live lever/truck lever connector pin)
3 - Same as No. 1 except live lever with worn pin holes and 5 worn pins (2 top rod pins, 2 truck lever connector pins, and dead lever/anchor pin)

APPENDIX G

Representative Dynamometer Data
From Brake Shoe Position Study

S-PLATE -- OVERHANGING SHOE -- TEST 2

Brk. Speed RPM	Brk. Speed MPH	Revs to Stop	DTS Feet	Stop Time Sec.	Torq. Max. X1000	Torq. Ave. X1000	Force Ave. X1000	Rel. Speed RPM	Cycle Time Sec.	Torq. Min. X1000	Torq. Init. X1000	Force Min. X1000	Force Max. X1000	Force Init. X1000	Temp.1 Init. Deg.F	Temp.1 Final Deg.F	Stop #
Section I.D. = 0011																	
414	41.0	666.1	5806	98.79	0.64	0.60	1.49	408	00	0.25	0.25	0.61	1.55	0.61	79	497	01
409	40.5	676.3	5895	99.80	0.61	0.58	1.51	411	120	0.54	0.60	1.47	1.55	1.51	515	588	02
411	40.7	681.7	5942	99.80	0.57	0.54	1.51	414	120	0.52	0.57	1.47	1.55	1.54	596	637	03
413	40.9	683.8	5960	99.79	0.55	0.51	1.51	414	120	0.49	0.53	1.48	1.55	1.52	643	659	04
406	40.2	673.2	5868	100.62	0.58	0.50	1.51	406	121	0.41	0.53	1.47	1.55	1.49	663	675	05
405	40.1	670.5	5844	99.79	0.53	0.45	1.51	406	121	0.38	0.47	1.47	1.55	1.51	674	660	06
406	40.2	670.7	5846	99.79	0.48	0.42	1.51	406	120	0.36	0.42	1.47	1.55	1.53	678	694	07
406	40.2	670.0	5840	99.79	0.46	0.40	1.51	406	120	0.34	0.42	1.46	1.56	1.55	678	689	08
406	40.2	671.6	5854	99.79	0.45	0.38	1.51	407	120	0.32	0.41	1.47	1.56	1.55	699	694	09
408	40.4	672.5	5862	99.79	0.45	0.37	1.51	407	120	0.33	0.41	1.46	1.56	1.55	686	700	10
405	40.1	671.3	5851	99.67	0.43	0.39	1.51	406	120	0.36	0.39	1.46	1.56	1.50	707	721	11
407	40.3	672.4	5861	99.79	0.42	0.39	1.51	407	120	0.37	0.38	1.46	1.56	1.54	723	755	12
407	40.3	672.7	5864	99.79	0.47	0.43	1.51	407	120	0.40	0.42	1.46	1.56	1.54	762	789	13
407	40.3	672.2	5859	99.80	0.45	0.41	1.51	407	120	0.38	0.42	1.46	1.56	1.55	780	791	14
407	40.3	673.2	5868	99.79	0.44	0.40	1.51	408	120	0.36	0.41	1.46	1.56	1.51	796	811	15

S-PLATE -- OVERRIDING SHOE -- TEST 6

Brk. Speed RPM	Brk. Speed MPH	Revs to Stop	DTS Feet	Stop Time Sec.	Torq. Max. X1000	Torq. Ave. X1000	Force Ave. X1000	Rel. Speed RPM	Cycle Time Sec.	Torq. Min. X1000	Torq. Init. X1000	Force Min. X1000	Force Max. X1000	Force Init. X1000	Temp.1 Init. Deg.F	Temp.1 Final Deg.F	Stop #
Section I.D. = 0010																	
391	38.7	637.5	5557	98.71	0.63	0.54	1.51	385	00	0.47	0.49	1.07	1.53	1.08	71	100	01
385	38.1	645.6	5627	99.79	0.52	0.47	1.51	386	121	0.42	0.50	1.49	1.53	1.51	108	151	02
386	38.2	647.3	5642	99.79	0.49	0.45	1.51	386	120	0.39	0.48	1.49	1.54	1.52	162	220	03
386	38.2	650.8	5673	99.79	0.49	0.45	1.51	388	120	0.41	0.45	1.50	1.53	1.52	230	279	04
390	38.6	654.4	5704	99.79	0.54	0.49	1.51	391	120	0.43	0.46	1.50	1.53	1.51	282	311	05
391	38.7	656.2	5720	99.80	0.57	0.52	1.51	393	120	0.40	0.54	1.49	1.54	1.50	317	341	06
393	38.9	659.3	5747	99.80	0.56	0.51	1.51	394	120	0.38	0.54	1.49	1.54	1.51	346	388	07
393	38.9	660.9	5761	99.79	0.57	0.55	1.51	394	120	0.52	0.55	1.49	1.53	1.50	399	445	08
395	39.1	663.3	5782	99.67	0.60	0.56	1.51	397	120	0.50	0.52	1.49	1.53	1.51	460	514	09
397	39.3	667.9	5822	99.79	0.65	0.58	1.51	398	120	0.50	0.60	1.48	1.55	1.50	528	636	10
400	39.6	670.2	5842	99.79	0.52	0.48	1.51	399	120	0.39	0.49	1.48	1.55	1.50	655	676	11
399	39.5	668.8	5830	99.79	0.53	0.50	1.51	399	120	0.48	0.48	1.48	1.54	1.49	676	681	12
399	39.5	669.1	5832	99.79	0.55	0.52	1.51	399	120	0.49	0.52	1.47	1.54	1.53	685	685	13

STRAIGHT PLATE -- OVERHANGING SHOE -- TEST 6

Section I.D. = 0010

Brk. Speed RPM	Brk. Speed MPH	Revs to Stop	DTS Feet	Stop Time Sec.	Torq. Max. X1000	Torq. Ave. X1000	Force Ave. X1000	Rel. Speed RPM	Cycle Time Sec.	Torq. Min. X1000	Torq. Init. X1000	Force Min. X1000	Force Max. X1000	Force Init. X1000	Temp.1 Init. Deg.F	Temp.1 Final Deg.F	Stop #
397	39.2	679.4	5908	102.08	0.67	0.62	1.50	410	00	0.42	0.42	0.96	1.54	0.96	77	477	01
411	40.6	680.7	5919	100.62	0.58	0.54	1.51	407	124	0.50	0.56	1.47	1.55	1.51	495	564	02
408	40.3	674.2	5863	99.67	0.53	0.49	1.51	409	121	0.45	0.52	1.47	1.56	1.54	577	602	03
409	40.4	677.6	5892	99.80	0.46	0.44	1.51	410	120	0.42	0.45	1.47	1.56	1.48	601	622	04
409	40.4	680.1	5914	100.62	0.46	0.44	1.51	407	120	0.41	0.45	1.47	1.56	1.54	631	655	05
407	40.2	674.8	5868	99.80	0.45	0.43	1.51	408	121	0.41	0.43	1.47	1.56	1.49	662	673	06
409	40.4	676.5	5883	99.79	0.45	0.42	1.51	408	120	0.41	0.42	1.47	1.55	1.49	680	700	07
409	40.4	679.6	5910	99.79	0.46	0.43	1.51	411	120	0.41	0.43	1.47	1.55	1.51	706	727	08
412	40.7	681.6	5927	99.79	0.54	0.46	1.51	413	120	0.43	0.43	1.47	1.55	1.48	735	746	09
411	40.6	682.3	5933	99.79	0.53	0.44	1.51	414	120	0.37	0.42	1.47	1.55	1.48	741	743	10
414	40.9	681.6	5927	99.79	0.55	0.43	1.51	412	120	0.38	0.39	1.47	1.55	1.48	746	781	11
413	40.8	682.5	5935	99.79	0.50	0.41	1.51	413	120	0.35	0.38	1.47	1.56	1.48	778	770	12
413	40.8	685.2	5958	100.62	0.45	0.37	1.51	410	120	0.33	0.38	1.47	1.55	1.49	768	768	13
410	40.5	678.4	5899	99.79	0.43	0.34	1.51	410	121	0.24	0.38	1.46	1.56	1.50	748	724	14
411	40.6	678.6	5901	99.79	0.38	0.33	1.51	411	120	0.27	0.28	1.47	1.56	1.48	720	735	15
412	40.7	678.6	5901	99.79	0.42	0.27	1.51	409	120	0.21	0.39	1.46	1.56	1.52	746	696	16
409	40.4	676.3	5881	99.79	0.40	0.32	1.51	410	120	0.25	0.30	1.45	1.56	1.52	705	699	17

STRAIGHT PLATE -- OVERRIDING SHOE -- TEST 1

Section I.D. = 0010

Brk. Speed RPM	Brk. Speed MPH	Revs to Stop	DTS Feet	Stop Time Sec.	Torq. Max. X1000	Torq. Ave. X1000	Force Ave. X1000	Rel. Speed RPM	Cycle Time Sec.	Torq. Min. X1000	Torq. Init. X1000	Force Min. X1000	Force Max. X1000	Force Init. X1000	Temp.1 Init. Deg.F	Temp.1 Final Deg.F	Stop #
417	41.1	673.6	5850	98.70	0.93	0.74	1.49	417	00	0.32	0.32	0.60	1.53	0.60	82	242	01
417	41.1	683.0	5932	100.63	0.69	0.63	1.51	409	120	0.58	0.68	1.49	1.53	1.51	264	375	02
411	40.5	679.1	5898	99.79	0.61	0.53	1.51	413	121	0.47	0.60	1.50	1.53	1.52	391	415	03
413	40.7	678.9	5896	99.80	0.50	0.48	1.51	412	120	0.45	0.48	1.50	1.53	1.52	428	488	04
412	40.6	678.4	5892	99.80	0.61	0.51	1.51	411	120	0.38	0.45	1.50	1.53	1.51	496	499	05
412	40.6	684.1	5941	100.63	0.46	0.43	1.51	410	120	0.41	0.45	1.49	1.53	1.53	514	539	06
409	40.3	676.1	5872	99.79	0.43	0.41	1.51	410	121	0.39	0.42	1.49	1.53	1.52	551	566	07
409	40.3	676.2	5873	99.79	0.40	0.38	1.51	410	120	0.36	0.39	1.49	1.53	1.49	573	592	08
409	40.3	676.4	5875	99.80	0.38	0.36	1.51	410	120	0.34	0.37	1.49	1.53	1.52	591	597	09
410	40.4	675.7	5869	99.67	0.38	0.36	1.51	410	120	0.33	0.37	1.49	1.54	1.53	611	629	10
410	40.4	677.4	5883	99.79	0.39	0.37	1.51	410	120	0.35	0.36	1.49	1.54	1.53	606	622	11
410	40.4	677.2	5882	99.81	0.38	0.36	1.51	410	120	0.35	0.37	1.49	1.54	1.53	621	629	12
410	40.4	678.1	5889	99.79	0.37	0.35	1.51	410	120	0.34	0.35	1.49	1.54	1.49	629	633	13
410	40.4	678.2	5890	99.79	0.36	0.35	1.51	410	120	0.33	0.34	1.49	1.54	1.51	640	640	14
410	40.4	678.6	5894	99.80	0.37	0.34	1.51	410	120	0.33	0.36	1.49	1.54	1.52	647	643	15
410	40.4	679.1	5898	99.80	0.36	0.33	1.51	410	120	0.32	0.35	1.49	1.54	1.50	644	647	16
410	40.4	679.1	5898	99.79	0.35	0.33	1.51	411	120	0.31	0.35	1.49	1.54	1.51	653	654	17
410	40.4	679.5	5902	99.79	0.36	0.33	1.51	411	120	0.32	0.35	1.49	1.54	1.51	654	658	18