89/04

LABORATORY INVESTIGATION OF ROLLER BEARING DAMAGE DUE TO IMPACT

ENSCO, INC.

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LABORATORY INVESTIGATION OF ROLLER BEARING DAMAGE DUE TO IMPACT

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16. Abstract

This report presents the results of a two phase testing program to measure the strains in the roller separators (cages) of a bearing during impact loading. The impact loading is similar to the impacts encountered during in-service operations with flat spots on the wheels. The first phase of the program was conducted at the ENSCO facility located in Springfield, Virginia while the second phase was conducted at the Southern Railroad Research Facility in Alexandria, Virginia.

The results show that significant stresses on the bearing roller separators can be generated from impact. The mechanism for generating the strain was not investigated as part of this effort.

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NOTICE

NOTICE

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

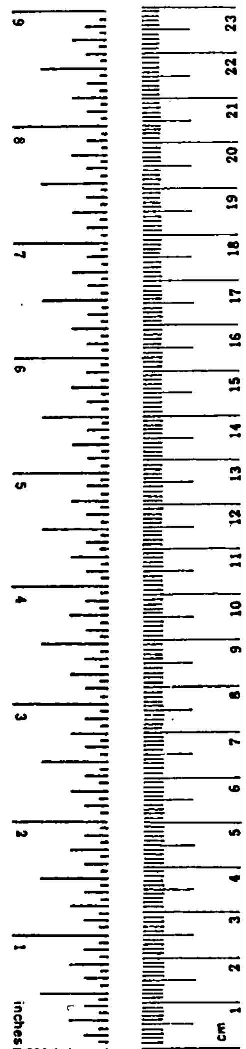
VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac

MASS (weight)

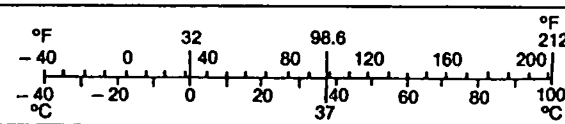
Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

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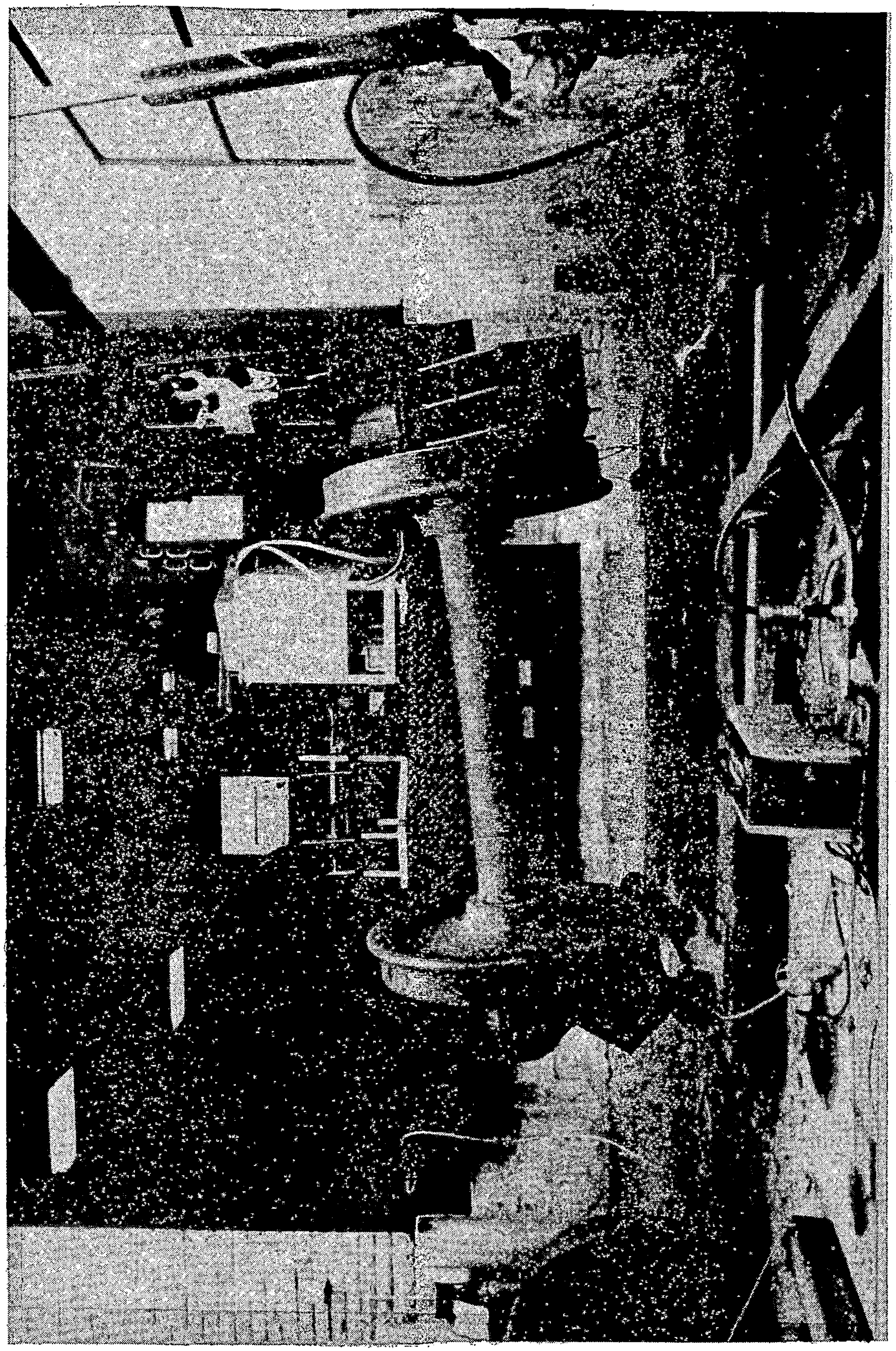


Introduction

Large vertical accelerations have been measured on the bearings of railroad freight cars in revenue service. These large accelerations have been attributed to flat spots on the wheels. The stress levels in the cages of the bearing as a result of the imposed acceleration are not known. This report investigates a method of producing large vertical accelerations of a wheelset and bearing assembly using a drop test procedure. The strain levels in the cage of the bearing are measured along with the bearing acceleration, the rail force and axle bending moment.

This report presents the results of a two phase testing program to measure the strains in the cages of a bearing during impact loading. The impact loading is similar to the impacts encountered during in-service operations with flat spots on the wheels. The first phase of the program was conducted at the Ensco facility located in Springfield, Virginia while the second phase was conducted at the Southern Railroad Research Facility in Alexandria Virginia.

The test procedure consisted of raising one wheel of a wheel set a distance of 6 to 10 inches above the rail and allowing the wheelset to fall onto the rail. Rail forces, wheelset acceleration, axle bending and strains in the inner and outer cages of the roller bearing were measured. The configuration of the test is shown in Figure 1. A L-shaped bracket was attached to the end of the axle. A jack between this bracket and a special bearing adapter applied a constant 30,000 pound load to the bearing to simulate the "sprung" load (bolster load) on the bearing. The special bearing adapter was firmly attached to the bearing. The bearing adapter was designed to simulate the mass of the side frame of a truck. The weight of the adapter could be adjusted by adding steel plates to the lower section of the adapter.

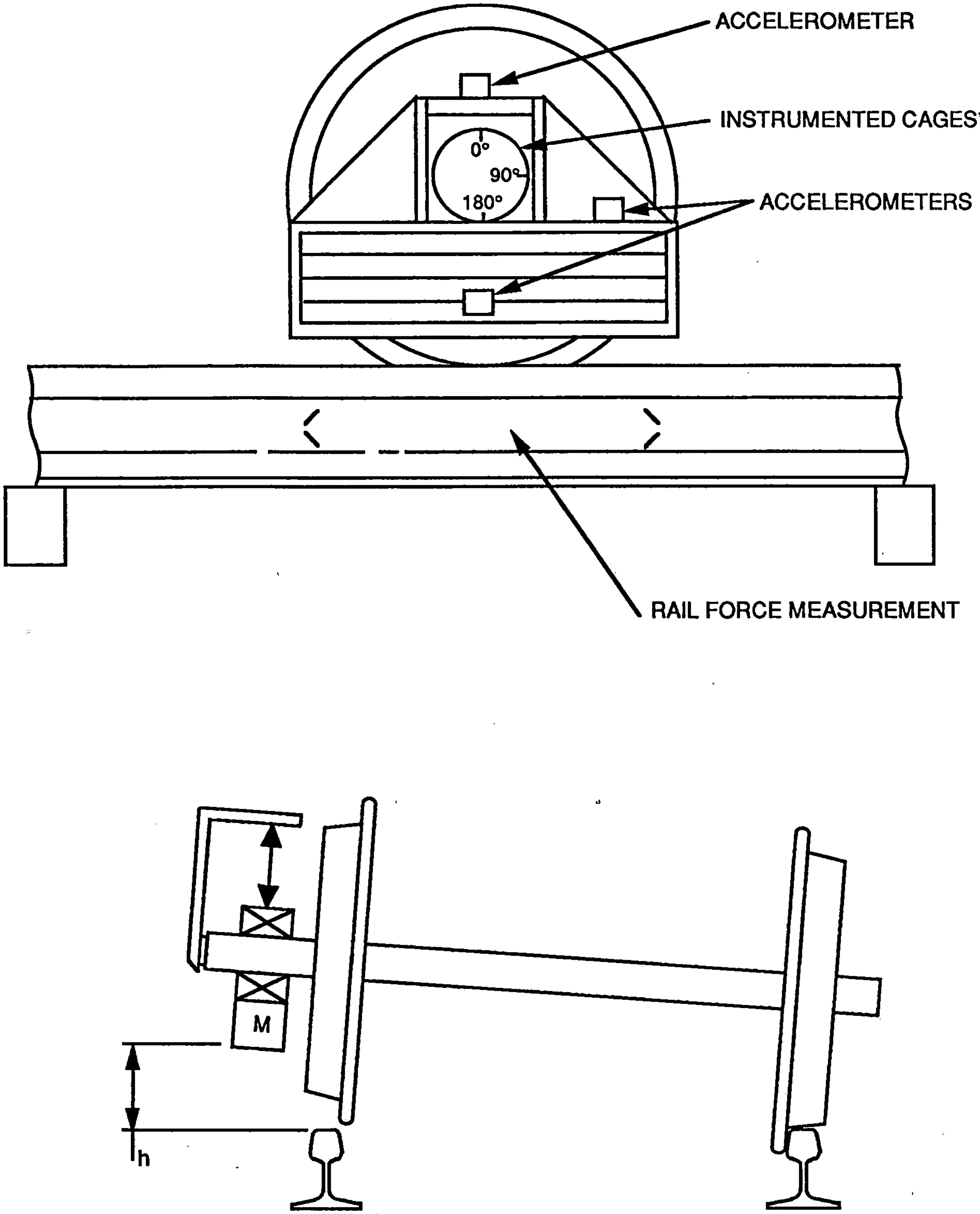


Figure 1. Test configuration.

A modified bearing was attached to the axle on the impact side of the axle. The modification included an increased diameter of the the inner races (cones) of the bearing to allow easy installation of the bearing and modification of the cones to allow the instrumented cages to be installed

The Phase I testing was conducted on a "track" consisting of two ties, four tie plates and a two 3 ft section rail. The "track" rested on a concrete driveway. The Phase I testing demonstrated the ability of the test method to provide short duration, high rail force loading to the wheel set and thus induce stresses in the instrumented bearings. Phase I testing was conducted in March, 1987.

Phase II testing was conducted on a section of yard track. Phase II included 25 tests. The tests were assigned test numbers based on the month and day of the test and the sequence number.

EXAMPLE Test Number 83115

August 31 - Sequence Number 15

Phase II testing was conducted in August and September of 1987.

Instrumentation

The instrumentation consisted of:

- Instrumented rail
- Accelerometer
- Axle bending moment transducer
- Two instrumented bearing cages

A 14 channel analog recorder was used to record the data from the drop test. The recording speed was 15 inches/second providing a bandwidth of 5,000 hz. The data reduction was based on playing back the data at a speed of 1 7/8 inches/second and recording the data on a strip chart. The playback reduction of 8 to 1 provided an effective bandwidth for data reduction of 500 hz or more.

Limited data was digitized based on the reduced play back speed. The antialiasing filters for digitizing were set at 300 hz and a 1,000 hz sampling rate used. This provides an effective sampling rate of 8,000 samples per sec and a 2,400 hz bandwidth.

A. Instrumented rail

The instrumented rail used the Battelle shear bridge concept and was calibrated to measure rail impact force. The calibration curve for the rail force transducer is shown in figure 2.

B. Accelerometer

The accelerometer used in the test was a model 793 manufactured by Wilcoxon Research. This model is a piezoelectric accelerometer with a range of 75 g's. The response is $\pm$ 5% with the frequency range 2 to 5,000 hz. The accelerometer was mounted on the adapter.

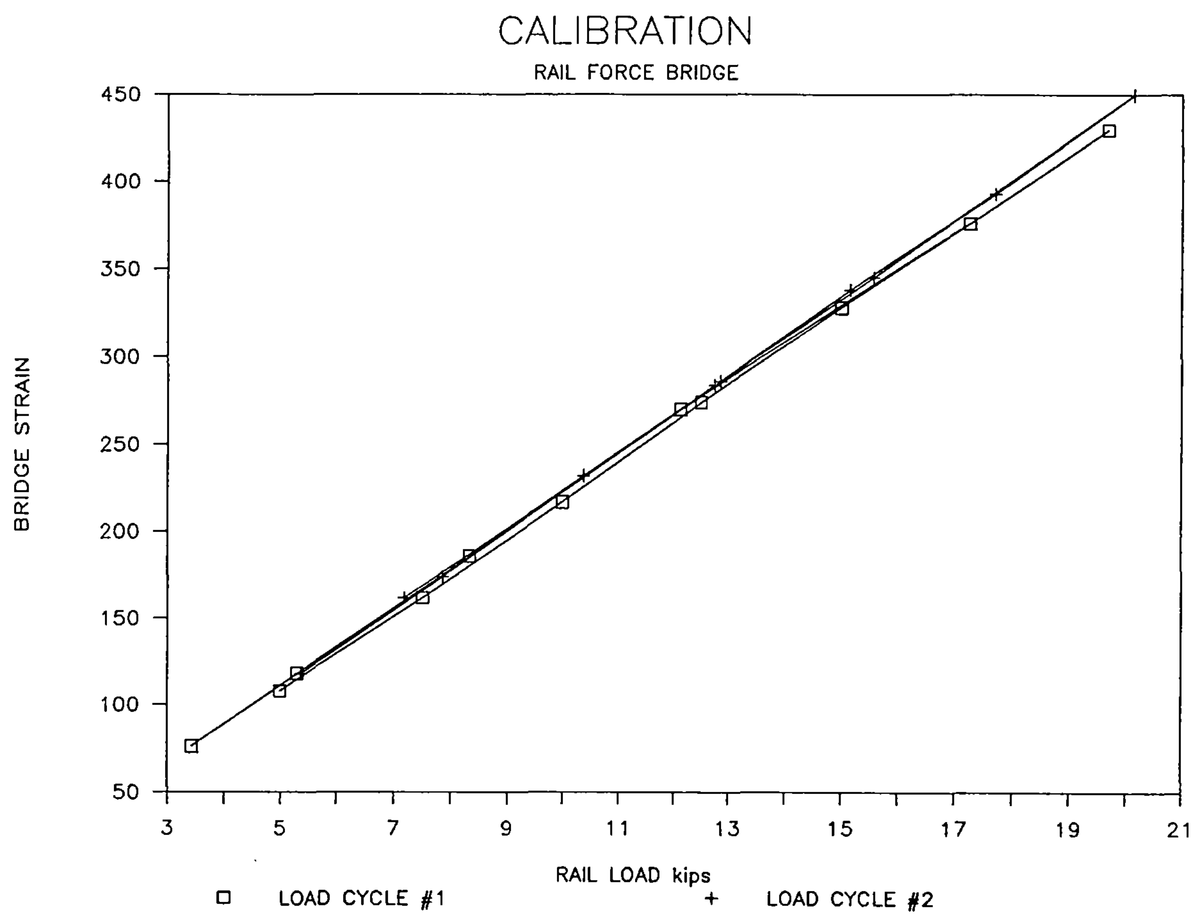


Figure 2. Rail Force Calibration.

C. Axle bending moment

The axial bending was measured using strain gages attached to the axle inboard of the bearing. Four strain gages were applied to the axle and connected in a Wheatstone bridge configuration as shown in figures 3 and 4.

The theoretical factor for the bridge (microstrain per pound-inch of bending moment) is given by:

$$\text{microstrain/bending moment} = (4\ c)/(E\ I_{xx}) = 0.00322$$

where M = bending moment in lb-in

c = distance from neutral axis = 3.75 in

$E = 30x10^6\ lb/in^2$

$I_{xx} = pi\ R^4/4 = 3.1416x(3.75)^4/4 = 155.32\ in^4$

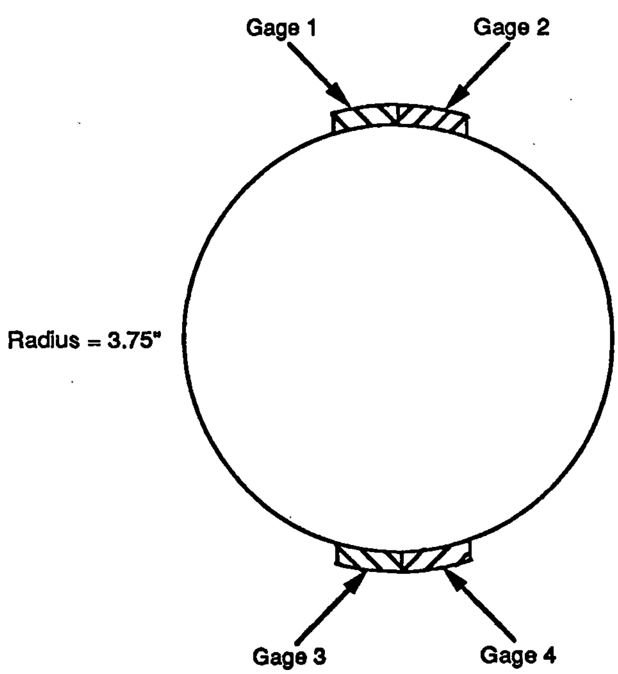


Figure 3. Axle Bending Configuration

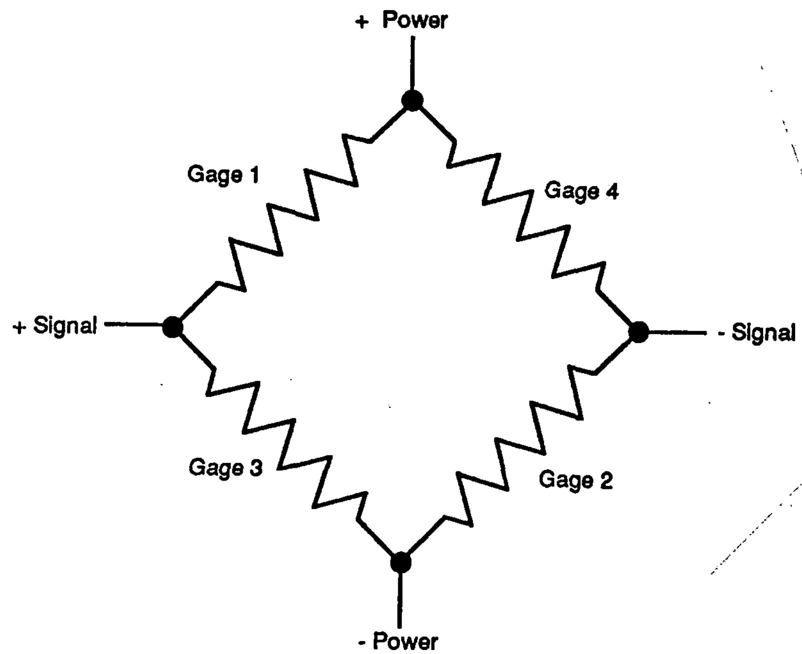


Figure 4. Axle Bending Moment Transducer.

D. Instrumented cages

Both cages of the roller bearings were instrumented with strain gages to measure strain in the cages during impact. The cages have 23 ribs to hold the 23 rollers in place. Each cage had 24 gages installed. Four locations were instrumented (six gages at each location) as listed in Table 1. The strain gages were part CEA 06062UW-120. The gage locations on the cage are shown in figure 5.

The rib was instrumented with two gages. Both gages were located in the center of the rib with one on the outside and one on the inside. The gages were connected in a Wheatstone bridge in either an addition or subtraction configuration. The addition configuration is called the tension configuration since it tends to be sensitive to tension/compression of the rib while tending to cancel bending. The tension configuration is show in figure 6.

Table 1. Nomenclature for instrumented cage.

POSITION 4-G L TOP DEAD CENTER

INNER CAGE RIB	INNER CAGE ROLLER	INNER CAGE GAGE LOCATION	INNER CAGE ANGLE	OUTER CAGE RIB	OUTER CAGE ROLLER	OUTER CAGE GAGE LOCATION	OUTER CAGE ANGLE
	1	1-G L	266.1	1		1-RIB	86.1
1		1-RIB	273.9		1	1-G L	93.9
	2		281.7	2			101.7
2			289.6		2		109.6
	3		297.4	3			117.4
3			305.2		3		125.2
	4		313.0	4			133.0
4			320.9		4		140.9
	5		328.7	5			148.7
5			336.5		5		156.5
	6		344.3	6			164.3
6			352.2		6		172.2
	7	4-G L	0.0	7			180.0
7		4-RIB	7.8		7	2-RIB	187.8
	8		15.7	8		2-G L	195.7
8			23.5		8		203.5
	9		31.3	9			211.3
9			39.1		9		219.1
	10		47.0	10			227.0
10			54.8		10		234.8
	11		62.6	11			242.6
11			70.4		11		250.4
	12		78.3	12			258.3
12			86.1		12	3-RIB	266.1
	13	3-G L	93.9	13		3-G L	273.9
13		3-RIB	101.7		13		281.7
	14		109.6	14			289.6
14			117.4		14		297.4
	15		125.2	15			305.2
15			133.0		15		313.0
	16		140.9	16			320.9
16			148.7		16		328.7
	17		156.5	17			336.5
17			164.3		17		344.3
	18	2-G L	172.2	18		4-RIB	352.2
18		2-RIB	180.0		18	4-G L	0.0
	19		187.8	19			7.8
19			195.7		19		15.7
	20		203.5	20			23.5
20			211.3		20		31.3
	21		219.1	21			39.1
21			227.0		21		47.0
	22		234.8	22			54.8
22			242.6		22		62.6
	23		250.4	23			70.4
23			258.3		23		78.3

Table 1 continued

POSITION 3-G L TOP DEAD CENTER

INNER CAGE RIB	INNER CAGE ROLLER	GAGE LOCATION		OUTER CAGE RIB	OUTER CAGE ROLLER	GAGE LOCATION	
	1	1-G L	172.2	1		1-RIB	180.0
1		1-RIB	180.0		1	1-G L	187.8
	2		187.8	2			195.7
2			195.7		2		203.5
	3		203.5	3			211.3
3			211.3		3		219.1
	4		219.1	4			227.0
4			227.0		4		234.8
	5		234.8	5			242.6
5			242.6		5		250.4
	6		250.4	6			258.3
6			258.3		6		266.1
	7	4-G L	266.1	7			273.9
7		4-RIB	273.9		7	2-RIB	281.7
	8		281.7	8		2-G L	289.6
8			289.6		8		297.4
	9		297.4	9			305.2
9			305.2		9		313.0
	10		313.0	10			320.9
10			320.9		10		328.7
	11		328.7	11			336.5
11			336.5		11		344.3
	12		344.3	12			352.2
12			352.2		12	3-RIB	0.0
	13	3-G L	0.0	13		3-G L	7.8
13		3-RIB	7.8		13		15.7
	14		15.7	14			23.5
14			23.5		14		31.3
	15		31.3	15			39.1
15			39.1		15		47.0
	16		47.0	16			54.8
16			54.8		16		62.6
	17		62.6	17			70.4
17			70.4		17		78.3
	18	2-G L	78.3	18		4-RIB	86.1
18		2-RIB	86.1		18	4-G L	93.9
	19		93.9	19			101.7
19			101.7		19		109.6
	20		109.6	20			117.4
20			117.4		20		125.2
	21		125.2	21			133.0
21			133.0		21		140.9
	22		140.9	22			148.7
22			148.7		22		156.5
	23		156.5	23			164.3
23			164.3		23		172.2

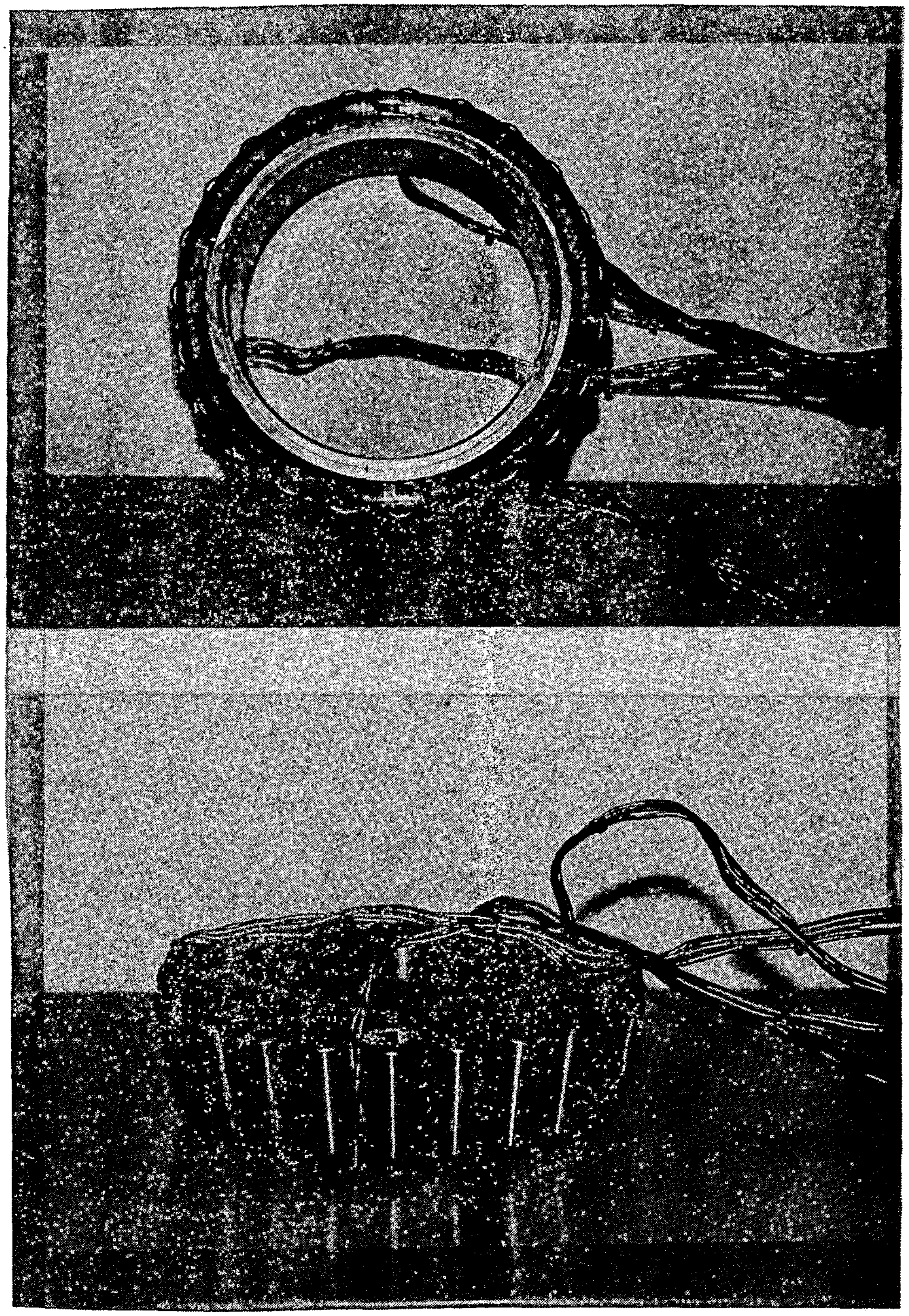
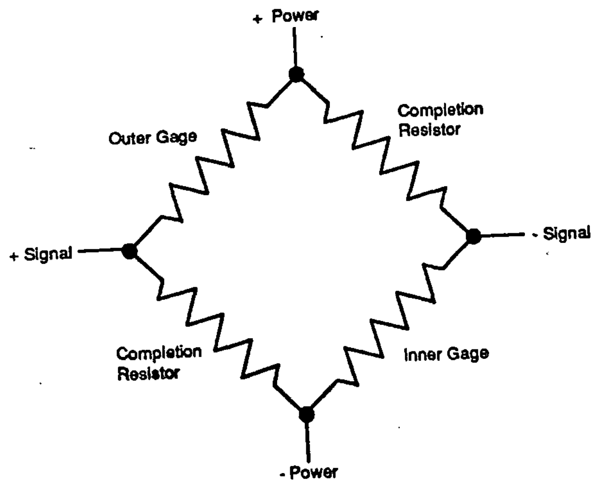


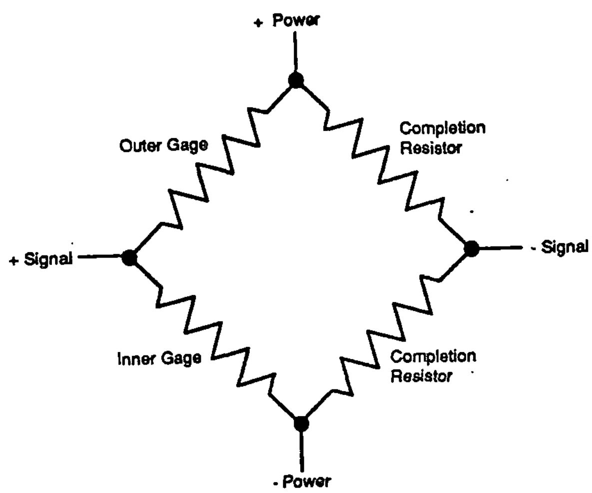
Figure 5. Gages applied to cages.



Compression of gages produces positive output

Figure 6. Tension Bridge Configuration.

The second configuration (subtraction) is called the bending configuration since it is sensitive to bending and tends to cancel tension/compression effects. The bridge configuration is shown in figure 7.



Bending causing compression of inner gage is positive

Figure 7. Bending Bridge Configuration.

Physics of Experiment

The drop test experiment is based on lifting one wheel above the rail and dropping it from a height H. The test method is shown in figure 8.

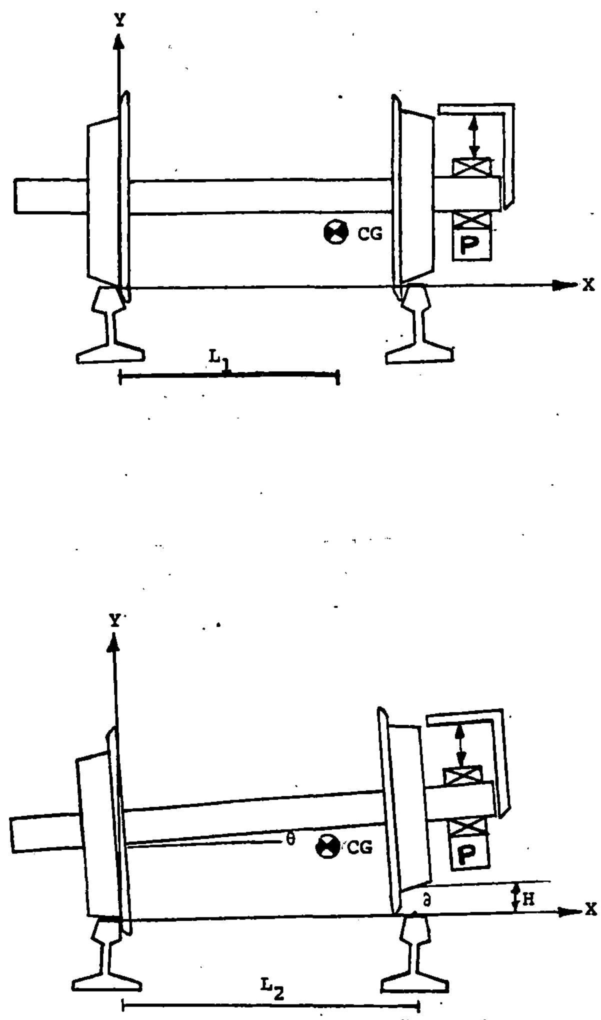


Figure 8. Model for Analysis.

The initial potential energy of the system is given by:

$$PE = W\ H_{cg}$$

The system is released from rest and rotates about the pivot point o impacting the anvil when θ is equal to zero. The rotation rate at this time is calculated by equating the loss in potential energy to the gain in kinetic energy. $\dot{\theta}$ is given by:

$$\text{delta PE} = \text{delta KE}$$

$$W\ H_{cg} = .5\ I_p\ \dot{\theta}^2$$

$$M\ g\ H_{cg} = .5\ M\ R_p^2\ \dot{\theta}^2$$

$$\dot{\theta} = \frac{\sqrt{2\ g\ H_{cg}}}{R_p}$$

where

M	=	mass of system
L_1	=	horizontal distance from pivot point to CG
L_2	=	horizontal distance from pivot point to anvil
θ	=	rotation angle
W	=	weight of rod = $M\ g$
g	=	acceleration of gravity
H	=	height system raised about anvil
H_{cg}	=	height CG is raised
I_p	=	mass moment of inertia about pivot point
R_p	=	radius of gyration about pivot point

The increase in the height of the CG is given by:

$$H_{cg} = D\ [\ \sin(\theta_2 + \theta_1) - \sin\theta_1\ ]$$

where

$$D = \sqrt{X_{cg}^2 + Y_{cg}^2}$$
$$\theta_1 = \tan^{-1} (Y_{cg} / X_{cg})$$
$$\theta_2 = \tan^{-1} (H / L_2)$$

X_{cg} = X location of CG
Y_{cg} = Y location of CG
H = height of wheel above ground

During the impact, the system has three degrees of freedom. It can translate in the XY plane and it can rotate. The equation for translation in the X direction is given by:

$$M \ddot{X} = F_p + W - F_i$$

where
M = total mass of system
F_p = force at pivot point (cannot be negative)
F_i = impact force
W = weight of system

The equation of motion for the translation in the Y direction is given by:

$$M \ddot{Y} = - P_i$$

where P_i = impact force in Y direction

The equation of motion for rotation is given by:

$$I_{cg} \ddot{\theta} = F_p L_1 - F_i (L_2 - L_1) + P_i Y_{cg}$$

where I_{cg} = moment of inertia about CG = $M R_{cg}^2$

Integration of these equations with respect to time provides:

$$M \dot{X}_f = M \dot{X}_o - \hat{F}_p + W\,T - \hat{F}_i$$

$$M \dot{Y}_f = M \dot{Y}_o - \hat{P}_i$$

$$I_{cg} \dot{\theta}_f = I_{cg} \dot{\theta}_o + \hat{F}_o L_1 - \hat{F}_i (L_2 - L_1)$$

where

$\dot{X}_f$ = final X velocity = $\dot{X}(T)$

$\dot{X}_o$ = Initial X velocity = $\dot{X}(0)$

$\dot{Y}_f$ = Final Y velocity = $\dot{Y}(T)$

$\dot{Y}_o$ = Initial Y velocity = $\dot{Y}(0)$

$\dot{\theta}_f$ = Final rotation rate = $\dot{\theta}(T)$

$\dot{\theta}_o$ = Initial rotation rate = $\dot{\theta}(0)$

$$\hat{F}_i = \int_0^T F_i \, dt$$

$$\hat{F}_p = \int_0^T F_i \, dt$$

The velocity in the x direction at point A at time = 0 is given by:

$$\dot{X}_o + (L_2 - L_1) \dot{\theta}_o = V_a(0)$$

The velocity in the x direction at point A at time = T is given by:

$$\dot{X}_f + (L_2 - L_1) \dot{\theta}_f = V_a(T)$$

The initial velocity is positive (into rail) while the final velocity will be negative as the wheelset rebounds. The ratio of the final to initial velocity is assumed to be constant for the impact:

$$e = -V_a(T)/V_a(0)$$

The impulsive force equation becomes:

$$(1 + e) V_a(0) M = \frac{(1 + e) \sqrt{2 g H_{cg}}}{R_o}$$

$$= \hat{F}_i S_1 + W T - \hat{F}_p S_2 + \hat{P}_i Y_{cg}$$

where

$$S_1 = \frac{(L_2 - L_1)^2 + R^2_{cg}}{R^2_{cg}}$$

$$S_2 = \frac{(L_2 - L_1) L_1 + R^2_{cg}}{R^2_{cg}}$$

$$S_3 = \frac{(L_2 - L_1) Y_{cg} + R^2_{cg}}{R^2_{cg}}$$

The expression for the impulse of the impact force is given by:

$$\hat{F}_i = \frac{M (1+e) V_a(0) + W T + \hat{F}_p S_2 + \hat{P}_i S_3}{S_1}$$

The time interval of the impact force can be written in the form:

$$\int_0^T F_i \, dt = F_{max} \, T \, b$$

where F_{max} = maximum force on the anvil
b = shape factor for rail force pulse (see figure 9)

The data from test 83115 was typical of the rail force versus time data from the test program. The data from this test was digitized and the value of the shape factor calculated. Figure 10 shows a plot of the data. The calculated result for the shape factor was 0.433.

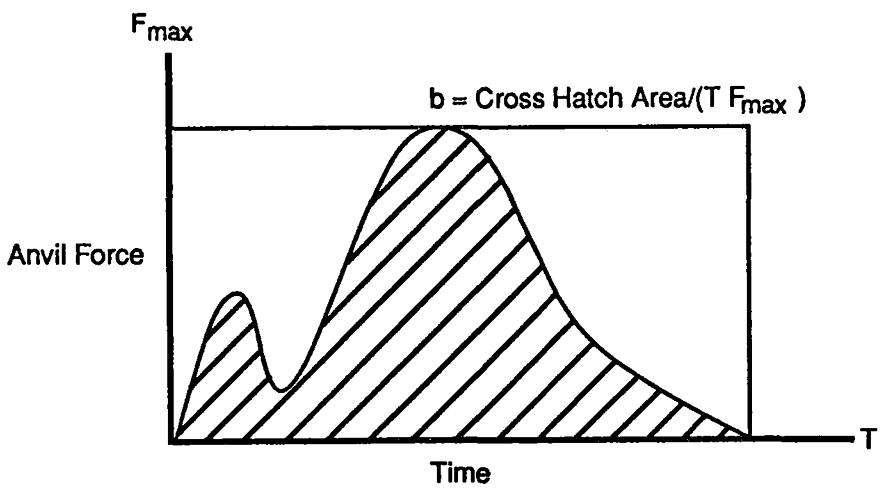


Figure 9. Definition of shape factor.

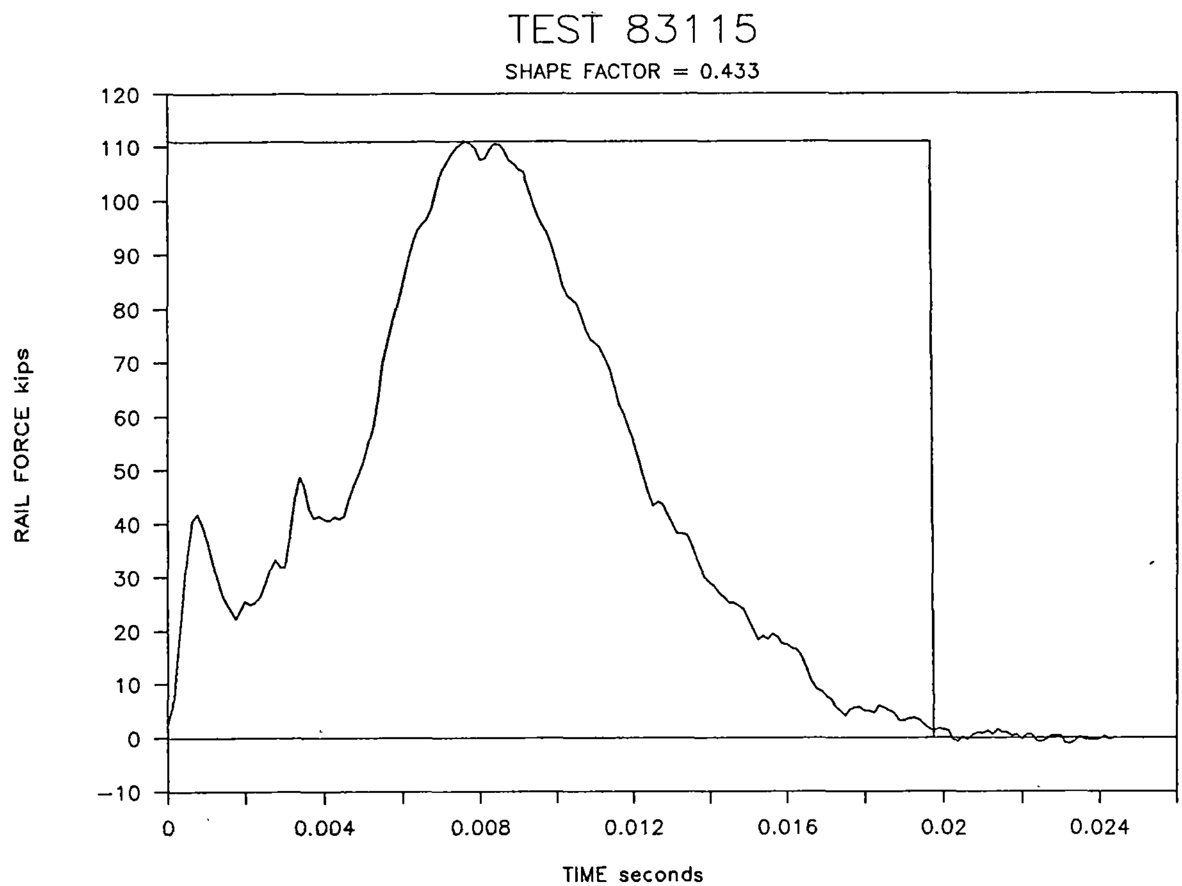


Figure 10. Calculation of Shape Factor.

Dimensions and Weight for Experiment

To estimate the values of the parameters in the above model, the wheel set for the drop test is divided into 7 parts:

W_1	pivot side wheel
W_2	axle
W_3	drop side wheel
W_4	instrumented bearing
W_5	clamp and load cell
W_6	adapter
W_7	load plates

Figure 11 shows the idealized configuration of the wheelset. The value of R_g is calculated by:

$$M\,R_g = \sum_{i=1}^{6} M_i\,R_{goi}^2 + M_i\sqrt{X_i^2 + Y_i^2}$$

where
M_i = mass of i^{th} part
R_{goi} = radius of gyration of i^{th} part about it's CG
X_i = X coordinate of CG for i^{th} part
Y_i = Y coordinate of CG for i^{th} part
M = Mass of system

The value of L_1 is calculated from the expression:

$$L_2 = \frac{\sum_{i=1}^{6} W_i\,X_i}{\sum_{i=1}^{6} W_i}$$

Table 2 provides the summary of the calculations for a 7 plate configuration. Values of L_1 and R_g for other plate configurations are given in table 2.

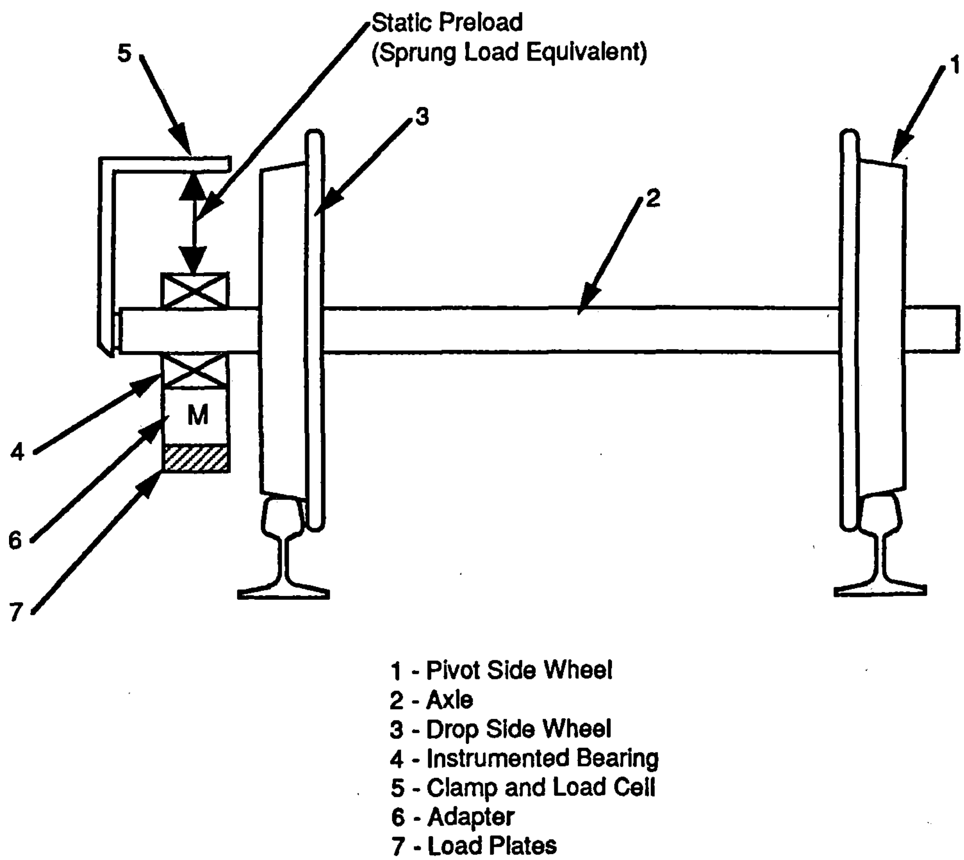


Figure 11. Model for Calculation of CG and Moment of Inertia

Table 2. Center of Gravity and Radius of Gyration Calculations

DROP TEST OF WHEELSET

SYSTEM OF 6 MASSES	X_{cg}	Y_{cg}
1. PIVOT SIDE WHEEL	0	19 in
2. AXLE	30	19 in
3. DROP SIDE WHEEL	60	19 in
4. BEARING	70	19 in
5. CLAMP/JACK	75	29 in
6. ADAPTER	70	13 in
7. PLATES	70	3 in

	WEIGHT	W X_i	W Y_i
1. PIVOT SIDE WHEEL	900	0	17,100
2. AXLE	1,200	36,000	22,800
3. DROP SIDE WHEEL	900	54,000	17,100
4. BEARING	50	3,500	950
5. CLAMP/JACK	145	10,875	4,205
6. ADAPTER	362	25,340	4,706
7. PLATES 7	455	31,850	1,365
WEIGHT =	4,012	161,565	68,226

$L_1 =$ 40.27 $Y_1 = 17.01$

	ROGcg	MASS	Io
1. PIVOT SIDE WHEEL	15.2	28.0	16,563
2. AXLE	43.2	37.3	116,652
3. DROP SIDE WHEEL	15.2	28.0	117,278
4. BEARING	8	1.6	8,276
5. CLAMP/JACK	6	4.5	29,306
6. ADAPTER	10	11.3	58,165
7. PLATES	2	14.1	69,488
TOTAL		124.7	415,729

ROG_o = 57.7 inches

Variations in Rail Forces

Tables 3 and 4 list the parameters for the 6 and 10 inch drop tests. These tables list the value of maximum rail force, momentum change and maximum accelerations obtained during testing. A shape factor of 0.433 is used to calculate momentum change. Note that the period of the impact ranges from 17 milliseconds to 24 milliseconds as shown in figure 12.

The analysis indicates that the system will lose contact with the rail on the pivot side since the impact reduces the rotation to nearly a zero rate while providing an upward velocity at the CG. For a drop height of 6 inches, the upward velocity is 1.9 ft/sec. The time during which the wheelset would lose contact with both rails would be:

$$t = 2\ V/g = 2\ (1.9)/(32.17)$$
$$= 0.118 \text{ seconds}$$

For a 10 inch drop height, the time is given by:

$$t = 2\ (2.5)/(32.17)$$
$$= 0.155 \text{ seconds}$$

The distance the wheel moves above the rail is given by:

$$h = 0.5\ V^2 / g = 0.5\ (2.5)^2/(32.17)$$
$$= 0.097 \text{ inches for 10 inch drop}$$

$$h = 0.5\ (1.9)^2/(32.17)$$
$$0.670 \text{ inches for 6 inch drop}$$

Test results show the initial impact is followed by a second impact. The timing between the first and second impacts are of the same within milliseconds of the above calculations.

Table 3. System parameters for 6 inch drop height.

L2 = 60 inches   MASS = 124.7 slugs
a = 0.433   H = 0.500 ft

NUMBER OF PLATES	Xcg in	Ycg in	R_o in	DISTANCE FROM CG D in	R_{cg} in	L_2-L_1 in	S_1	S_2
1	37.1	18.5	56.2	41.4	38.0	22.9	1.36	-0.23
2	37.6	18.2	56.5	41.8	38.0	22.4	1.35	-0.25
3	38.2	18.0	56.8	42.2	38.0	21.8	1.33	-0.26
4	38.8	17.7	57.0	42.6	37.9	21.2	1.31	-0.27
5	39.3	17.5	57.3	43.0	37.9	20.7	1.30	-0.29
6	39.8	17.2	57.5	43.4	37.8	20.2	1.29	-0.30
7	40.3	17.0	57.7	43.7	37.7	19.7	1.27	-0.31
8	40.7	16.8	58.0	44.1	37.6	19.3	1.26	-0.33

LOCATION = 60 in

NUMBER OF PLATES	$\dot{\theta}(0)$	$\dot{X}(0)$	$\dot{\theta}(T)$	$\dot{X}(T)$	$V_a(0)$	$V_a(T)$	delta V	H_{cg}
1	0.937	2.9	0.000	-2.0	4.7	-2.0	6.7	3.60
2	0.940	2.9	0.011	-2.1	4.7	-2.0	6.7	3.66
3	0.943	3.0	0.021	-2.1	4.7	-2.0	6.8	3.71
4	0.946	3.1	0.031	-2.1	4.7	-2.0	6.8	3.77
5	0.948	3.1	0.041	-2.1	4.7	-2.1	6.8	3.82
6	0.951	3.2	0.051	-2.1	4.8	-2.1	6.8	3.87
7	0.953	3.2	0.061	-2.2	4.8	-2.1	6.8	3.92
8	0.955	3.2	0.071	-2.2	4.8	-2.1	6.8	3.97

NUMBER OF PLATES	X TRANS ft-lbs	ROT ft-lbs	Y TRANS ft-lbs	TOTAL ft-lbs	X TRANS ft-lbs	ROT ft-lbs	X DELTA MV lb-sec	Y DELTA MV lb-sec
1	522	550	130	1,202	257	0	614	180
2	542	553	127	1,222	263	0	624	178
3	562	555	124	1,241	270	0	634	176
4	582	557	122	1,260	276	1	643	174
5	601	558	119	1,278	281	1	652	172
6	620	559	116	1,295	287	2	661	170
7	638	560	114	1,311	292	2	669	168
8	656	560	111	1,328	297	3	677	167

Table 4. System parameters for 10 inch drop.

L2 = 60 in MASS = 124.7 slugs
a = 0.433 H = 0.833 ft

NUMBER OF PLATES	Xcg in	Ycg in	PIVOT ROG in	D_o in	ROG in	(L2-L1) in	S1	S2
1	37.1	18.5	56.2	41.4	38.0	22.9	1.36	-0.23
2	37.6	18.2	56.5	41.8	38.0	22.4	1.35	-0.25
3	38.2	18.0	56.8	42.2	38.0	21.8	1.33	-0.26
4	38.8	17.7	57.0	42.6	37.9	21.2	1.31	-0.27
5	39.3	17.5	57.3	43.0	37.9	20.7	1.30	-0.29
6	39.8	17.2	57.5	43.4	37.8	20.2	1.29	-0.30
7	40.3	17.0	57.7	43.7	37.7	19.7	1.27	-0.31
8	40.7	16.8	58.0	44.1	37.6	19.3	1.26	-0.33

LOCATION = 60 in

NUMBER OF PLATES	$\dot{\theta}(0)$	$\dot{X}(0)$	$\dot{\theta}(T)$	$\dot{X}(T)$	$V_a(0)$	$V_a(T)$	delta V	H_{cg}
1	1.194	3.7	0.000	-2.6	6.0	-2.6	8.6	5.84
2	1.198	3.8	0.014	-2.6	6.0	-2.6	8.6	5.94
3	1.202	3.8	0.026	-2.7	6.0	-2.6	8.6	6.04
4	1.206	3.9	0.039	-2.7	6.0	-2.6	8.6	6.13
5	1.210	4.0	0.052	-2.7	6.0	-2.6	8.7	6.22
6	1.213	4.0	0.065	-2.7	6.1	-2.6	8.7	6.31
7	1.216	4.1	0.078	-2.8	6.1	-2.6	8.7	6.39
8	1.220	4.1	0.090	-2.8	6.1	-2.6	8.7	6.47

NUMBER PLATES	X TRANS ft-lbs	ROT ft-lbs	Y TRANS ft-lbs	TOTAL ft-lbs	X TRANS ft-lbs	ROT ft-lbs	X DELTA MV lb-sec	Y DELTA MV lb-sec
1	848	893	212	1,953	417	0	783	230
2	882	898	207	1,986	428	0	796	227
3	914	902	202	2,018	438	0	808	225
4	946	905	198	2,049	448	1	820	222
5	978	908	194	2,079	458	2	832	220
6	1,009	910	189	2,108	467	3	843	217
7	1,039	912	185	2,136	475	4	853	215
8	1,069	913	181	2,163	484	5	864	213

Table 5. Test Results.

Test	H	p	Bending Moment lb-in	Rail Force kips	Duration Duration msec.	Momentum Change lb.-sec	Maximum Accel. g's
82801	6	4	192,547	81	17	596	43
83101 A	6	4	242,236	81	18	631	41
82802	6	4	198,447	81	17	596	41
83102 A	6	4	229,814	81	17	596	44
82803	6	4	192,547	84	17	618	44
82804	6	4	195,652	84	17	618	50
83105	10	4	298,137	99	17	729	59
83106	10	4	322,981	107	17	784	57
83107	10	4	316,770	104	17	762	56
83108	10	4	322,981	104	17	762	54
83109	6	7	239,130	86	20	790	38
83110	6	7	260,870	87	18	678	47
83111	6	7	236,025	84	20	727	42
83112	6	7	267,081	90	18	701	47
83113	10	7	316,770	108	17	795	50
83114	10	7	357,143	111	18	865	47
83115	10	7	349,379	111	18	961	46
83116	10	7	318,323	110	21	996	47
83117	6	7	248,447	86	21	777	NA
83117 A	6	7	248,447	84	21	764	38
83118	6	7	236,025	80	23	792	38
83119	6	7	242,236	81	23	807	38
83120	6	7	239,130	78	23	777	36
83121	6	7	245,342	72	23	717	38
83122	6	7	263,975	83	23	822	35
83122	6	7	270,186	75	24	779	31
83123	6	7	254,658	86	21	777	31
83124	6	7	263,975	81	23	807	30
83125	6	7	254,658	84	22	800	31
83126	10	7	349,379	108	20	935	32
90101 A	6	7	229,814	72	23	717	NA
90101	6	4	217,391	78	21	709	37
90102	6	4	245,342	68	24	701	36
90103	6	4	245,342	78	21	709	38
90104	6	4	239,130	81	21	737	38
90105	10	4	318,323	99	18	772	40

The duration of impact for the test in the phase II sequence is illustrated in figure 12.

The relationship between rail force and pulse duration is shown in figure 13 for a drop height of 6 inches and a drop height of 10 inches (for 7 plate configuration). The lines in this figure are based on the above analysis and symbols represent the data points from the test program. The expression for the impulse of the impact force was calculated from the expression:

$$\hat{F}_i = M\ (1+e)\ V_a(0)\ /\ S_1$$
$$= F_{max}\ T\ b$$

The relationship between maximum rail force and bending moment is shown in figure 14. The relationship between maximum force and peak acceleration is shown in figure 15.

Comparison of Field Measurements and Drop Test Results

The time history of the vertical rail force was used to compare the drop test results with field measurements. The same measurement concept was used to measure vertical rail forces in the drop test as Battelle has used for numerous revenue train measurements. The field measurements indicate that the vertical rail forces have a duration of 15 milliseconds and peak force levels of 100 kips. The shape of the vertical rail force has either a half sine-wave shape or a double peak shape. The drop test results have a duration of 15 to 25 milliseconds with peak forces in the 100 kip range for a 10 inch drop height. The shape factor for the test is a double peak.

The conclusion based on the comparison is that the drop test is a realistic simulation of "in-service" vertical rail force impacts experienced by rail vehicles.

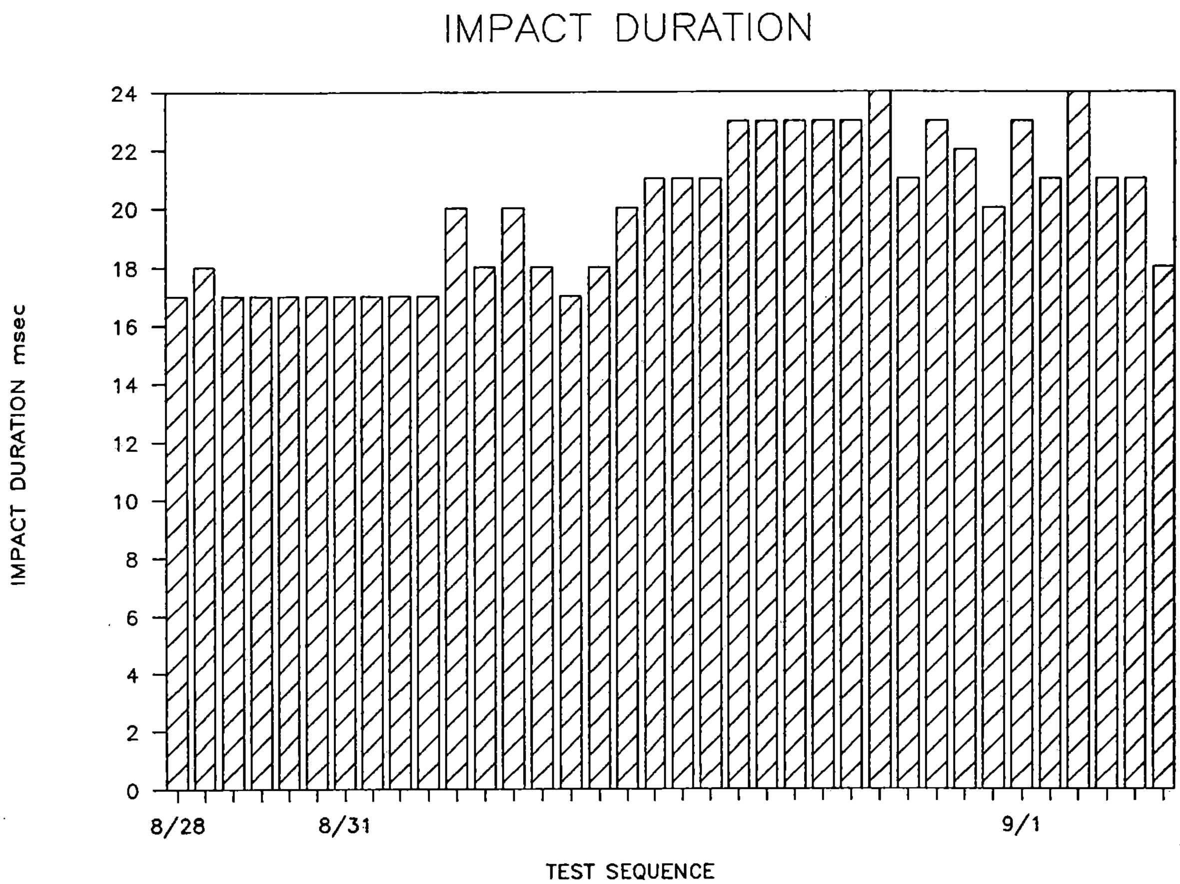


Figure 12. Impact Duration.

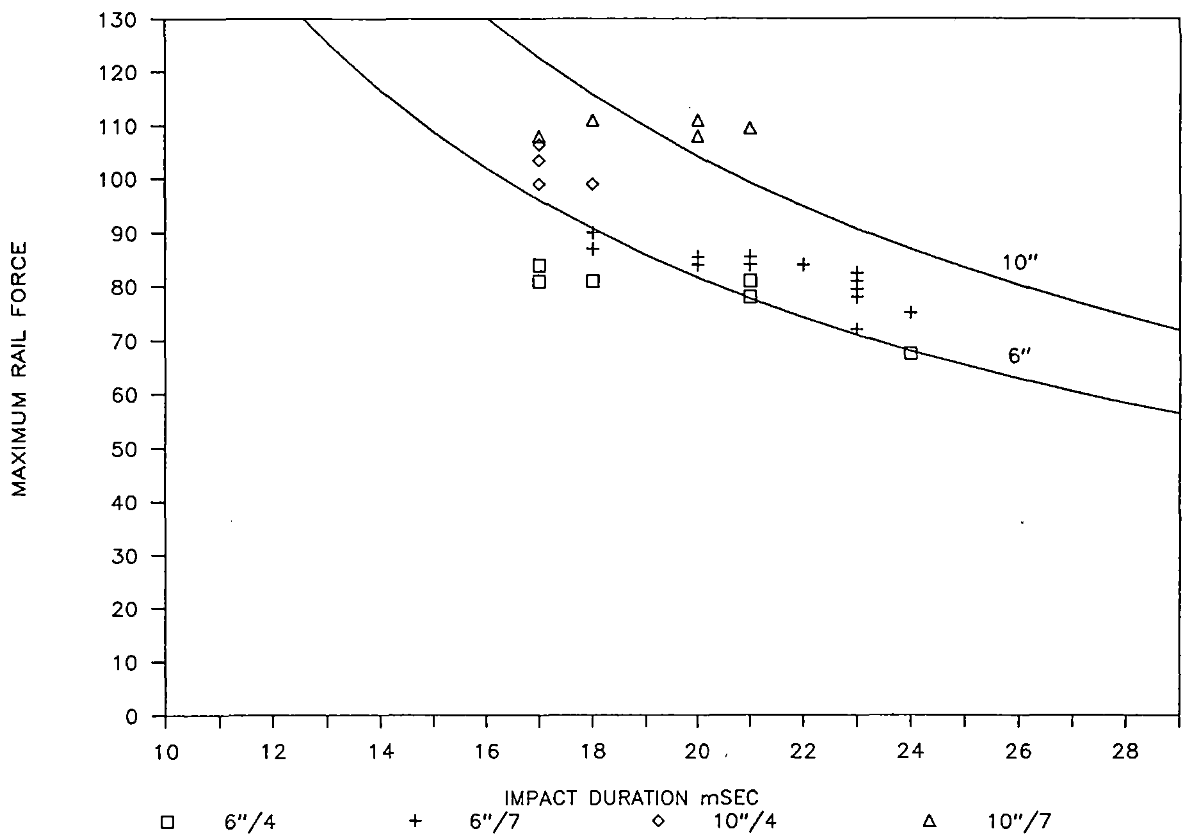


Figure 13. Maximum Rail Force versus Impact Duration.

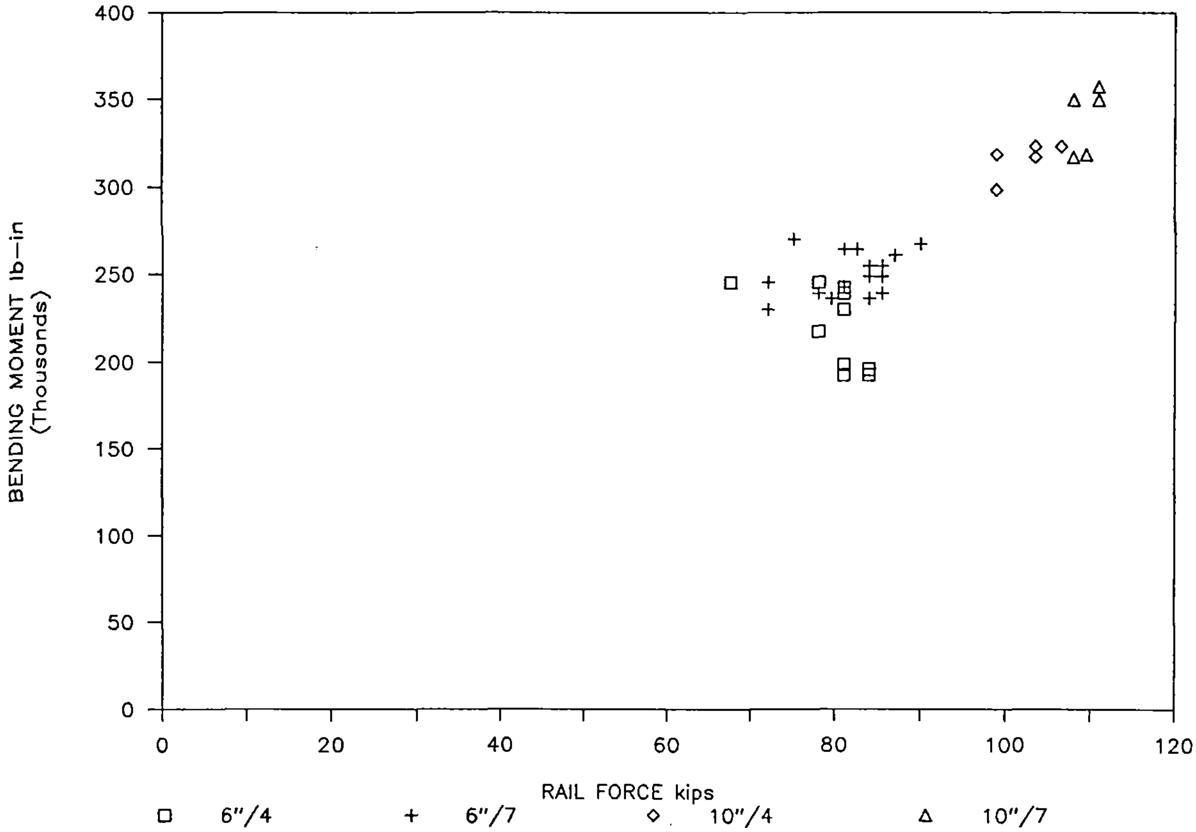


Figure 14. Bending Moment versus Maximum Rail Force.

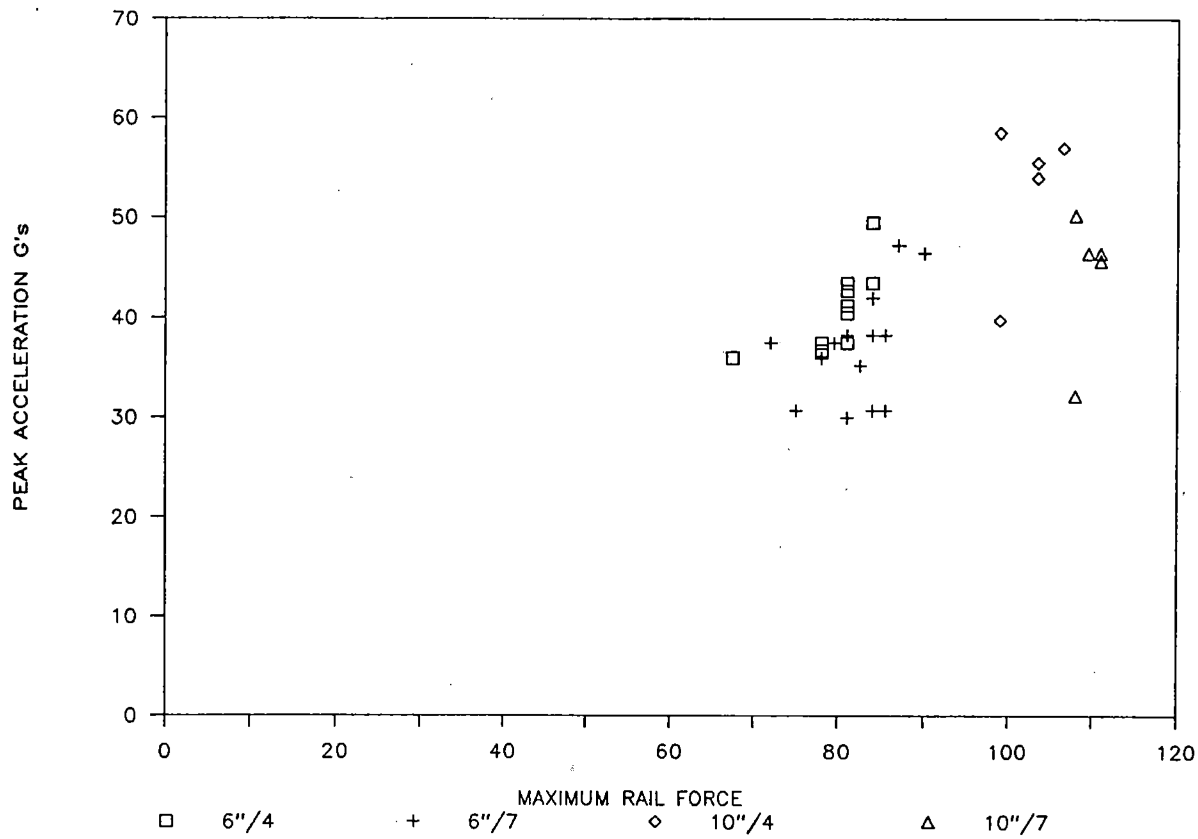


Figure 15. Peak Acceleration versus Maximum Rail Force.

Quick Look Results

The test results were collected on an analog recorder at a speed of 15 ips. For data reduction the data was played back at a speed of 1 7/8 ips and recorded on a strip chart. The data reduction procedure was based on the strip chart representation of the data. The following tables summarize the results. Each table corresponds to a channel on the tape recorder. The following applies to the tables:

1. All angles measured are referenced to the top of the axle (12 o'clock position).
   Clockwise is positive looking into the instrumented end of axle.

2. Location: Cage location is either inner or outer
   Inner location is closest to wheel
   Outer location is closest to end of axle

3. All strains are measured in microstrain. Material strain is one half for pure bending or tension.

4. All data values are zero to peak values. Values taken near the major rail impact.

5. Sign was not retained.

6. Notation H = drop height = distance from rail to wheel
   T = tension bridge configuration
   B = bending bridge configuration

7. All tests were conducted with the instrumentation location 4-G L top dead center except test on 9/1/87 when 3-G L was top dead center.

LOCATION: *******************LESSER**************

CHANNEL:				4	4	4	4	4
ANGLE:				172.2	195.7	101.7	266.1	172.2
LOCATION:				INNER	OUTER	OUTER	INNER	INNER
MAXIMUM BRIDGE STRAIN:				16	12	20	32	36
TEST		H	P					
82801		6	4	14 T				
83101	A	6	4	10 T				
82802		6	4	8 T				
83102	A	6	4	10 T				
82803		6	4	8 T				
82804		6	4	10 T				
83105		10	4	16 T				
83106		10	4	14 T				
83107		10	4	12 T				
83108		10	4	14 T				
83109		6	7	14 T				
83110		6	7	12 T				
83111		6	7	12 T				
83112		6	7	8 T				
83113		10	7	14 T				
83114		10	7	12 T				
83115		10	7	14 T				
83116		10	7	10 T				
83117		6	7		10 T			
83117	A	6	7		12 T			
83118		6	7		8 T			
83119		6	7		10 T			
83120		6	7		8 T			
83121		6	7			20 T		
83122		6	7				20 T	
83122		6	7				22 T	
83123		6	7				26 T	
83124		6	7				26 T	
83125		6	7				24 T	
83126		10	7				32 T	
90101	A	6	7					24 T
90101		6	4					28 T
90102		6	4					28 T
90103		6	4					32 T
90104		6	4					32 T
90105		10	4					36 T

LOCATION:				^^^^^^^^^^^^^^^^^^RIB^^^^^^^^^^^^^^^^^^^^^^^				
CHANNEL:				5	5	5	5	5
ANGLE:				180.0	187.8	101.7	273.9	180.0
LOCATION:				INNER	OUTER	OUTER	INNER	INNER
MAXIMUM BRIDGE STRAIN:				10	8	6	12	10
TEST		H	P					
82801		6	4	4 T				
83101	A	6	4	4 T				
82802		6	4	4 T				
83102	A	6	4	8 T				
82803		6	4	4 T				
82804		6	4	6 T				
83105		10	4	8 T				
83106		10	4	8 T				
83107		10	4	10 T				
83108		10	4	10 T				
83109		6	7	6 T				
83110		6	7	8 T				
83111		6	7	6 T				
83112		6	7	6 T				
83113		10	7	6 T				
83114		10	7	6 T				
83115		10	7	8 T				
83116		10	7	6 T				
83117		6	7		6 T			
83117	A	6	7		8 T			
83118		6	7		6 T			
83119		6	7		4 T			
83120		6	7		4 T			
83121		6	7			6 T		
83122		6	7				6 T	
83122		6	7				8 T	
83123		6	7				4 T	
83124		6	7				4 T	
83125		6	7				6 T	
83126		10	7				12 T	
90101	A	6	7					8 T
90101		6	4					6 T
90102		6	4					6 T
90103		6	4					4 T
90104		6	4					6 T
90105		10	4					10 T

LOCATION:	****************GREATER****************				
CHANNEL:	6	6	6	6	6
ANGLE:	172.2	195.7	101.7	266.1	172.2
LOCATION:	INNER	OUTER	OUTER	INNER	INNER
MAXIMUM BRIDGE STRAIN:	960	8	4	6	8

TEST	H	P					
82801	6	4	800 T				
83101 A	6	4	62 T				
82802	6	4	600 T				
83102 A	6	4	100 T				
82803	6	4	T				
82804	6	4	520 T				
83105	10	4	130 T				
83106	10	4	190 T				
83107	10	4	120 T				
83108	10	4	11 T				
83109	6	7	120 T				
83110	6	7	155 T				
83111	6	7	50 T				
83112	6	7	105 T				
83113	10	7	150 T				
83114	10	7	T				
83115	10	7	810 T				
83116	10	7	960 T				
83117	6	7		8 T			
83117 A	6	7		6 T			
83118	6	7		4 T			
83119	6	7		4 T			
83120	6	7		4 T			
83121	6	7			4 T		
83122	6	7				4 T	
83122	6	7				4 T	
83123	6	7				4 T	
83124	6	7				4 T	
83125	6	7				4 T	
83126	10	7				6 T	
90101 A	6	7					4 T
90101	6	4					6 T
90102	6	4					4 T
90103	6	4					6 T
90104	6	4					8 T
90105	10	4					8 T

LOCATION: ********************LESSER*********************

CHANNEL:	7	7	7	7	7	7
ANGLE:	187.8	172.2	266.1	93.8	266.1	187.8
LOCATION:	OUTER	INNER	INNER	INNER	OUTER	OUTER
MAXIMUM BRIDGE STRAIN:	14	6	34	44	12	12

TEST		H	P						
82801		6	4	B					
83101	A	6	4	8 B					
82802		6	4	B					
83102	A	6	4	14 B					
82803		6	4	10 B					
82804		6	4	8 B					
83105		10	4	10 B					
83106		10	4	12 B					
83107		10	4	12 B					
83108		10	4	12 B					
83109		6	7	14 B					
83110		6	7	10 B					
83111		6	7	10 B					
83112		6	7	8 B					
83113		10	7	6 B					
83114		10	7	12 B					
83115		10	7	10 B					
83116		10	7	12 B					
83117		6	7	10 T					
83117	A	6	7		6 B				
83118		6	7		4 B				
83119		6	7		4 B				
83120		6	7		6 B				
83121		6	7						
83122		6	7			34 T			
83122		6	7				36 T		
83123		6	7				44 T		
83124		6	7					8 B	
83125		6	7					8 B	
83126		10	7					12 B	
90101	A	6	7						8 B
90101		6	4						8 B
90102		6	4						8 B
90103		6	4						12 B
90104		6	4						12 B
90105		10	4						12 B

LOCATION:			^^^^^^^^^^^^^^^^^^RIB^^^^^^^^^^^^^^^^^^^^^^^^^					
CHANNEL:			8	8	8	8	8	8
ANGLE:			180	180	273.9	101.7	258.3	180
LOCATION:			OUTER	INNER	INNER	INNER	OUTER	OUTER
MAXIMUM BRIDGE STRAIN:			30	14	10	106	40	90
TEST	H	P						
82801	6	4	20 B					
83101 A	6	4	20 B					
82802	6	4	22 B					
83102 A	6	4	20 B					
82803	6	4	20 B					
82804	6	4	18 B					
83105	10	4	24 B					
83106	10	4	26 B					
83107	10	4	28 B					
83108	10	4	28 B					
83109	6	7	20 B					
83110	6	7	20 B					
83111	6	7	18 B					
83112	6	7	18 B					
83113	10	7	28 B					
83114	10	7	28 B					
83115	10	7	30 B					
83116	10	7	28 B					
83117	6	7	12 T					
83117 A	6	7		12 B				
83118	6	7		14 B				
83119	6	7		10 B				
83120	6	7		10 B				
83121	6	7			10 B			
83122	6	7			6 T			
83122	6	7				46 T		
83123	6	7				106 T		
83124	6	7					30 B	
83125	6	7					30 B	
83126	10	7					40 B	
90101 A	6	7						62 B
90101	6	4						66 B
90102	6	4						64 B
90103	6	4						76 B
90104	6	4						84 B
90105	10	4						90 B

LOCATION: ****************GREATER************************

CHANNEL:			9	9	9	9	9	9
ANGLE:			187.8	172.2	266.1	93.8	266.1	187.8
LOCATION:			OUTER	INNER	INNER	INNER	OUTER	OUTER
MAXIMUM BRIDGE STRAIN:			2000	960	32	12	40	32
TEST	H	P						
82801	6	4	34 B					
83101 A	6	4	20 B					
82802	6	4	38 B					
83102 A	6	4	26 B					
82803	6	4	36 B					
82804	6	4	34 B					
83105	10	4	30 B					
83106	10	4	42 B					
83107	10	4	40 B					
83108	10	4	40 B					
83109	6	7	26 B					
83110	6	7	26 B					
83111	6	7	26 B					
83112	6	7	24 B					
83113	10	7	44 B					
83114	10	7	42 B					
83115	10	7	44 B					
83116	10	7	40 B					
83117	6	7	280 T					
83117 A	6	7		320 B				
83118	6	7		375 B				
83119	6	7		540 B				
83120	6	7		960 B				
83121	6	7			32 B			
83122	6	7			8 T			
83122	6	7				12 T		
83123	6	7				12 T		
83124	6	7					35 B	
83125	6	7					40 B	
83126	10	7					30 B	
90101 A	6	7						22 B
90101	6	4						24 B
90102	6	4						26 B
90103	6	4						26 B
90104	6	4						32 B
90105	10	4						30 B

LOCATION:			*******************LESSER*******************					
CHANNEL:			10	10	10	10	10	10
ANGLE:			0	0	93.9	93.9	0	0
LOCATION:			OUTER	INNER	INNER	OUTER	OUTER	INNER
MAXIMUM BRIDGE STRAIN:			80	18	8	16	12	58
TEST	H	P						
82801	6	4	10 B					
83101 A	6	4	80 B					
82802	6	4	20 B					
83102 A	6	4	40 B					
82803	6	4	12 B					
82804	6	4	14 B					
83105	10	4	64 B					
83106	10	4	48 B					
83107	10	4		16 T				
83108	10	4		16 T				
83109	6	7	10 B					
83110	6	7	B					
83111	6	7		10 T				
83112	6	7		10 T				
83113	10	7		12 T				
83114	10	7						
83115	10	7		18 T				
83116	10	7		14 T				
83117	6	7		16 B				
83117 A	6	7		18 B				
83118	6	7		16 B				
83119	6	7	10 T					
83120	6	7	10 T					
83121	6	7			6 B			
83122	6	7			8 T			
83122	6	7				8 B		
83123	6	7				10 B		
83124	6	7				12 B		
83125	6	7				12 B		
83126	10	7				16 B		
90101 A	6	7					12 B	
90101	6	4					10 B	
90102	6	4					8 B	
90103	6	4						56 T
90104	6	4						58 T
90105	10	4					12 B	

LOCATION: ^^^^^^^^^^^^^^^^^^^^RIB^^^^^^^^^^^^^^^^^^^^^^^^^^

CHANNEL:				11	11	11	11	11	11
ANGLE:				352.2	7.8	101.7	180	352.2	7.8
LOCATION:				OUTER	INNER	INNER	OUTER	OUTER	INNER
MAXIMUM BRIDGE STRAIN:				100	90	130	170	46	36
TEST		H	P						
82801		6	4	90 B					
83101	A	6	4	84 B					
82802		6	4	92 B					
83102	A	6	4	72 B					
82803		6	4	4 B					
82804		6	4	4 B					
83105		10	4	92 B					
83106		10	4	94 B					
83107		10	4		12 T				
83108		10	4		8 T				
83109		6	7	68 B					
83110		6	7	74 B					
83111		6	7		6 T				
83112		6	7		4 T				
83113		10	7		90 T				
83114		10	7	100 B					
83115		10	7		4 T				
83116		10	7		4 T				
83117		6	7		62 B				
83117	A	6	7		70 B				
83118		6	7		60 B				
83119		6	7	4 T					
83120		6	7	4 T					
83121		6	7			130 B			
83122		6	7			120 T			
83122		6	7				170 B		
83123		6	7				110 B		
83124		6	7				90 B		
83125		6	7				90 B		
83126		10	7				100 B		
90101	A	6	7					40 B	
90101		6	4					40 B	
90102		6	4					38 B	
90103		6	4						32 T
90104		6	4						36 T
90105		10	4					46 B	

LOCATION: ****************GREATER**************************

CHANNEL:				12	12	12	12	12	12
ANGLE:				0	0	93.9	93.9	0	0
LOCATION:				OUTER	INNER	INNER	OUTER	OUTER	INNER
MAXIMUM BRIDGE STRAIN:				20	18	50	44	48	12
TEST		H	P						
82801		6	4	16 B					
83101	A	6	4	12 B					
82802		6	4	14 B					
83102	A	6	4	12 B					
82803		6	4	4 B					
82804		6	4	8 B					
83105		10	4	20 B					
83106		10	4	16 B					
83107		10	4		12 T				
83108		10	4		12 T				
83109		6	7	16 B					
83110		6	7	14 B					
83111		6	7		6 T				
83112		6	7		4 T				
83113		10	7		16 T				
83114		10	7	14 B					
83115		10	7		10 T				
83116		10	7		8 T				
83117		6	7		18 B				
83117	A	6	7		18 B				
83118		6	7		10 B				
83119		6	7	6 T					
83120		6	7	4 T					
83121		6	7			40 B			
83122		6	7			50 T			
83122		6	7				24 B		
83123		6	7				24 B		
83124		6	7				32 B		
83125		6	7				30 B		
83126		10	7				44 B		
90101	A	6	7					48 B	
90101		6	4					38 B	
90102		6	4					32 B	
90103		6	4						12 T
90104		6	4						12 T
90105		10	4					48 B	

Table 6. Summary of Maximum Bridge Strain by Location

LESSER

	inner B	inner T	outer B	outer T
0	18	58	80	10
93.8	16	44	16	NT
101.7	NT	NT	NT	20
172.2	6	36	NT	NT
187.8	NT	NT	14	10
195.7	NT	NT	NT	12
266.1	NT	34	12	NT

IB

	inner B	inner T	outer B	outer T
7.8	70	90	NT	NT
101.7	130	120	NT	6
180.0	14	10	170	12
187.5	NT	8	NT	NT
258.3	NT	NT	40	NT
273.9	10	12	NT	NT
352.2	NT	NT	46	4

GREATER

	inner B	inner T	outer B	outer T
0	18	16	48	6
93.8	40	50	44	NT
101.7	NT	NT	NT	4
172.2	960	960	NT	NT
187.8	NT	NT	44	280
195.7	NT	NT	NT	8
266.1	32	8	40	NT

Table 7 Summary of Strain Data.

BRIDGE STRAIN
MAXIMUM VALUE AT LOCATION

LESSER

CLOCK POSITION	inner B	inner T	outer B	outer T
12	18	58	80	10
3	16	44	16	20
6	6	36	12	22
9	0	34	12	0

RIB

CLOCK POSITION	inner B	inner T	outer B	outer T
12	70	90	100	0
3	130	120	0	6
6	14	10	170	12
9	10	12	40	0

GREATER

CLOCK POSITION	inner B	inner T	outer B	outer T
12	16	18	48	6
3	40	50	44	4
6	960	960	44	280
9	32	8	40	0

CLOCK POSITION	
12	near 0 degrees
3	near 90 degrees
6	near 180 degrees
9	near 270 degrees

Stress Analysis

The results of the test program indicate that the largest strains occur in the outer ring of the cage. The dimensions of the outer ring are shown in figure 16.

The maximum bridge tensile strain observed in the ring was 960 microstrain. Assuming that the strain is uniformly distributed over the cross section, the material strain is one half the bridge strain. The force required to produce this strain is:

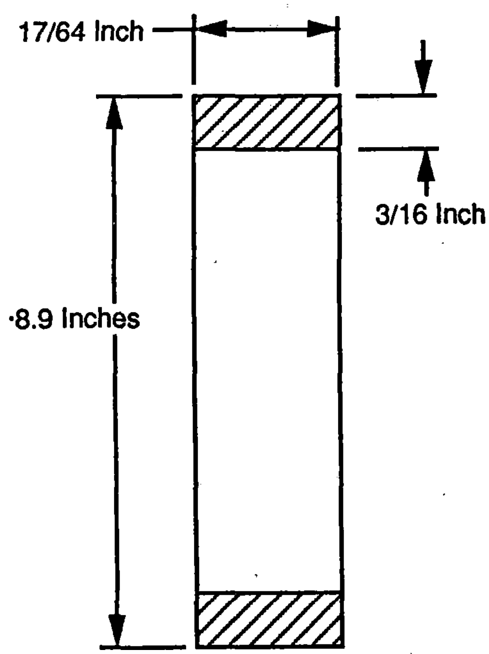


Figure 16. Dimensions of outer ring.

where

F = force in pounds
A = cross sectional area (square inches)
E = Young's modulus (30×10^6 pounds/square inch)
e = strain level (1/2 bridge strain)

$$F = A\,E\,e$$
$$= (17/64)(3/16)(30 \times 10^6)(480 \times 10^6)$$
$$= 717.\ \text{pounds}$$

The maximum bridge bending strain was also 960 microstrain. The bending moment required to produce this this level of strain assuming straight beam theory and pure bending is:

$$S = \frac{M\,c}{I}$$

$$e = \frac{S}{E} = \frac{M\,c}{E\,I}$$

$$M = \frac{E\,I\,e}{c}$$

where

M = bending moment (inches pounds)
I = moment of inertia (inches^4)
$= (1/12)\ (17/64)\ (3/16)^3$
$= 0.000146$ inches^4
c = distance from neutral axis (3/32 inches)

$$M = \frac{(30\ 10^6)\ (0.000146)\ (480\ 10^{-6})}{(3/32)}$$
$$= 22.4\ \text{inch pounds}$$

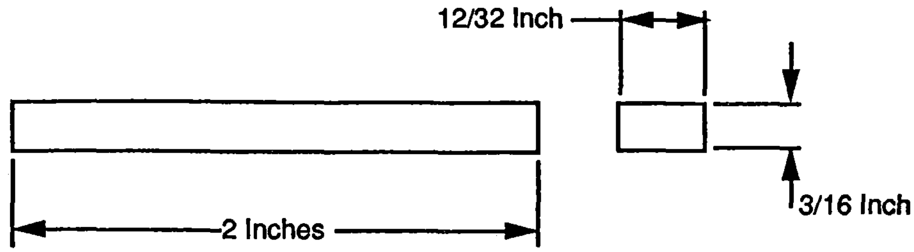


Figure 17. Rib dimensions.

The ribs show a lower level of strain than the outer ring. The largest strains in the ribs were recorded with the bending bridge configuration. The rib will be analyzed by considering it as a cantilever beam build in at the inner ring of the cage and free where it connects to the outer ring. The dimensions of the rib are shown in figure 17.

The model for the Rib is shown in figure 18.

The strain gages were located in the center of the Rib. The force F_1 required to produce a bending strain e_b at the gage location is given by:

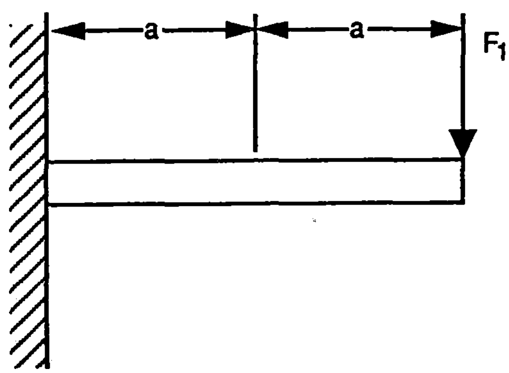


Figure 18. Rib model

$$E\ e_b = \frac{F_1\ a\ c}{I}$$

where

e_b = bending strain (170/2 microstrain)

F_1 = force at free end

c = distance from neutral axis (3/32 inches)

I = momemt of inertia

$= (1/12)(12/32)(3/16)^3$

$= 0.000206$ inches^4

a = 1 inch

$$F_1 = \frac{E\ e_b\ I}{a\ c}$$

$$= \frac{(30\ 10^6)\ (85\ 10^{-6})\ (0.000206)}{(1)(3/32)}$$

= 5.60 pounds

The displacement at the free end of the Rib for a force of 5.6 pounds is given by:

$$d = \frac{(1/3)\ F_1\ L^3}{EI}$$

where

L = length of beam (2 inches)

$$d = \frac{(1/3)(5.6)(2)^3}{(30\ 10^6)(0.000206)}$$

= .00242 inches

Conclusions

1. Data quality is good. The rail force and acceleration data are in agreement with the analysis of the drop test. The strain gage data returns to the pre-impact level after the impact is completed and there are no dropouts or spikes in the data.

2. Large strain values can be induced in the cages for drop heights of 6 to 10 inches. The largest strain values observed occurred in the inner cage at an axle angle of 180 degrees. The maximum bridge strain value was greater than 1000 microstrain (instrumentation limit) for the tension bridge of the greater ring of the cage. The bending bridge for this location had a maximum reading of 960 microstrain. The maximum material strain is estimated to be at least 600 microstrian. The corresponding stress level is 18,000 pounds per square inch.

3. Impact duration is 17 to 24 milliseconds. This is a similar duration to the the duration of the impulsive rail forces measured by Battelle during field tests on the Northeast Corridor.

4. Maximum rail forces are as high as 110 kips.

5. Vertical accelerations reach 50 g's.

6. The mechanism for generating the strains in the cages is not known.

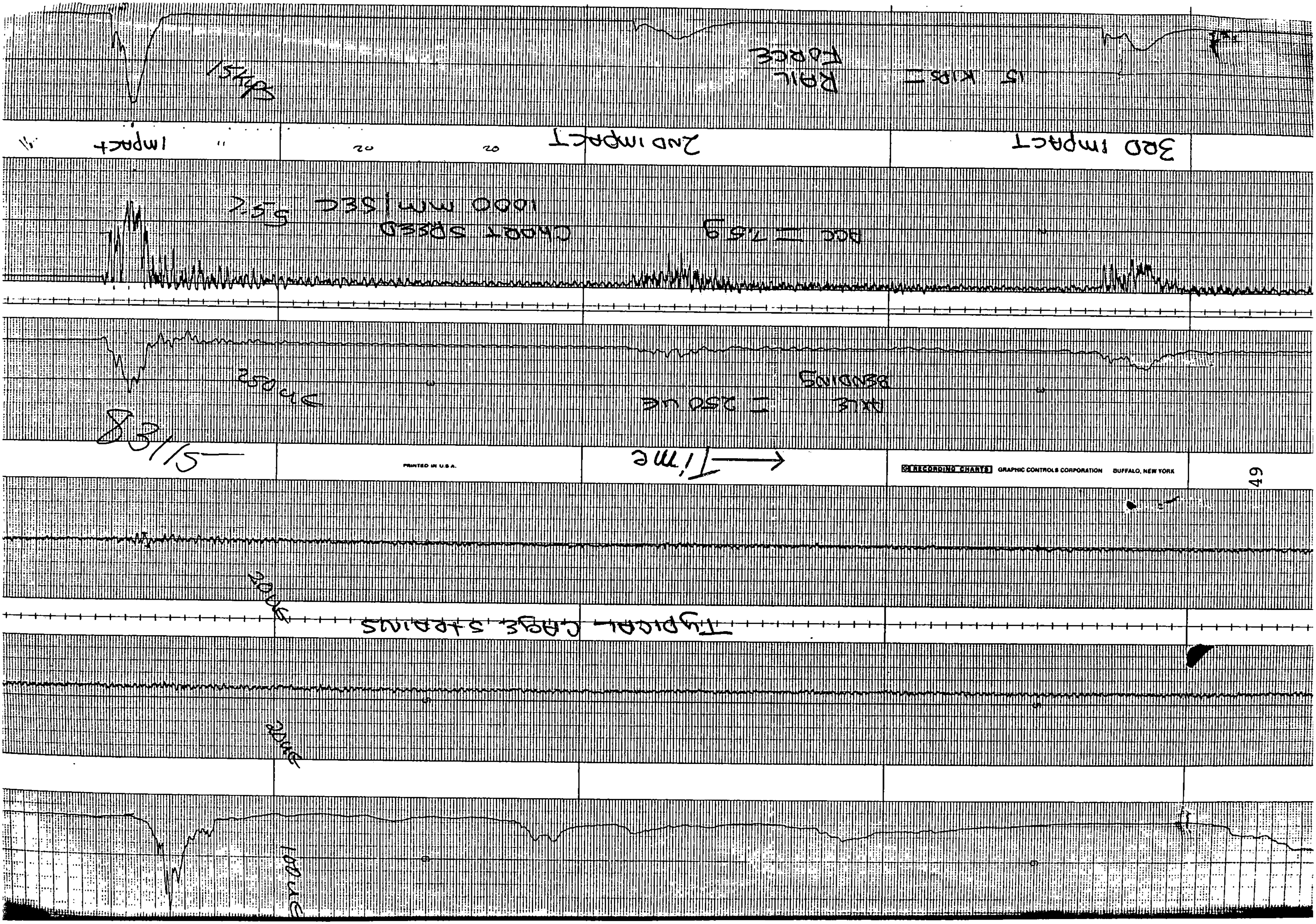
7. The results of the testing are not highly repeatable if the bearing is disassembled and than reassembled and tested under the same nominal conditions. The results are more repeatable if the test procedure is applied without disassemble of the bearing.

the test procedure is applied without disassemble of the bearing.

8. The importance of the horizontal component of the impulse is not known.

Typical Test Results

The following copies of the strip chart from the test show the basic characteristics of the data.



RAIL FORCE
5 KIPS =
15 kips
1st impact
2nd impact
3rd impact
CHART SPEED
1000 mm/SEC
ACC = 7.5 g
AXLE BENDING = 250 ue
250 ue
Time
Typical Cage Strains
20 ue
100 ue
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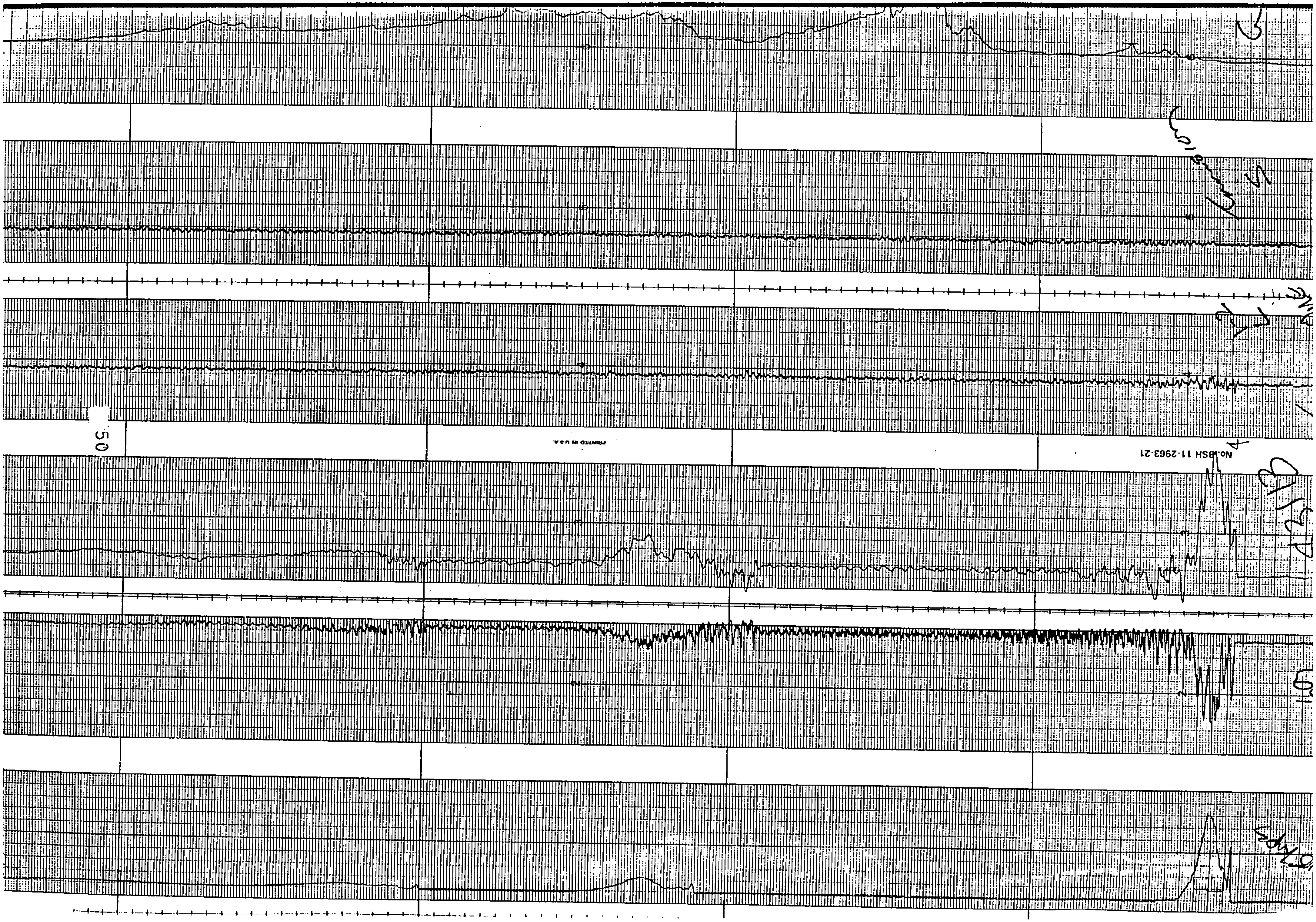
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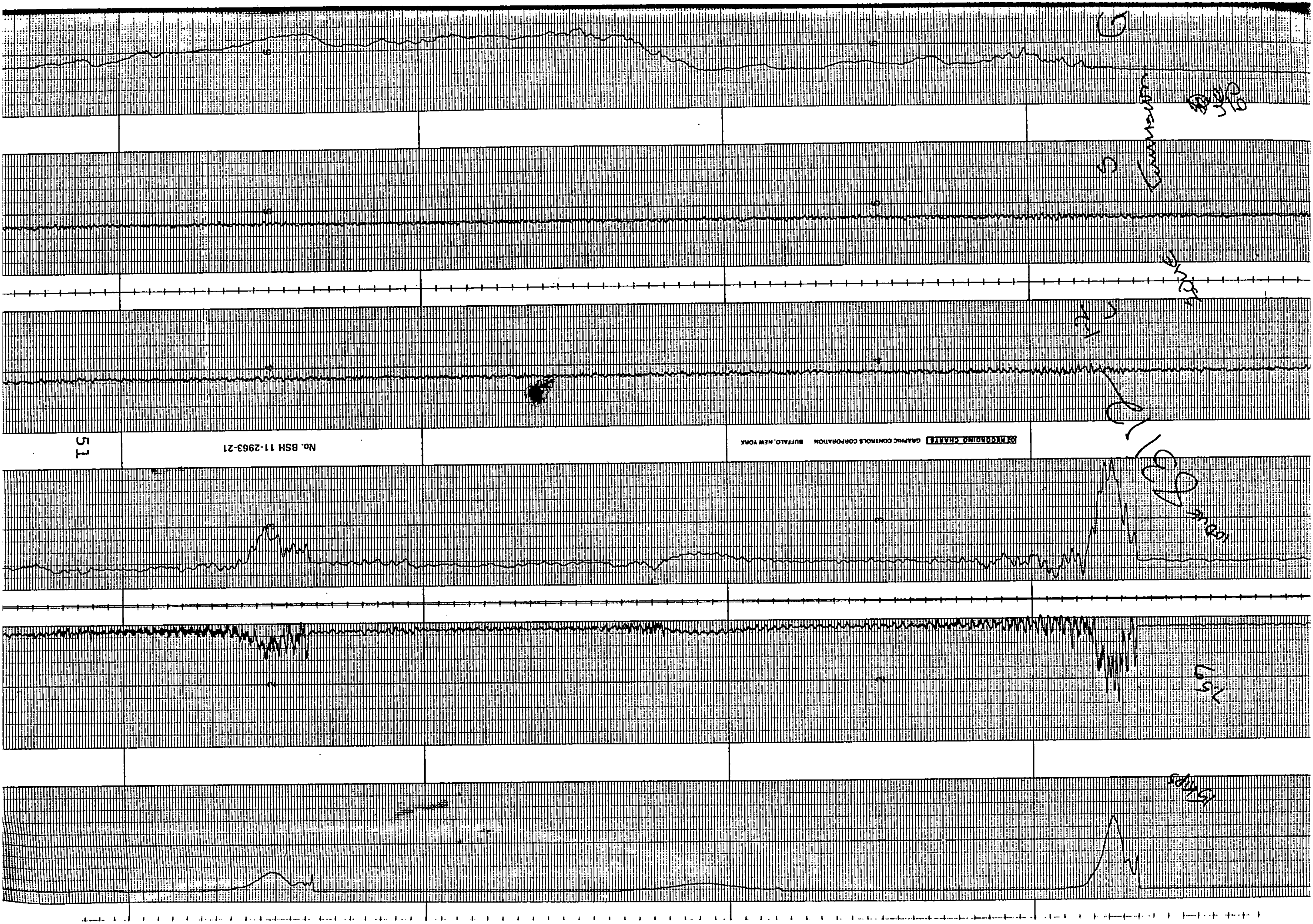
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Laboratory Investigation of Roller Bearing Damage Due to Impact,1988, Ensco, Inc., JK Kesler, B Jordan, RP Owings, 03-Rail Vehicles & Components

03 - Rail Vehicles &
Components