Technical Memorandum

THIS IS A SYDIA CORPORATION WORKING PAPER AND IS INTENDED PRIMARILY FOR INTERNAL DISTRIBUTION, THE IDEAS EXPRESSED HEREIN DO NOT NECESSARILY REFLECT THE OPINION OF THE CORPORATION.

THIS MEMORANDUM IS NOT TO BE REPRODUCED WITHOUT THE EXPRESS WRITTEN PERMISSION OF SYDIA CORPORATION

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

SCTM 406-60(73)

RAILROAD TRANSPORTATION SHOCK
AND VIBRATION TESTING

P. H. Adams, 7323

ABSTRACT

This report describes a test made to determine how successfully precision equipment can withstand transportation environments and to obtain data on this environment.

RECEIVED

FEB 6 1961
u/43
7118

Case Nos. 433.00 and 579.00

January 1961

DISTRIBUTION:

R. W. Hager, Boeing Airplane Co., Seattle 24, Washington
C. E. Crede, California Institute of Technology, Pasadena,
California
I. Vigness, Naval Research Laboratory, Washington, D. C.
B. C. Dial, Southwest Research Institute, San Antonio, Texas
R. A. Buck, The Martin Company, Denver, Colorado
A. V. Engel, Jr., 7115
E. I. Bruce, 7117
E. L. Harley, 7118
L. A. Dunn, 7122
W. J. Denison, 7124
V. E. Blake, 7125
J. J. Kane, 7145
W. E. Treibel, 7146
J. W. McKiernan, 7147
A. A. Lieber, 7161
D. M. Olson, 7162
R. L. Peurifoy, 7164
D. M. Bruce, 7182
P. F. Jones, 7183
P. Syroid, 7184
C. L. Carpenter, 7185
H. E. Viney, 7210
G. E. Hansche, 7220
J. H. Scott, 7230
W. T. Moffat, 7240
J. C. Eckhart, 7250
D. Williams, Jr., 7311
C. N. Giles, 7312
E. H. Copeland, 7321
A. W. Reger, 7322
P. H. Adams, 7323 (10)
A. D. Ford, Jr., 8116
H. C. Walker, 8121
W. A. Little, 8122
D. A. Skinrood, 8123
M. O. Jones, 8124
C. W. Winter, 8141
D. E. Gregson, 8142
P. W. Rowe, 8143

DISTRIBUTION (cont.)

R. A. Baroody, 8152

F. J. Murar, 8153

E. F. Ingledue, 8161

E. A. Aas, 8162

F. J. Maloney, 8163

L. M. Spivey, 8164

R. K. Smeltzer, 3421-3

A. D. Pepmueller, 8233

W. F. Carstens, 3423

R. C. Smelich, 3466-1 (5)

1

2

3

4

5

6

7

8

9

RAILROAD TRANSPORTATION SHOCK AND VIBRATION TESTING

Introduction

For many years Sandia Corporation has been conducting tests designed to determine how successfully precision equipment and its shipping containers can withstand the environments of transportation. Railway shipment has of course been one of the primary modes of transport, especially for heavy items. The several effects of rail transportation have therefore been the subject of extensive investigations, and the results of such studies can be of interest to those concerned with mechanical design and with packaging. This report describes a field test of shock and vibration effects upon an item of heavy, precision equipment and its container shipped by rail and presents data accumulated during the test.

Purposes of Test

This railroad transportation test, conducted in early 1951, was designed to (1) determine the feasibility of railroad shipment of a heavy item of electromechanical equipment that must operate with a high degree of reliability, (2) prove out the design of its shipping and storage crate, and (3) obtain field data on shock and vibration effects upon such equipment during railroad shipment.

Test Equipment and Instruments

The equipment and instruments used in this test were as follows:

1. Three units of precision equipment and their crates.
2. A freight car with ASF Type A3 ride control trucks, and an instrumentation car for recording instruments and equipment.

3. Thirteen Statham accelerometers (see Table I), each with a 6-volt battery for bridge voltage supply.
4. A DC generator-type speedometer.
5. A Signal Corps Type PE75, 110-volt, 60-cycle, AC gasoline generator and rectifier panel (battery charging supply and recording equipment power supply).
6. A portable battery of Edison cells and 28-volt DC, 110-volt, 60-cycle, AC dynamotors (recording equipment power supply).
7. Thirteen Brush Type BL-905 AC amplifiers.
8. Four Brush Type BL-202A two-channel magnetic oscillographs.
9. One Brush Type BL-206, six-channel magnetic oscillograph.

Procedures

The equipment was mounted in its crate and instrumented with seven accelerometers (see Table I). Three accelerometers were mounted on the crate. The instrumented unit and its crate were placed at one end of a Santa Fe Railroad freight car so as to sit partly over the ASF Type 3 ride control car trucks. Along with two other units and their crates, the instrumented unit and crate was tied down to the car floor in the standard manner. Near to the accelerometers on the crate frame, three more accelerometers were placed on a mounting block which was bolted to the car floor next to the crate.

Instrument cables from the accelerometers were run from the sealed freight car to the instrumentation car coupled adjacent to it. In the instrumentation car a gasoline generator and Edison cell battery were employed to supply power for the Brush AC amplifiers and magnetic oscillographs which amplified and recorded the accelerometer signals. The speedometer consisted of a small DC motor mounted so that the generator driven by the freight car wheels also drove the DC motor, generating a voltage proportional to car speed. The speedometer signal was also recorded on a Brush oscillograph.

The test freight car and instrumentation car were connected into a train making a 700-mile trip from Albuquerque, New Mexico. At the end of this journey they were connected into another train and returned to Albuquerque over the same route. During the outward trip, sample records from each accelerometer were taken at various intervals. On the basis of these records, the signals of certain accelerometers were recorded for only certain periods or portions of the trip. The signals of the rest of the accelerometers were recorded throughout most of the time while the train was in motion, and part of the time while the train was involved in the switching and coupling of cars other than the test and instrument cars (0-mph measurements), and in the process of starting and stopping. Several times during the trip when vibrations were observed on the test records, the oscillographs were run at high recording speed, so that the characteristics of the vibrations could be readily observed. From these high-speed records a limited frequency analysis was obtained.

During the return trip to Albuquerque, accelerations were recorded at only those positions where appreciable signals had been recorded on the outward trip. Again, some accelerometer signals were recorded for only certain periods, while the rest were recorded regularly throughout most of the trip.

Following the round trip, the test units were inspected for any damage incurred. Likewise, crates and shear pads were examined critically.

Prior to the test, the natural frequency of the unit on the shear pads of the crate was determined in the laboratory to be 8.95 cps. Damping was computed from experimental data to be 2.3 percent of critical. The rocking frequencies computed were 5.98 and 9.00 cps.

Data Analysis

Since a large quantity of data was acquired during the test, an essentially statistical analysis of the data was deemed most practical, and the records for shocks and vibrations were analyzed separately. Since data reduction from the Brush oscillograph records is a slow, arduous process, only the most significant records showing greater numbers and higher magnitudes of shocks were chosen for analysis. Records selected on these criteria were those which measured the following accelerations: vertical and lateral on the end of the electrical portion of the equipment; vertical, longitudinal, and lateral on the freight car floor.

The speedometer apparatus either operated improperly or was entirely inoperative during most of the outward trip but was repaired and functioned satisfactorily during the return trip. Since it was desirable to correlate shock and vibration measurements with train speed, only the records taken during the return trip were analyzed, but these are assumed to be typical of the entire trip.

Shock and vibration magnitudes measured on the test records were divided into six ranges:

1/4 to 1/2 g	1 to 2 g
1/2 to 3/4 g	2 to 3 g
3/4 to 1 g	3 to 4 g

Train speeds were divided into nine ranges:

0 mph	
0 to 10	40 to 50
10 to 20	50 to 60
20 to 30	60 to 70
30 to 40	over 70

Each shock acceleration measured on a record was tabulated as one unit, according to its magnitude and the range of speed at the time of occurrence. Each apparent steady vibration acceleration, differentiated from a continuous series of shocks, was tabulated according to the range of magnitude into which it fell and the speed range at which it was recorded. The unit of measurement in terms of which the vibration data were tabulated for each magnitude and speed range was the cumulative number of minutes during which vibration was measured for those ranges. Both the shock and vibration magnitudes which were measured from the test records were the zero-to-peak magnitudes.

To facilitate rapid, comprehensive observation of test results, shock data were plotted on graphs showing the number of individual shocks in each range of magnitude measured for each range of train speed at each of the locations for which data were analyzed. Since data were not recorded for the same lengths of time at all locations used in the analysis, the data obtained from each record were adjusted as illustrated in the following example to make possible direct comparison of the data for the various locations:

1. Eighty-seven lateral shocks measured on the end of the electrical section fell into the 1/4 to 1/2 g range of magnitude for the 60 to 70 mph range of train speed.

2. Acceleration data were recorded at the 60 to 70 mph speed for 1.350 hours.
3. Lateral direction shock was recorded on the electrical section at the 60 to 70 mph speed for 1.275 hours.
4. The factor by which all data at this position were adjusted for this speed range was therefore derived as follows:

$$F = \frac{1.350 \text{ hrs}}{1.275 \text{ hrs}} = 1.059$$

5. The number of 1/4- to 1/2-g lateral shocks which would have been expected to occur during the 1.250 hours of travel at speeds from 60 to 70 mph is now computed as follows:

$$\text{No. shocks } (87) \times \text{Factor } (1.059) = 92.$$

Summary of Results

The adjusted shock data analyzed for the equipment (shipping unit) are plotted in Figures 1 and 2. Those for the freight car floor are shown in Figures 3, 4, and 5. To simplify reading of the graphs, lines are drawn between the points corresponding to a given acceleration range. All the shock data are tabulated in Table II.

Analysis of the test records showed that very little steady vibration occurred during the test trip. The largest cumulative total time of vibration was measured on the unit in the vertical direction but amounted to only 1.8 percent of the time during which data were recorded on the trip. The short total times of vibration detected in the test records are tabulated in Table III for each speed range and position of measurement. As for the shock data, these vibration times were adjusted to make possible direct comparisons among the five locations.

To show the extent to which the test data were adjusted, in tabulating and plotting the results, the total times for each of the speed ranges used in reporting the results and the adjustment factors are presented in Table IV. Of the adjustment factors, 91 percent are less than 1.2.

The approximate frequencies detected in the high-speed oscillograph records are listed in Table V, although the predominant frequencies observed in all the records analyzed were approximately 30 and 90 cps. The frequencies listed which are greater than 100 cps were definitely detectable in the vibration records for which they were measured. Their measured amplitudes were very small, but they are listed because the frequency responses of the Brush AC amplifier and magnetic oscillograph recording systems are only about 50 percent of their flat response value at 120 cps and about 10 to 20 percent of that value at 200 cps. (Their average range of flat response is from 0.5 to 70 cps.) This indicates that some higher frequency vibrations of appreciable magnitude may have occurred during the test, perhaps excited by higher frequency shocks.

An attempt was made to fit the shock data measured in the vertical direction on the car floor (the severest and most numerous shocks) to a distribution curve. The experimental data fit reasonably well the curve of the form $y = 152 e^{-2.85x}$ in which y is the average number of shocks measured per mile of car travel (at all speeds) and x is the shock acceleration magnitude in g. This curve and the measured data are plotted on a semilogarithmic scale in Figure 6.

Examination of the test units and crates showed no evidence of other than minor damage having occurred during the test trip.

Conclusions

Assuming the railroad trip from which the data were obtained during this test to be typical of most railroad freight trips, the following conclusions may be drawn from the test results:

1. The shocks and vibrations (excluding switching shocks) to which freight cars and their lading are subjected during railroad transit are small in magnitude, generally less than 1 g.
2. Although the frequency of occurrence of shocks of 1/4 g or greater magnitude occurring while freight cars are in motion increases as speed increases, particularly at speeds above 50 mph, the numbers of shocks received during a trip are approximately evenly distributed over the range of speeds from 20 to 70 mph, considering the length of time spent traveling at each of the various speeds.

3. The severest and greatest number of shocks received by freight cars in motion are in the vertical direction. At least 90 percent of the vertical shocks are of less than 1-g magnitude.
4. The shear pads of the crates on which the units were mounted highly attenuated the shocks transmitted by the freight car to the unit. Conversely, they apparently amplified the vibrations of the car, although vibration data are limited.

TABLE I
Accelerometer Data

<u>Accel. No.</u>	<u>Location</u>	<u>Direction</u>	<u>Serial No.</u>	<u>Range (g)</u>	<u>Statham Model No.</u>	<u>Natural Frequency (cps)</u>
1	Rear cover	Vertical	284	±50	A5A-50-240	580
2	Front cover	Vertical	280	±50	A5A-50-240	600
3	Rear cover	Longitudinal	285	±50	A5A-50-240	580
4	Top segment	Lateral	1014	±25	C-25-325	
5	End of elec- trical package	Vertical	275	±50	A5A-50-240	550
6	End of elec- trical package	Longitudinal	150	±500	A5A-500-700	1550
7	End of elec- trical package	Lateral	1017	±30		
8	Crate frame	Vertical	283	±50	A5A-50-240	550
9	Crate frame	Longitudinal	274	±50	A5A-50-240	550
10	Crate frame	Lateral	279	±50	A5A-50-240	560
11	Freight car floor	Vertical	276	±50	A5A-50-240	560
12	Freight car floor	Longitudinal	277	±50	A5A-50-240	570
13	Freight car floor	Lateral	281	±50	A5A-50-240	580

TABLE II

Summary of Railroad Transportation Test
Adjusted Shock Data

Speed (mph)	0	0-10	10-20	20-30	30-40	40-50	50-60	60-70	Over 70
Time of Speed (hr)	1.517	2.308	1.525	3.283	3.425	1.742	0.992	1.350	0.050

Number of Individual Shocks Measured
Vertical on End of Electrical Package

Range of
Magnitude

1/4 - 1/2 g	17*(15)	22(13)	16	5	37	79	449	772	26
1/2 - 3/4 g	5(5)	10(6)	9	3	5	26	85	169	
3/4 - 1 g	5(5)	10(7)	5	5	4	12	13	30	
1 - 2 g	8(8)	8(6)	7	1	1	4	2	13	
2 - 3 g	2(2)		1						

Lateral on End of Electrical Package

1/4 - 1/2 g	6	12	19	128	135	58	57	92
1/2 - 3/4 g	1			2	1	1	2	4

Vertical on Freight Car Floor

1/4 - 1/2 g	15	551	1450	4820	4892	2957	2445	4180	199
1/2 - 3/4 g	5	148	619	2066	1639	1078	849	1701	43
3/4 - 1 g	3	30	271	829	847	550	487	1079	24
1 - 2 g	4	15	174	385	608	335	336	777	7
2 - 3 g	1	1	5	1	27	22	3	17	
3 - 4 g						2			

* () indicates number of shocks measured during starting and stopping.

TABLE II (cont.)

Longitudinal on Freight Car Floor

1/4 - 1/2 g	23	53	51	227	501	347	540	944	27
1/2 - 3/4 g	19	16	18	40	68	43	56	107	1
3/4 - 1 g	8	9	5	6	1	5	7	10	
1 - 2 g	6	11	7	1		2	6	6	
2 - 3 g	2	2	4						

Lateral on Freight Car Floor

1/4 - 1/2 g	15	24	69	321	377	183	140	239	6
1/2 - 3/4 g	2	4	2	10	18	8	8	11	
3/4 - 1 g	2			1			1	2	
1 - 2 g				2					

TABLE III

Summary of Railroad Transportation Test
Adjusted Steady Vibration Data

Speed	Speed (mph)	0	0-10	10-20	20-30	30-40	40-50	50-60	60-70	Over 70
	Time at Speed (hr)	1.517	2.308	1.525	3.283	3.425	1.742	0.992	1.350	0.050
30-40 50-60										

Total Time Duration
(Minutes) of Vibration Measured

40-50 50-60 60-70	<u>Range of Magnitude</u>		<u>Vertical on End of Electrical Package</u>
	1/4 - 1/2 g	1	2 14

40-50 50-60 60-70 No re		<u>Lateral on End of Electrical Package</u>
	1/4 - 1/2 g	1/2 1/2 1 6

40-50	<u>Vertical on Freight Car Floor</u>
	1/4 - 1/2 g 1/2 1/2 4

40-50
* No steady vibrations were measured in the longitudinal and lateral directions on the freight car floor.

Figure 1. Numbers of vertical shocks measured on shipping unit

Figure 2. Numbers of lateral shocks measured on shipping unit

Figure 3. Numbers of vertical shocks measured on freight car floor

Figure 4. Numbers of lateral shocks measured on freight car floor

Figure 5. Numbers of longitudinal shocks measured on freight car floor

Figure 6. Average number of vertical shocks on freight car floor per mile of car travel. Railroad transportation shock and vibration test