FRA/ORD-81-55

VIBRATION TEST REQUIREMENTS FOR A 70 TON BOXCAR

REVISION 1

JULY 1981

PREPARED FOR
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
Office of Research and Development
Washington, D.C. 20590

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FRA/ORD-81-55		

4. Title and Subtitle	5. Report Date
Vibration Test Requirements for a 70 Ton Boxcar Revision 1	July 1981
	6. Performing Organization Code
7. Author(s) George Kachadourian	8. Performing Organization Report No. MTR-80W149 R. 1
9. Performing Organization Name and Address The MITRE Corporation, Metrek Division 1820 Dolley Madison Boulevard McLean, Virginia 22102	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. DOT-FR-54090
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Railroad Administration 400 7th Street, S.W. Washington, D.C. 20590	13. Type of Report and Period Covered Technical Report
	14. Sponsoring Agency Code FRA-RRD-11

15. Supplementary Notes

Ground Transportation Systems Department
Project Number: 274L

16. Abstract

The Federal Railroad Administration is to perform a parallel effort of test and analysis of a 70 ton boxcar configuration. The program objectives are to develop and demonstrate a validation procedure, to provide an analytic capability of predicting accurate over-the-road boxcar response calculations, and to evaluate the relative performance of two shipper lading designs. The purpose of this report is to define the vibration testing requirements and procedure outline.

17. Key Words	18. Distribution Statement
Boxcar Vibration Test Modal Test Lading Vibration Test Vibration Test Procedures	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-72)

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	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 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	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	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

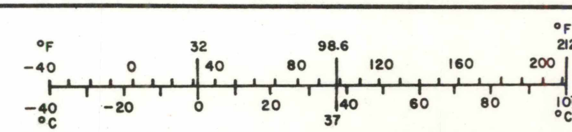


TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

1. INTRODUCTION

The Federal Railroad Administration (FRA) is sponsoring a program composed of the test and analysis of a 70-ton boxcar with two basic objectives. The first is to establish a method for validation of a railroad boxcar simulation against laboratory testing for the following purposes:

a. to create a design tool which can be used in the calculation of boxcar dynamic loads,

b. to develop an analysis capable of accurate over-the-road boxcar response calculations, and

c. to demonstrate a validation procedure.

The second objective is to study two lading configurations with respect to resonant characteristics and the comparative response to representative track input. Analytical work will be done by The MITRE Corporation. MITRE has prepared a validation plan,* and will monitor technical aspects of the test. The test boxcar will be arranged for by FRA. Testing of the boxcar and all data processing will be performed at the Rail Dynamic Laboratory in Pueblo, Colorado, using the Vibration Test Unit (VTU).

The Michigan State University, School of Packaging has arranged for the lading and two alternate shipper designs to be tested. They will also be responsible for defining stowage arrangements of the lading in the boxcar.

Validation of the FRATE/boxcar computer simulation will be based on the comparisons of two types of vehicle responses. The first comparison will be vibration characteristics consisting of resonant frequencies, deflection shape at resonance and damping associated with resonance. The second comparisons will be the dynamic responses throughout the vehicle to specific input at the wheel-rail interface.

*Kachadourian, George, "Validation Plan for a 70-Ton Boxcar Model," MTR-79W434, The MITRE Corporation, McLean, Virginia, December 1979.

Both the vibration characteristics and dynamic response validation parameters are needed. The vibration criteria will show that general, overall dynamic characteristics of the vehicle have been accurately simulated. This is important because the primary use of the validated computer program simulation will be to investigate the effects of modifying parts within the vehicle. For example, side bearing changes or the addition of or changes to hydraulic snubbers, or changes in the spring rate of the truck primary suspension system. It is necessary that the physical part and its mathematical counterpart be clearly identifiable and properly modeled so that not only is the basic model valid but accuracy of the simulation is retained with moderate changes to components. The dynamic response criteria will provide a more direct measure of the accuracy of the analysis.

The purpose of this report is to present requirements for vibration testing, outlining test procedures and data processing, analysis and display requirements.

2. TEST OBJECTIVES

The basic objective of the vibration testing is to obtain definitions of the vibration characteristics of the boxcar and lading which can be used for comparisons to the respective analytical models. Two types of testing will be performed:

1. Resonance
2. Response

The objectives of the resonance testing will be to identify resonant frequencies, to define the deflection shape at each resonance, to obtain a measure of the damping associated with each resonance, to measure nonlinear effects with respect to amplitude of motion and to determine the effects of certain configurational changes.

The objectives of the response testing will be to obtain a measure of responses on and in the boxcar to simulations of two track profile conditions and simulation of one hunting condition.

For the lading, in addition to the model validation objectives, the relative performance of two shipper designs will be evaluated.

3. TEST VEHICLE AND TEST SET UP

The test vehicle will be a 70 ton boxcar supplied by the FRA. The vehicle will be tested in empty and loaded conditions. The boxcar will be loaded to 70-80 percent of full load capacity with the c.g. location between 70 and 80 inches above top of rail. The test vehicle basic data, which is to be generated for the final configuration by the RDL, is shown in Table 3-1. The coordinate notation and dimensional origin which is to be used in the basic data and in instrumentation location is shown in Figure 3.1.

The boxcar will be tested in four configurations. The configurations and the test sequence are:

- loaded - snubbers (cartoned lading),
- loaded - no snubbers,
- empty - no snubber, and
- loaded - snubbers (stretch wrapped lading).

TABLE 3-1 - TEST VEHICLE DATA REQUIRED

Gross Weight (on the rails)

Truck Weight

Empty Car Body (less trucks)
- weight
- c.g. location
- pitch inertia
- roll inertia
- yaw inertia

Car Body Data

- make, class, tonnage
- interior dimensions
- distance between truck centers
- spring type and number
- spring height
  - free
  - rated load (height and load)
  - bottomed (height and load)
  - side bearing type
  - side bearing clearance
  - gib clearance
  - type of friction snubbers
  - travel-force data
- Height of center bowl above top of rails (reference spring height)

Lading Description

- unit dimension and weight
- stack configuration
- tie down detail
- clearances to side walls and between stacks
- total lading weight

Note: Side bearings will be shimmed for equal clearance at all four locations and will be checked at the start of each testing day and re-shimmed if needed. To be kept at .250 ± .025 inches.

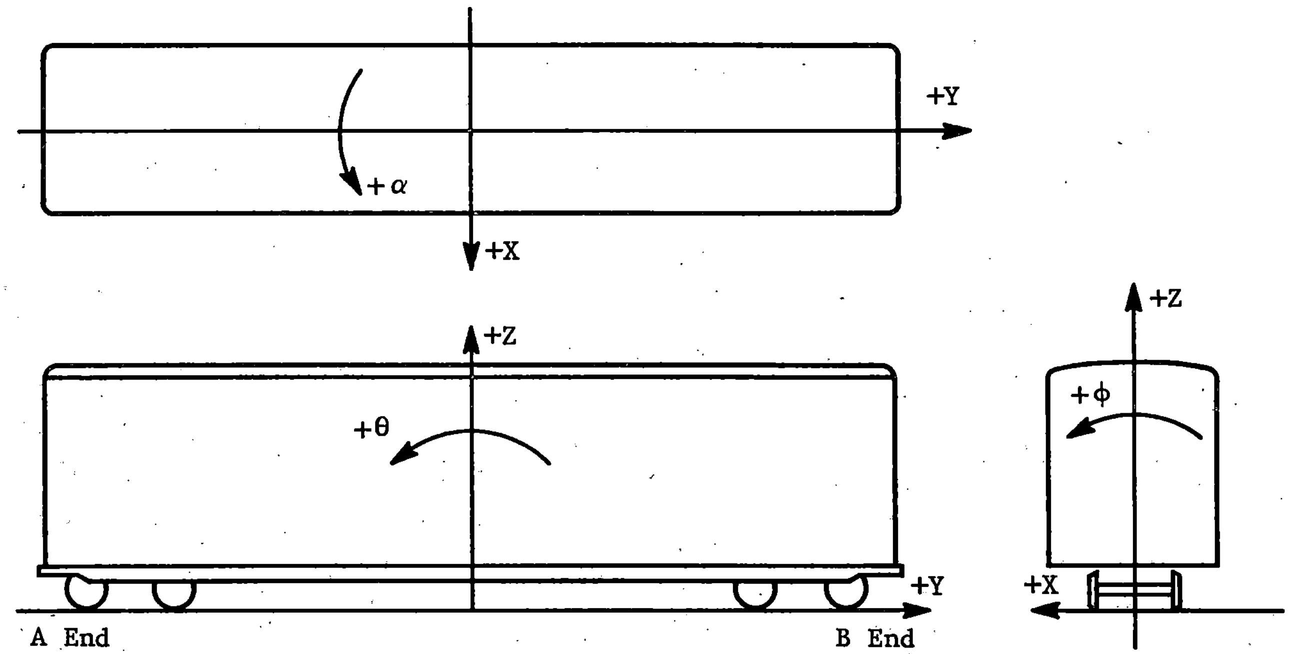


FIGURE 3.1. BOXCAR COORDINATE SYSTEM. COORDINATE ORIGIN IS ON THE TOP OF THE RAIL AT THE GEOMETRIC CENTER OF THE BOXCAR PLATFORM (RIGHT HAND RULE APPLIES)

4. INSTUMENTATION REQUIREMENTS

This section defines the type of instruments to be used and where they are to be located. Special requirements on the frequency response of accelerometers and associated signal conditioning are reviewed.

4.1 Instrument Type and Location

The instrumentation to be used is given in the Measurement List of Table 4-1. It consists of 56 accelerometers, 4 displacement transducers and 2 gyros. The displacement transducers are to measure relative vertical motion between each side frame and bolster on both trucks. The gyros are to measure the roll angle of the carbody at each end.

The bulk of the measurements will be with accelerometers. There will be 12 to measure imput accelerations, one for each shaker thruster. There will be 7 on each truck, as shown in Figure 4.1. There will be 12 on the carbody as shown in Figure 4.2. There will be 16 on the lading as shown in Figure 4.3.

4.2 Accelerometer Characteristics Requirements

The test vehicle resonant frequencies of primary interest are expected to fall in the 0.5 to 10.0 Hz range, with secondary interest out to 35 Hz. It is also expected that maximum responses in the 0.5 to 35 Hz range will not exceed 2.0 g (0-peak).

There will be two characteristics of the acceleration data which will make measurement difficult. First, the low frequency, 0.5 Hz, g levels will be on the order of .05 g's. Second, there will be higher frequency transients and harmonics superimposed on the low frequency excitations. These higher frequencies will be the result of nonlinearities in the test vehicle, the shaker mechanism and the result of characteristic roughness of hydraulic actuators at low frequencies. The net result is that the high frequency "noise" will probably be much higher in g level than the excitation frequency and will mask the data of primary interest. For example, if the "noise" vibration is 0.5 g and the data is at .05 g, it will be difficult to extract accurate data.

To alleviate this problem all accelerometer data will be low-pass filtered prior to the A-to-D conversion. The "corner" frequency setting of the filters will probably be at about 30 Hz.

TABLE 4-1 - MEASUREMENT LIST

Number		Description
1	A1AZ	Input Accel. - axle 1 - left side vertical
2	A1BZ	" " 1 - right side vertical
3	A1CX	" " 1 - lateral
4	A2AZ	" " 2 - left side vertical
5	A2BZ	" " 2 - right side vertical
6	A2CX	" " 2 - lateral
7	A3BZ	" " 3 - left side vertical
8	A3BZ	" " 3 - right side vertical
9	A3CX	" " 3 - lateral
10	A4AZ	" " 4 - left side vertical
11	A4BZ	" " 4 - right side vertical
12	A4CZ	" " 4 - lateral
13	A13Z	B Truck Accel. - left side frame - vertical
14	A14X	" - " - lateral
15	A15Z	" - bolster left end - vertical
16	A16X	" - " - lateral
17	A17Z	" - right side frame - vertical
18	A18Z	" - bolster right end - vertical
19	A19Y	" - bolster center - longitudinal
20	D20Z	B Truck LVDT - left side frame/bolster - vertical
21	D21Z	" - right side frame/bolster - vertical
22	A22Z	A Truck Accel. - left side frame - vertical
23	A23X	" - " - lateral
24	A24Z	" - bolster left end - vertical
25	A25X	" - " - lateral
26	A26Z	" - right side frame - vertical
27	A27Z	" - bolster right end - vertical
28	A28Y	" - bolster center - longitudinal
29	D29Z	A Truck LVDT - left side frame/bolster - vertical
30	D30Z	" - right side frame/bolster - vertical
31	A31X	Carbody Accel. - B Truck - Right Side - Top - Lateral
32	A32X	" - " " Bottom "
33	A33Z	" - " " " Vertical
34	A34Z	" - " Left Side " "
35	A35X	" - Center - Right Side - Top - Lateral
36	A36X	" - " " Bottom "
37	A37Z	" - " " " Vertical
38	A38Z	" - " Left Side " Vertical
39	A39X	" - A Truck - Right Side - Top - Lateral
40	A40X	" - " " Bottom "
41	A41Z	" - " " " Vertical
42	A42Z	" - " Left Side " "
43	A43Z	Lading Accel. - Opposite B Truck
44	A44Z	" "
45	A45X	" "
46	A46Z	" "
47	A47X	" "
48	A48Z	" "
49	A49Z	" "
50	A50Z	" Near Carbody Center
51	A51X	" "
52	A52Z	" "
53	A53Z	" Opposite A Truck
54	A54Z	" "
55	A55X	" "
56	A56Z	" "
57	A57X	" "
58	A58Z	" "
59	GBR	Roll Gyro - Carbody at B Truck
60	GAR	Roll Gyro - Carbody at A Truck

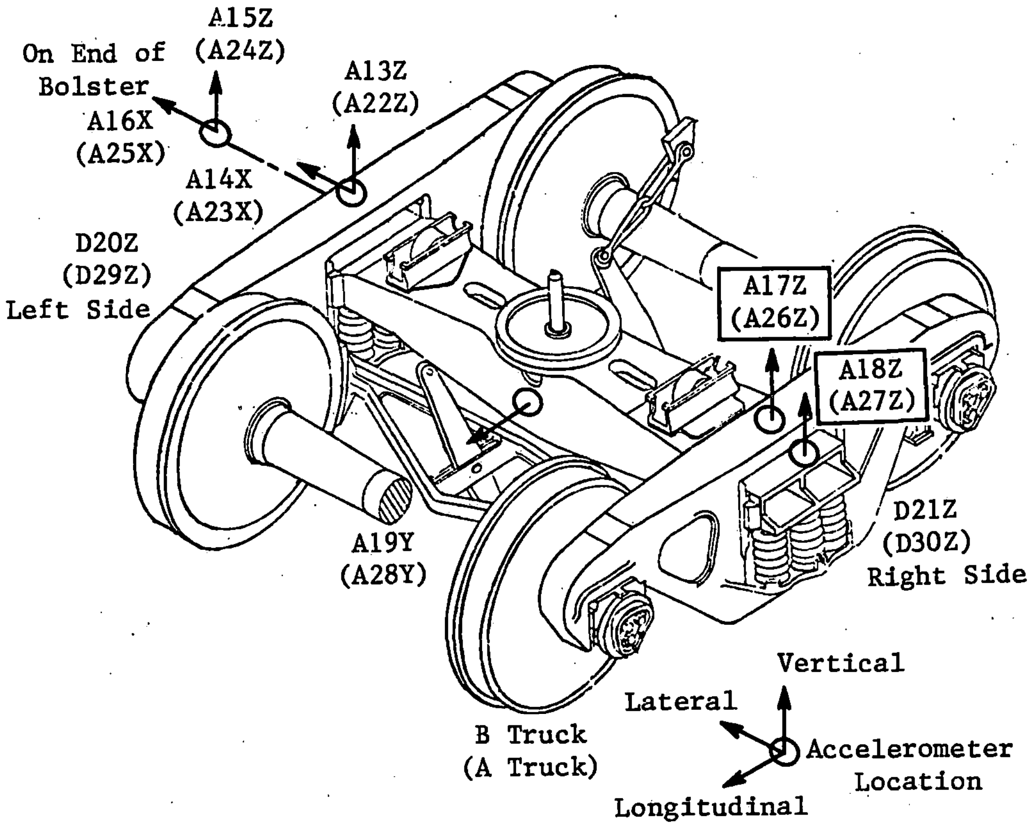


FIGURE 4.1. ACCELEROMETER LOCATIONS ON TRUCKS

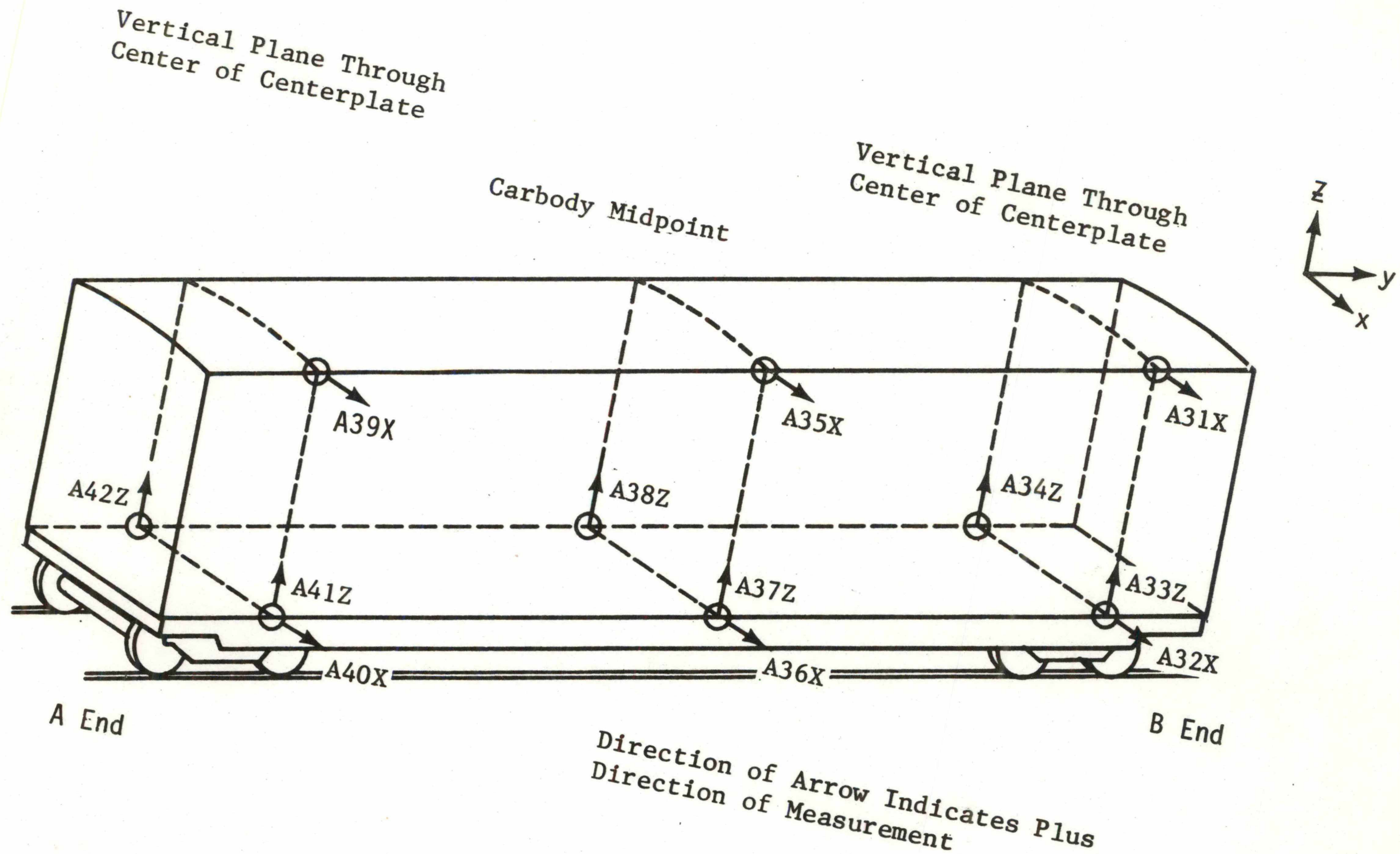


FIGURE 4.2. ACCELEROMETER LOCATIONS ON CARBODY

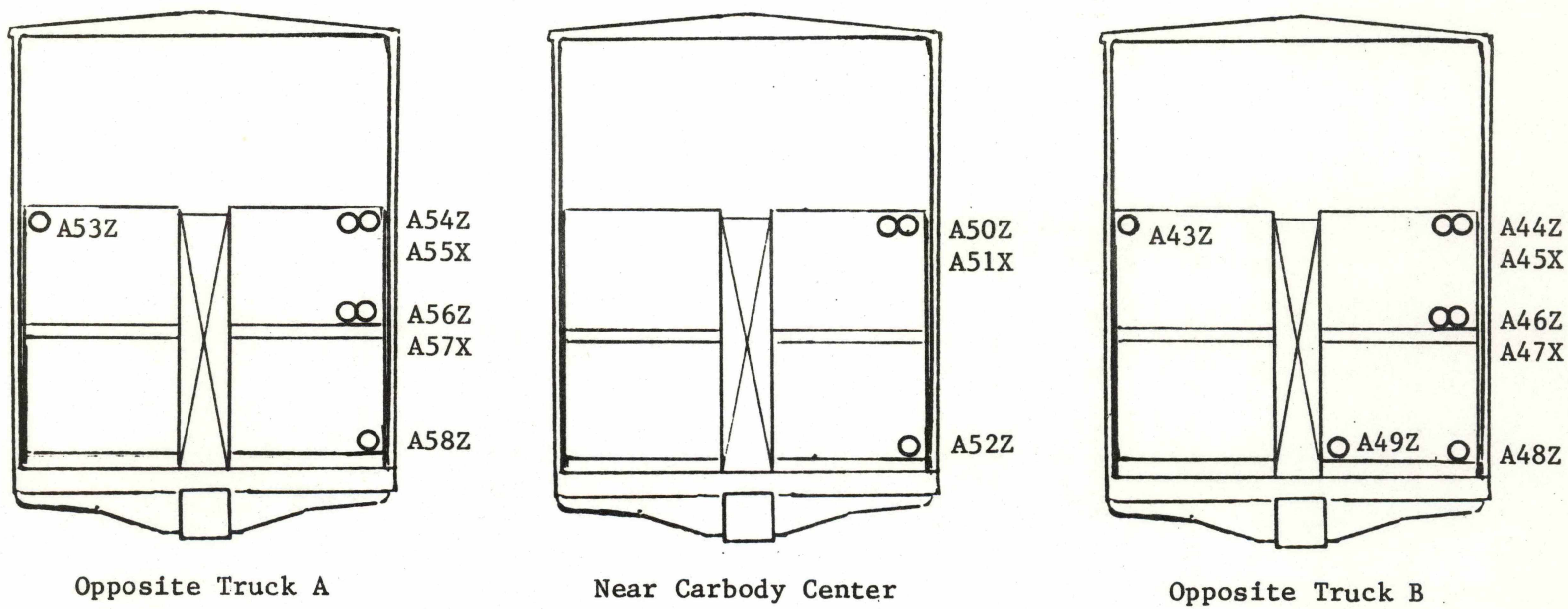


FIGURE 4.3. LADING ACCELEROMETER LOCATIONS

4.3 Photographic Coverage

Still photographs will be taken to show both the overall test configuration and details. Detail shots should include the following:

a. instrument installations;

b. shaker thruster, wheel cradle and slip table;

c. restraint systems; longitudinal and roll;

d. cargo arrangements - some photographs should be taken in loading process to be able to show how the cargo is being stowed;

e. video camera installation (inside car); and

f. shipping containers.

A video camera will be placed in such a way that it can be supported from the floor of the VTU and focus on the lading inside the boxcar. The camera may be inside or outside the boxcar whichever will provide the best view to show lading motion. The boxcar doors will be open.

A split screen display/recording will be used to show lading motion and lading accelerometer output simultaneously.

4.4 Test Stop Measurements

In anticipation of instrument malfunctions in the course of testings, it may be necessary to stop test and repair the instrument prior to continuing. It is the purpose of this section to list those critical measurements.

a. Input: There must be two input accelerometers recorded. However, if a designated input accelerometer is out, an alternate may be used.

b. <u>Trucks</u>: One truck must have all measurements to be recorded active. If both trucks are missing the same instrument, one must be fixed. If both trucks have instruments out but they are not the same, it may be possible to continue the test depending on the particular test and which instruments are missing.

c. <u>Carbody</u>: In any given test, all called for carbody instruments or a suitable alternate must be active.

d. <u>Lading</u>: Measurements A50Z and A51X must be active on all tests. Measurements A44Z and A45X <u>or</u> A54Z and A55X must be active on all tests.

e. <u>LVDT</u>: The loss of LVDTs will not stop test.

f. <u>Gyro</u>: The loss of one gyro will not stop test.

5. TEST PROCEDURE

For each configuration there will be three types of testing performed. The first will be sinusoidal sweeps which will be used for identifying resonant frequencies and defining the associated deflection shapes and damping. The second will be simulations of representative track conditions and the third will be a random vibration test.

The data processing will consist of on-line oscillograph records, quick look Bode plots and the completed data package including time histories, Bode plots, Agrand plots, deflection shape plots and data tabulations. It is planned to review the oscillograph records and quick look Bode plots to determine whether or not test objectives have been met prior to test continuation. This will require that the quick look Bode plots be generated as quickly as possible and will probably require a second shift effort.

The objective of this section is to outline the tests to be performed, the data to be recorded and data processing to be performed. This outline will form the basis of the detailed test procedures to be written by the RDL.

5.1 Test Configurations Procedures

Table 5-1 lists information defining tests to be conducted. The RIF (Run Information File) number is used as the test numbering system. In the RIF number, the digit to the left of the decimal corresponds to the configuration number. The number to the right of the decimal is the run number for the particular configuration.

The Mode column in Table 5-1 defines the test objective. A resonance test is identified by calling the particular resonance being searched. A track profile test is identified by calling the particular track profile to be simulated.

Shaker configuration notation used in Table 5-1 is defined in Table 5-2.

The amplitudes of shaker motion are given in the fourth column of Table 5-1. The amplitudes are for the most part given in inches. In tests where the frequency range is extended to 20 Hz an acceleration amplitude is given with the intent that inches amplitude will be maintained at the lower frequencies and the g level will be maintained above the cross-over frequency. Both inches and g's are given as single amplitude.

TABLE 5-1A - TEST REQUIREMENTS: CONFIGURATION 1-A, BOXCAR VIBRATION TEST LOADED WITH CORRUGATED SHIPPERS, ACTIVE SNUBBERS

RIF No.	Mode	Shaker Config.	Input Amplitude (inches)	Input Frequency (Hertz)	Test Procedure
1.1a	Yaw & Torsion	3	±.4/.5g	.5-20.	Sine Sweep Up Boxcar Doors Closed
1.2a	Yaw,	3	±.2	.5-3.	Sine Sweep Up
b	Torsion		±.4/.5g	.5-20.	Boxcar Doors
c	& Lading		±.6	.5-3.	Open
1.3a	Yaw	3	±.4	3.-.5	Sine Sweep Down
1.4a	1st Roll	1	±.05	.3-1.5	Sine Sweep Up
b			±.15	"	
c			±.25	"	
1.5a	1st Roll	1	±.05	1.5-.3	Sine Sweep Down
b			±.15	"	
c			±.25	"	
1.6a	2nd Roll	2	±.1	.5-3.0	Sine Sweep Up
b			±.2	"	
c			±.2	"	
1.7a	2nd Roll	2	±.2	3.0-.5	Sine Sweep Down
1.8a	Bounce,	4	±.1	1.0-5.0	Sine Sweep Up
b	Body Bend		±.2/.3g	1.0-20.0	
c	& Lading		±.3	1.0-5.0	
1.9a	Pitch	5	±.1	2.0-8.0	Sine Sweep Up
b			±.2	"	
c			±.3	"	
1.10a	Staggered	6	.1	.8-.2	Rectified Sine
b	Rail		.2		Sweep Down (See
c	Profile		.3		Paragraph 5.2.1)
1.11a	Track	7	1.0	2.7	(See Paragraph
b	Irregu-			3.0	5.2.2)
c	larity			3.3	
1.12a	Hunting	8	±.2	1.2-2.4	Sine Sweep Up (See
b	Simula-		±.4		Paragraph 5.2.3)
c			±.6		
1.13	Random	9	.20 RMS	.2-20	60 Sec. Random

TABLE 5-1B - TEST REQUIREMENTS: CONFIGURATION 2, BOXCAR VIBRATION TESTS LOADED WITH CORRUGATED SHIPPERS, SNUBBERS INACTIVE

RIF No.	Mode	Shaker Config.	Input Amplitude (inches)	Input Frequency (Hertz)	Test Procedure
2.1a	1st Roll	1	±.05	.3-1.5	Sine Sweep Up
b			±.15	"	
c			±.25	"	
2.2a	1st Roll	1	±.05	1.5-.3	Sine Sweep Down
b			±.15	"	
c			±.25	"	
2.3a	2nd Roll	2	±.2	.5-3.0	Sine Sweep Up
2.3b	2nd Roll	2	±.2	3.0-.5	Sine Sweep Down
2.4a	Yaw, Body Torsion & Lading	3	±.4/.5g	.5-20.	Sine Sweep Up
2.4b	Yaw	3	±.4	3.0-.5	Sine Sweep Down
2.5a b c	Bounce, Body Bending and lading	4	±.2/.3g	1.0-20.0	Sine Sweep Up
2.6a	Pitch	5	±.2	2.0-8.0	Sine Sweep Up
2.7a	Staggered	6	.1	.8-.2	Rectified Sine
b	Rail		.2		Sweep Down (See
c	Profile		.3		Paragraph 5.2.1)
2.8a	Track	7	1.0	2.7	(See Paragraph
b	Irregu-			3.0	5.2.2)
c	larity			3.3	
2.9a	Hunting	8	±.2	1.2-2.4	Sine Sweep Up (See
b	Simula-		±.4		Paragraph 5.2.3)
c	lation		±.6		
2.10	Random	9	.25rms	.2-20	60 Sec. Random

TABLE 5-1C - TEST REQUIREMENTS: CONFIGURATION 3, BOXCAR VIBRATION TEST EMPTY BOXCAR, INACTIVE SNUBBERS

RIF No.	Mode	Shaker Config.	Input Amplitude (inches)	Input Frequency (Hertz)	Test Procedure
3.1a	Yaw & Torsion	3	±.4/.5g	1.-20.	Sine Sweep Up <u>Boxcar Doors Closed</u>
3.2a	Yaw &	3	±.2	1.-6.	Sine Sweep Up
b	Torsion		±.4/.5g	1.-20.	<u>Boxcar Doors</u>
c			±.6	1.-6.	<u>Open</u>
3.3a	1st Roll	1	±.05	.5-2.0	Sine Sweep Up
b			±.15	"	
c			±.25	"	
3.4a	1st Roll	1	±.05	2.0-.3	Sine Sweep Down
b			±.15	"	
c			±.25	"	
3.5a	2nd Roll	2	±.2	1.0-4.0	Sine Sweep Up
3.5b	2nd Roll	2	±.2	4.0-1.0	Sine Sweep Down
3.6a	Bounce &	4	1.2/.3g	2-20	Sine Sweep Up
3.7a	Pitch	5	±.2	2-8	Sine Sweep Up
3.8a	Staggered	6	.1	1.5-.5	Rectified Sine
b	Rail		.2		Sweep Down (See
c	Profile		.3		Paragraph 5.2.1)
3.9a	Track	7	1.0	3.6	(See Paragraph
b	Irregu-			4.0	5.2.2)
c	larity			4.4	
3.10a	Hunting	8	±.2	2.5-4.5	Sine Sweep Up (See
b	Simula-		±.6		Paragraph 5.2.3)
c	tion		±.8		
3.11	Random	9	.25 rms	.2-20	60 Sec. Random

TABLE 5-1D - TEST REQUIREMENTS: CONFIGURATION 4, BOXCAR VIBRATION TEST
LOADED STRETCH WRAP SHIPPERS, ACTIVE SNUBBERS

RIF No.	Mode	Shaker Config.	Input Amplitude (inches)	Input Frequency (Hertz)	Test Procedure
4.1a	1st Roll	1	±.05	.3-1.5	Sine Sweep Up
b			±.15	"	
c			±.25	"	
4.2a	2nd Roll	2	±.2	.5-3.0	Sine Sweep Up
4.3a	Yaw, Torsion and Lading	3	±.4/.5g	.5-20	Sine Sweep Up
4.4a	Bounce, Bending & Lading	4	±.2/.3g	1-20	Sine Sweep Up
4.5a	Pitch	5	±.2	2-8	Sine Sweep Up
4.6a	Staggered Rail Profile	6	±.1	.8-.2	Rectified Sine Sweep Down (See Paragraph 5.2.1)
b			.2		
c			.3		
4.7a	Track Irregularity	7	1.0	2.7	(See Paragraph 5.2.2)
b				3.0	
c				3.3	
4.8a	Hunting Simulation	8	±.2	1.2-2.4	Sine Sweep Up (See Paragraph 5.2.3
b			±.4		
c			±.6		
4.9	Random	9	.25 rms	.2-20	60 Sec. Random

TABLE 5-2 - SHAKER CONFIGURATIONS

Shaker Config.	B Truck						A Truck					
	Axle 1			Axle 2			Axle 3			Axle 4		
	1A	1B	1C	2A	2B	2C	3A	3B	3C	4A	4B	4C
1	1	-1	0	1	-1	0	1	-1	0	1	-1	0
2	.5	-.5	1	.5	-.5	1	.5	-.5	1	.5	-.5	1
3	0	0	1	0	0	1	0	0	-1	0	0	-1
4	1	1	0	1	1	0	1	1	0	1	1	0
5	1	1	0	1	1	0	-1	-1	0	-1	-1	0
6	1	-1	0	1	-1	0	1	-1	0	1	-1	0
7	1	1	0	1	1	0	1	1	0	1	1	0
8	0	0	1	0	0	1	0	0	-1	0	0	-1
9	1	0	1	1	0	1	0	0	0	0	0	0

Shaker Notations: A = left side vertical
B = right side vertical
C = lateral

Shaker heads are in-phase if + and -phase if -.
(1) See paragraph 5.2.1 and Figure 5
(2) See paragraph 5.2.2 and Figure 6
(3) See paragraph 5.2.3

5.2 Track Condition Simulations

This testing will consist of imposing three separate time related motions at the wheel rail interface. Two are simulation of track profile irregularities and one is a simulation of truck motions in a body hunting condition.

5.2.1 Staggered Joint Bolted Rail Track Profile Simulation

This track irregularity is to be imposed by actuating all eight vertical shakers according to the time function descriptions given in Figure 5.1. The reference motion function is a rectified sine with the frequency of $\omega/2$ radians per second. The frequency is to be varied in a down sweep to simulate a deceleration rate of approximately 0.5 mph./sec. starting at 23 mph.

5.2.2 Track Profile Irregularity, Vertical Hump Simulation

This track irregularity is to be imposed by actuating all eight vertical shakers according to the time function descriptions given in Figure 5.2. The value of pulse length (PL) and car speed (V) will be chosen to result in maximum response of the carbody pitch resonance according to the following relationships:

$$V = L\, f_p/1.5$$

$$PL = .8V/f_p$$

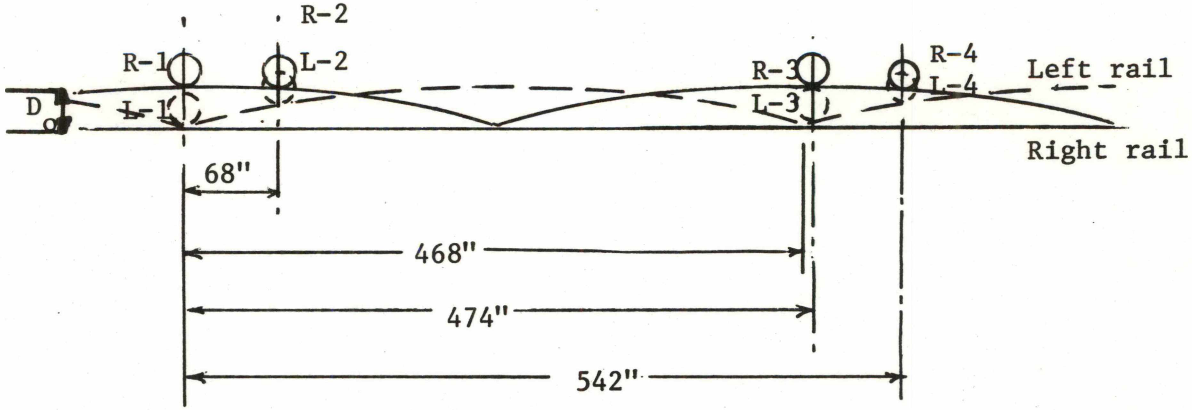
where V = car speed, feet per second

f_p = pitch resonant frequency of the carbody, Hz (from resonance test results)

PL = pulse length, feet

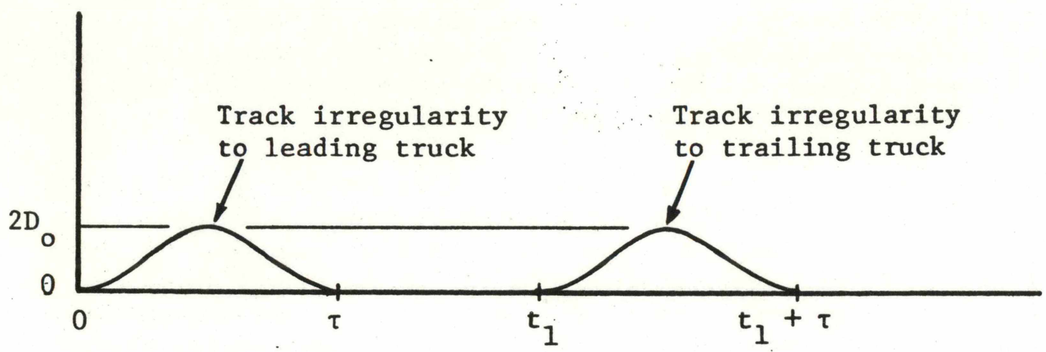
L = truck spacing, feet

The test is to be run three times for three values of f_p; the value obtained in the resonance tests and values at ± 10 percent.



$Z(I)$	=	input motion at location I
	=	D_o ABS $[\sin(\omega t/2 + \phi(I))]$
where D_o	=	maximum value of cross level
ω	=	track frequency, radians per second
	=	$2\pi V/\lambda$
V	=	car speed, feet per second (to be varied--see text)
λ	=	rail length, feet
$\phi(I)$	=	phase angle at wheel location (I)
ϕ (R-1)	=	$\pi/2$
ϕ (L-2)	=	$68\pi/468$
ϕ (R-2)	=	$(1/2 + 68/468)\pi$
ϕ (L-3)	=	$474\pi/468$
ϕ (R-3)	=	$(1/2 + 474/468)\pi$
ϕ (L-4)	=	$542\pi/468$
ϕ (R-4)	=	$(1/2 + 542/468)\pi$

FIGURE 5.1. RECTIFIED SINE INPUT MOTION



Leading Truck

$Zi = D_o \left(1 - \cos \frac{2\pi}{\tau}\right)$ if $t > o$ and $< \tau$

$Zi = 0$ if $t \leqq 0$ or $t \geqq \tau$

Trailing Truck

$Zi = D_o \left(1 - \cos \frac{2\pi}{\tau}(t-t_1)\right)$ if $t > t_1$ and $< (t_1 + \tau)$

$Zi = 0$ if $t \leqq t_1$ or $t \geqq (t_1 + \tau)$

where:

Zi = input motion , inches

D_o = single amplitude of cosine function, inches

τ = duration of track irregularity, seconds

= (irregularity length)/(speed)

t_1 = time trailing truck reaches track irregularity, seconds

= (truck spacing)/(speed)

FIGURE 5.2. (1-COS) SHAPED TRACK IRREGULARITY

5.2.3 Body Hunting Simulation

The condition of body hunting occurs when the truck hunting frequency is close to a body resonant frequency. Body hunting usually involves yaw motions of the carbody because the carbody yaw resonant frequency is usually in the truck hunting frequency range and because the lateral hunting movements of the trucks couple very well with the carbody yaw motion.

In order to duplicate the motions of body hunting in the carbody yaw mode it will be necessary to impose lateral sinusoidal motions at each truck with the truck motions being out of phase with each other. The frequency of the input should be at the carbody yaw resonant frequency. In order to avoid the problems of finding the resonant frequency of a nonlinear system where the resonant frequency will vary with amplitude of motion, the hunting test will be with a frequency sweep rather than a frequency dwell. In this way the resonant condition will be covered with one test. In typical service operations a hunting condition is encountered as train speed is being increased. Consequently, the hunting simulation will be made with increasing frequency sweep. Three different amplitudes of motion will be tested to investigate the nonlinear effects.

The body hunting simulation test shall have the following input motions:

Lateral motion at axles 1 and 2

$$x(1) = x(2) = D_o \sin(2(\dot{f}T + f_o))$$

Lateral motion at axles 3 and 4

$$x(3) = x(4) = D_o \sin(2(fT + f_o) + \pi)$$

where:

f_o = input frequency at start of run, Hz

$\dot{f}$ = rate of change of frequency, Hz/sec.
= .01 Hz/sec.

D_o = single amplitude of input motion, inches

= .4, .6 and .8 inches

length of each run = 60 sec.

With the above, the frequency range swept will be from 1.3 to 2.0 Hz for covering a predicted resonant frequency of 1.7 Hz. These frequencies should be reviewed and corrected to agree with the resonance test results.

6. DATA RECORDING AND ANALYSIS REQUIREMENTS

Data processing requirements will have four basic inputs:

1. Signal conditioning
2. Data recording
3. On-line or quick look data analysis
4. Off-line data analysis and display

The requirements are intended to be within VTU capabilities.

6.1 Signal Conditioning

The anticipated problems of high frequency vibrations masking the low frequency data is discussed in Section 4. Signal conditioning will be aimed primarily at filtering out frequencies above 30 Hz and keeping phase error to a minimum below 20 Hz.

Analog filters will be used prior to signal amplification and A to D conversion so that the primary, low frequency data is as large a percentage of full scale as possible.

6.2 Data Recording

Data recording will be in three forms:

1. There will be 12 channels of data played out in real time by an oscillograph.

2. Selected measurements will be low pass filtered and digitally recorded and used in the data processing in the Integrated Computer System Network (ICSN).

3. The data recorded digitally will also be recorded on analog tape (prior to A-D conversion) and kept as back-up to the digital tape.

Table 6-1 and Table 6-2 contain a matrix of measurements to be recorded in each test and data processing requirements. The measurements listed in the third column, Real Time O-Graph, will be so recorded for each RIF listed in column two. The measurements listed under Bode Plots will be recorded, for each RIF listed, on digital tape and the back-up analog tape.

TABLE 6-1 - DATA RECORDING AND PROCESSING REQUIREMENTS, MODAL TESTS

Mode	RIF Nos.	Real Time O-Graph & Quick Look Bode	Bode Plots	Mode Shapes
Yaw, Body Torsion, Lading	1.1 1.2 1.3 2.4 3.1 3.2 4.3	3 15,16 31,32,33,39 41,44,45,50 51	3.9 13-16,23,25 31-36,39-42 44-48,50,51, 54,55,59,60	Runs 1.1b,2.5a, 3.2b,4.3b only Yaw Modes: 14,16,23 25,31,32,36,39,40, 45,55 Torsion: 13-16,31-35,39-42,44,45 Lading: 31-33,44-48,50,51,54,55
1st Roll	1.4 1.5 2.1 2.2 3.3 3.4	1 15,16 31,32,33,39, 41,44,45,50, 51	1,7 13-18 22-25,27 31-35,39-42 44,45,50,51, 54,55,59,60	Runs 1.4b,1.5b,2.1b 2.2b,3.3b only 13-18 31-34,39-42 44,45,50,51
2nd Roll	1.6 1.7 2.3 3.5	Same as 1st Roll	Same as 1st Roll	Runs 1.6b,2.3a, 3.5a only Same as 1st Roll
Pitch	1.9 2.6 3.7	1 15,17 31,32,33,39, 41,44,45,50 51	1,7 13,15,17,18, 22,24,26,27, 33,34,37,38, 41,42,43,44, 45,48,50,51, 53,54,58	Runs 1.9b,2.8b & 3.8b only 13,15,17,18, 33,34,37,38,41,42 44,50,54
Bounce, Body Bending & Lading	1.8 2.5 3.6 4.4	1 15,17 31,32,33,39, 41,44,45,50, 51	1,7 13,15,17,18, 22,24,26,27 33,34,37,38 41,42,43-46, 48-56,58	Runs 1.8b,2.7b,3.7b & 4.4b only Bounce: 13,15,22,24 33,34,37,41,42,51 Bending: 13,15,22, 24,33,34,37,38,41, 42,45,51 Lading: 13,15,33, 34,43,44,46,48,49, 50,54
Random	1.13 2.10 3.11 4.9	1 15,16 31-34 44,45,50 51	1 14-18,24,25 31-35,37, 39-45,50,51 53,54,55	For selected modes. The extent of deriving mode shapes from random test data will depend on the success encountered in the first series of tests.

TABLE 6-2 - DATA RECORDING AND PROCESSING REQUIREMENTS, TRACK SIMULATION

Mode	RIF Nos.	Real Time O-Graph	Digital Time Data
Staggered Rail Profile	1.10 2.7 3.8 4.6	1 15,16 31,32,33,39,41 44,45,50,51	1,7 13-18,22-25,27 31-35,39-42 43-45,50,51,53,54,55
Track Irregu-larity	1.11 2.8 3.9 4.7	Same	1,7 13,15,17,18,22,24,26,27,33,34,37,38,41,42,43,44,46,48,49,50,52,53,54,56,58
Hunting Motion Simula-tion	1.12 2.9 3.10 4.8	3 14,16 31,32,33,39,40 44,45,50,51	3,9 13-18,22-25,27 31-35,39-42 43,44,45,50,51,53,54,55

6.3 Real Time and Quick Look Data

The measurements listed in column 3 of Table 6-1 will be displayed real time on ocillographic recordings. Bode plots will also be made of these measurements for each RIF listed in column two on a quick look basis. It is expected that these quick look Bode plots will be generated as soon as possible and will be available for study no later than the start of the first shift of the following day.

6.4 Off-Line Data Processing

Bode plots will be generated for those measurements listed in column four of Table 6-1 do not included in the quick look data processing. Modal data will be developed for the runs and measurements listed in column five. This will consist of generating Argand plots, performing the curve fitting process and obtaining plots of deflection shapes.

6.5 Random Test Data Analysis

The random test has been included in this test program as an alternate method for performing modal vibration testing of freight cars. Bode plots and modal data will be generated for the first configuration tested with both the sine test and the random test data. Depending on the success of the random test results the test plan will be altered to eliminate some of the sine testing or some of the random testing. It is anticipated that it will be possible to eliminate the sine modal testing of the final configuration and possibly a partial elimination of the sine testing in configurations 2 and 3.

6.6 Track Condition Simulation Data

The measurements to be recorded during the track condition simulation tests are listed in Table 6-2. As in the modal testing, measurements have been selected for real time o-graph display and for recording on digital tape with analog tape back-up. All accelerometer data will be low pass filtered prior to A-to-D conversion and/or recording.

The real time o-graph data will be used for initial analysis and evaluation of test results. Time history plots will be made from the digital data of all measurements listed in column four of Table 6-1 for final analysis and reporting.

The low pass filter setting for the digitally recorded data will be at 30 Hz for the initial tests and may be changed depending on results achieved. The analog tape back-up will use 125 Hz low pass filters.

7. TEST ABORT CRITERIA

Prior to the start of testing, safe response limits will be defined for carbody roll. An automatic abort system will be in effect during the test performance which will cause the test to stop when this predefined safe response limit is exceeded. The wheel cradle load conditions required by the shaker system will be the limiting condition insofar as vehicle response is concerned.

Vibration Test Requirements for a 70 Ton Boxcar Revision I, 1981
US DOT, FRA, George Kachadourian