NOAA Technical Report NOS 113
Charting and Geodetic Services Series CGS 6

Shock Environment NOAA 29-Foot Survey Launch

By Dr. Rudy Scavuzzo
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Vienna, Virginia 22180

March 1985
Rockville, Md.

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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U.S. DEPARTMENT OF COMMERCE
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PREFACE

This report was prepared by NKF Engineering Associates, Inc., Report No. 8433-001/1, for the National Charting Research and Development Laboratory, Nautical Charting Division, Charting and Geodetic Services, National Ocean Service, NOAA, Rockville, Maryland 20852, NOAA Contract No. NA-84-DDC-00002, and is reprinted in its entirety.

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NOAA 29 FOOT SURVEY LAUNCH

1.0 INTRODUCTION

1.1 Background

The National Ocean Service (NOS) is in the process of evaluating proposals for its new fleet hydrographic computer system. This system is to be installed in launches typically 29 feet in length. At times it is required that these launches operate in rough seas up to and including sea state 3. During these conditions the launch is subjected to slamming loads. The computer system must withstand the shock environment caused by this slamming as well as other shock loads in order to satisfy the mission requirements of NOS.

A shock and vibration environmental test on a 29 foot launch was recently conducted for the National Oceanic and Atmospheric Administration (NOAA) by the Naval Sea Combat Systems Engineering Station [5.1]. In this test program, accelerometers were used to measure the shock and vibration environment in the bow and cabin of a survey launch. Acceleration time-history motions were recorded. Specific tests conducted in this program are listed below:

(1) Rough Seas Test
(2) Pier Bump Test
(3) Davit Lift Test

The highest vertical shock loads occurred from hull slamming at full speed (2800 rpm) with a starboard bow sea. During this test, the sea was classified as low state 3. The Pier Bump Test caused the highest lateral dynamic loads. Shock loads from the davit lift were not significant.

1.2 Task Assignment

The primary objectives of the work done in this task are as follows:

(1) To evaluate the shock environment in the launch cabin for use in the design of the fleet hydrographic computer system,

(2) To suggest procurement specifications for the system,

(3) To suggest possible laboratory testing of the equipment of the system which simulates the ship board environment,

(4) To evaluate the feasibility of using an isolation system to reduce the effects of shock on the system.

(5) To provide a preliminary evaluation of the shock resistance of commercially available components.

It was also requested that a recommendation be made concerning safety of ship personnel from shock induced hazards.

2.0 TECHNICAL APPROACH

The basic approach used to establish the shock environment of the launch was to calculate the shock spectrum (or response spectrum) of the measured launch motion. The shock spectrum is a plot of the maximum possible relative motion of a single degree of freedom system of a given frequency to a foundation time-history input. Thus, the shock spectrum provides an evaluation of the damage potential of a given foundation motion over a specified frequency range. This concept is employed in both naval shock design and seismic design methods. Units of the spectrum may be displacement, velocity or acceleration. By using tri-part shock paper all units can be represented on one graph. This type of graph is used in this report even though displacement lines are not plotted. A derivation for the undamped spectrum and a discussion of the units are presented in Appendix A. Digital computer programs developed and verified by NKF Engineering Associates, Inc., were used to calculate shock spectrum graphs from measured motions on the launch.

The shock spectrum is calculated for a frequency range from 1 Hz to 100 Hz. The fundamental frequency of most equipment lies between 4 Hz and 50 Hz. For example, standard naval vibration tests conducted using MILSPEC 167 vary the input frequencies for Type 1 equipment from 4 Hz to 50 Hz. Thus the frequency range used for the shock spectrum, from 1 to 100 Hz, covers the useful input spectrum for equipment structures.

Most of the data recorded in Reference [5.1] is filtered at 50 Hz. Even though some high frequency inputs to the equipment are lost by this procedure, it is not considered to be significant since the fundamental modes of the equipment are normally below this frequency. Furthermore as indicated in Section 3.3, isolation mounts are recommended to eliminate this high frequency shock input to the electronic equipment.

3.0 DISCUSSION OF RESULTS

Results of this study are divided into six areas:

(1) Launch shock environment
(2) Shock design curves
(3) System isolation
(4) Recommended test motions
(5) Shock characteristics of system components
(6) Safety of personnel

3.1 Launch Shock Environment

Acceleration in the bow of the launch are characterized by a rapid rise from impact followed by a slow decay until another impact occurs. The period of motion is approximately 1.5 seconds. A typical time-history motion is shown on Figure 1. The maximum measured bow acceleration, filtered at 50 Hz, is plotted on Figure 2. This measurement was made at maximum speed (2800 rpm), starboard bow sea, at low sea state 3. The peak acceleration was 4.04 g and the pulse lasted 270 ms. The velocity change and displacement associated with this motion are 17.6 ft/sec and 3.2 feet, respectively (Appendix B). In the cabin near the location of the computer system (frame 4), the maximum measured acceleration was 3.26 g as compared to 4.04 g in the bow. Lateral accelerations from the Pier Bump Test are plotted on Figure 4. The maximum value is 1.09 g. High frequency accelerations associated with the hull natural frequencies were excited during this test. Vertical accelerations from the Davit Lift Test are plotted on Figure 5. Values are much less than those recorded from slamming loads (0.86 g vs 4.04 g).

Shock spectrum curves are presented for the maximum bow motion, the maximum cabin motion, and for the pier bump on Figures 6, 7, and 8, respectively. As seen on Figure 7, the maximum spectrum at frame 4 in the cabin is 6 g. At high, frequency the spectrum acceleration reduces to approximately 4 g for the filtered input motion. High frequency accelerations associated with hull vibration (> 50 Hz) are filtered from these records.

The effects of the duration of the acceleration time-history record and the details of the shape of the curve on the shock spectra were studied. Both a 406 ms record (Figure 3) and a 1500 ms record were found to yield the same spectrum response of the vertical cabin motion. Also, by approximating the curve by a ramp essentially the same spectrum response is calculated. Thus, these two effects do not influence the magnitude of the calculated spectra and the resulting spectra are not sensitive to slight variations of these two parameters.

3.2 Shock Design Curves

Based on all these studies of the shock environment on the launch a vertical design spectrum of 6 g is recommended for equipment located near frame 4 (Figure 9). A lateral design spectrum of 1.5 g is adequate for rough seas (Figure 10). However, a larger value is reached during high pier bump. Thus, a lateral design spectrum which envelopes the pier bump test data is plotted on Figure 9.

For equipment located in the bow (frame 2) a vertical design spectrum of 8.5 g is recommended. This design input is similar to that shown in Figure 6 for the environment in the launch cabin.

3.3 System Isolation

In order to isolate a system from a transient foundation motion, the system frequency must be less than 70 percent of the frequency of the forced motion. Since the period of the vertical bow motion is 540 ms (twice 270 ms, Figure 2), the system must have a natural frequency of less than 1.2 Hz. The static deflection of a system this soft is about 7 inches for a 1 g load; clearance for the dynamic response would have to be provided. These required deflections are much too large. Thus, isolation mounts can not be used to reduce the shock environment in the launch cabin (Figure 2) in the frequency range of interest (4 to 50 Hz).

As indicated on Figure 4, high frequency accelerations of the hull can be excited from impact loads to the hull. Therefore, it is recommended that the cabinet of the entire system be isolated from vibrations with frequencies above 30 Hz. Furthermore, in order not to increase the response from the low frequency basic motion associated with hull slamming, the isolators should have high damping similar to that provided by Aeroflex mounts [5.2] and the components of the system should be mounted rigidly to a stiff cabinet. The isolation should occur between the cabinet and the launch bulkhead and frames. The resonant frequency of the isolated system should be about 20 Hz in all degrees of freedom.

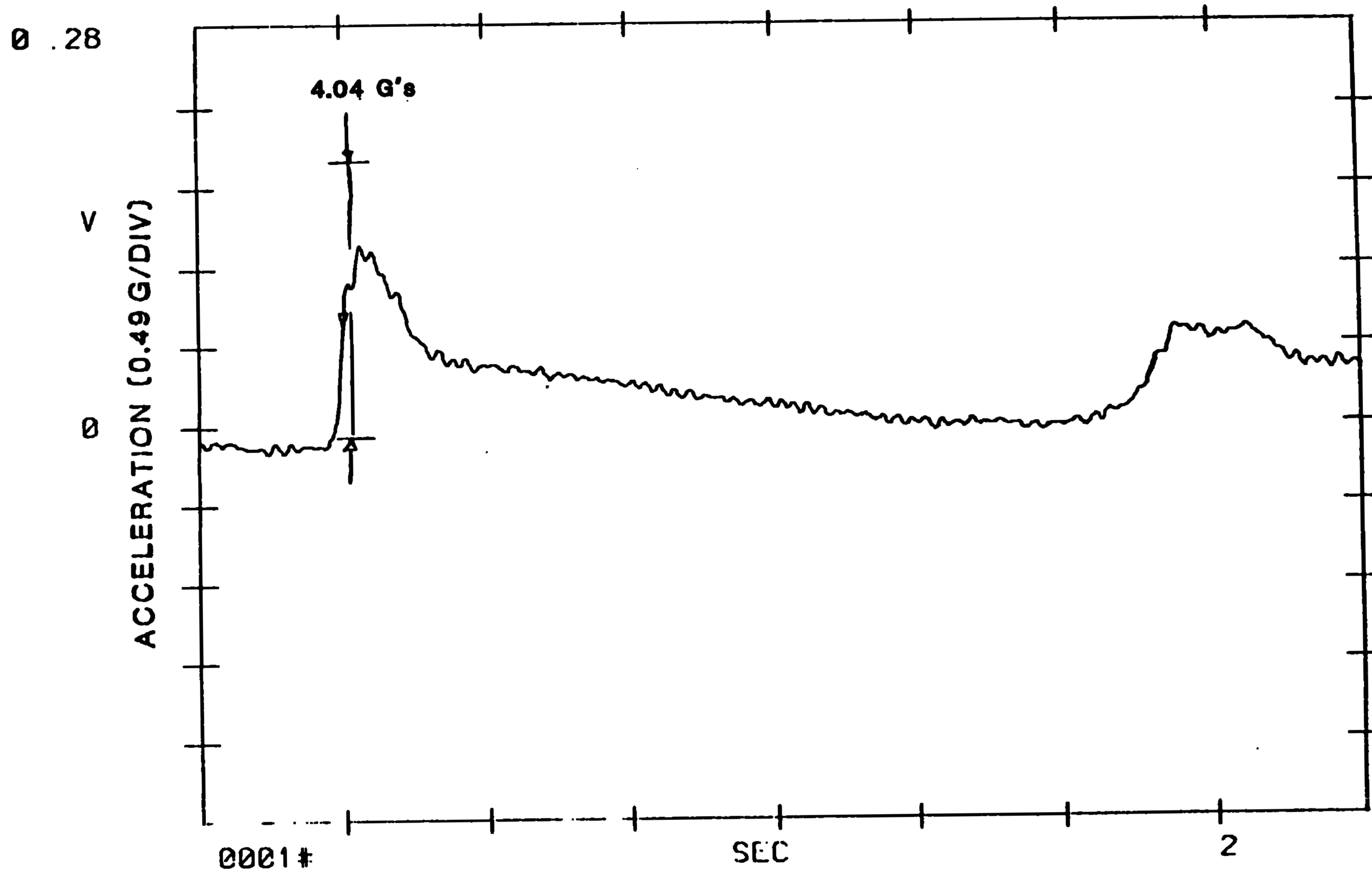


Figure 1. Measured Vertical Bow Motion (Frame 2); 2400 rpm, Head Sea [5.1]

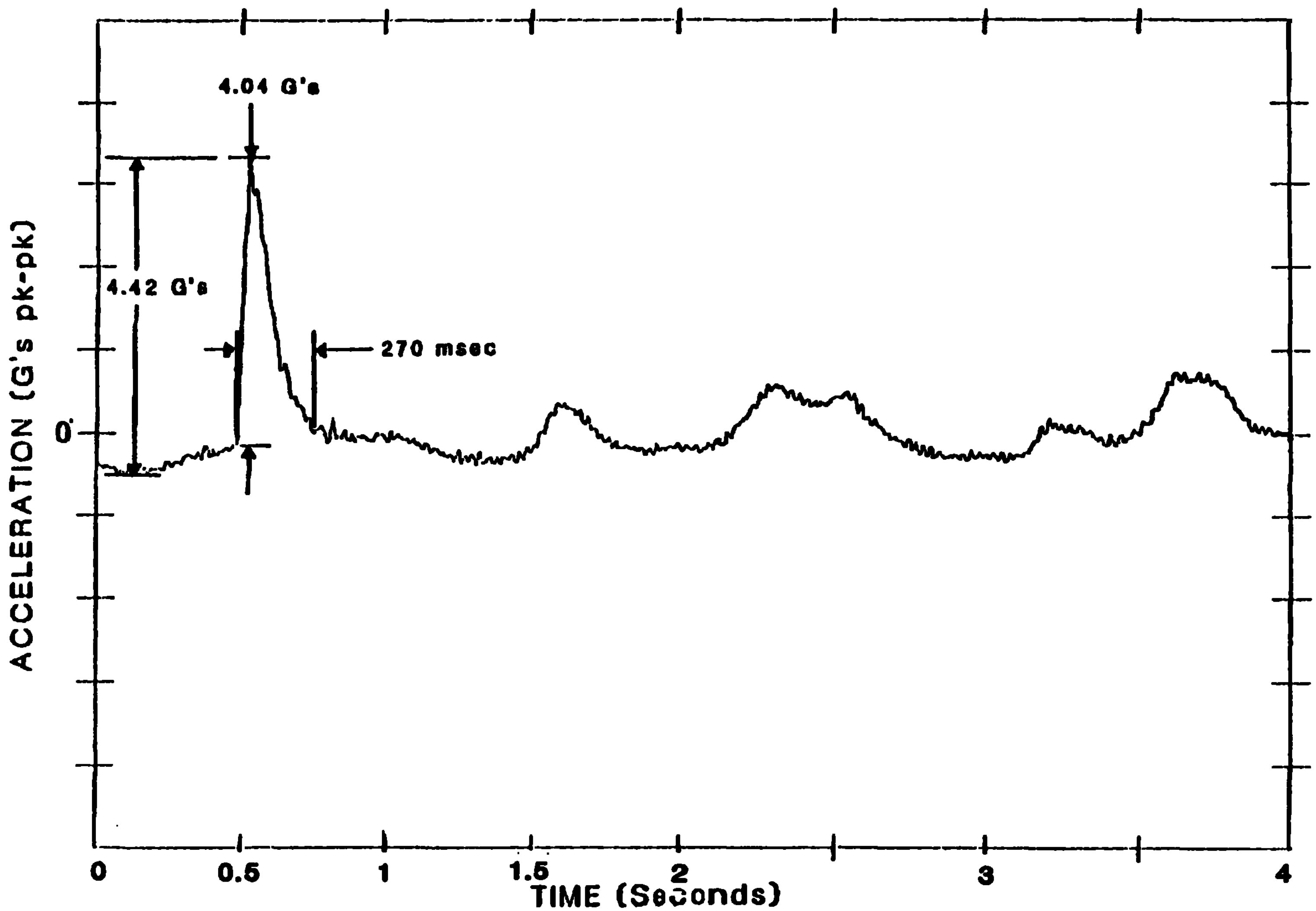


Figure 2. Acceleration of the Maximum Vertical Bow Shock (Frame 2) Filtered to 50 Hz; 2800 rpm, Starboard Bow Sea [5.1]

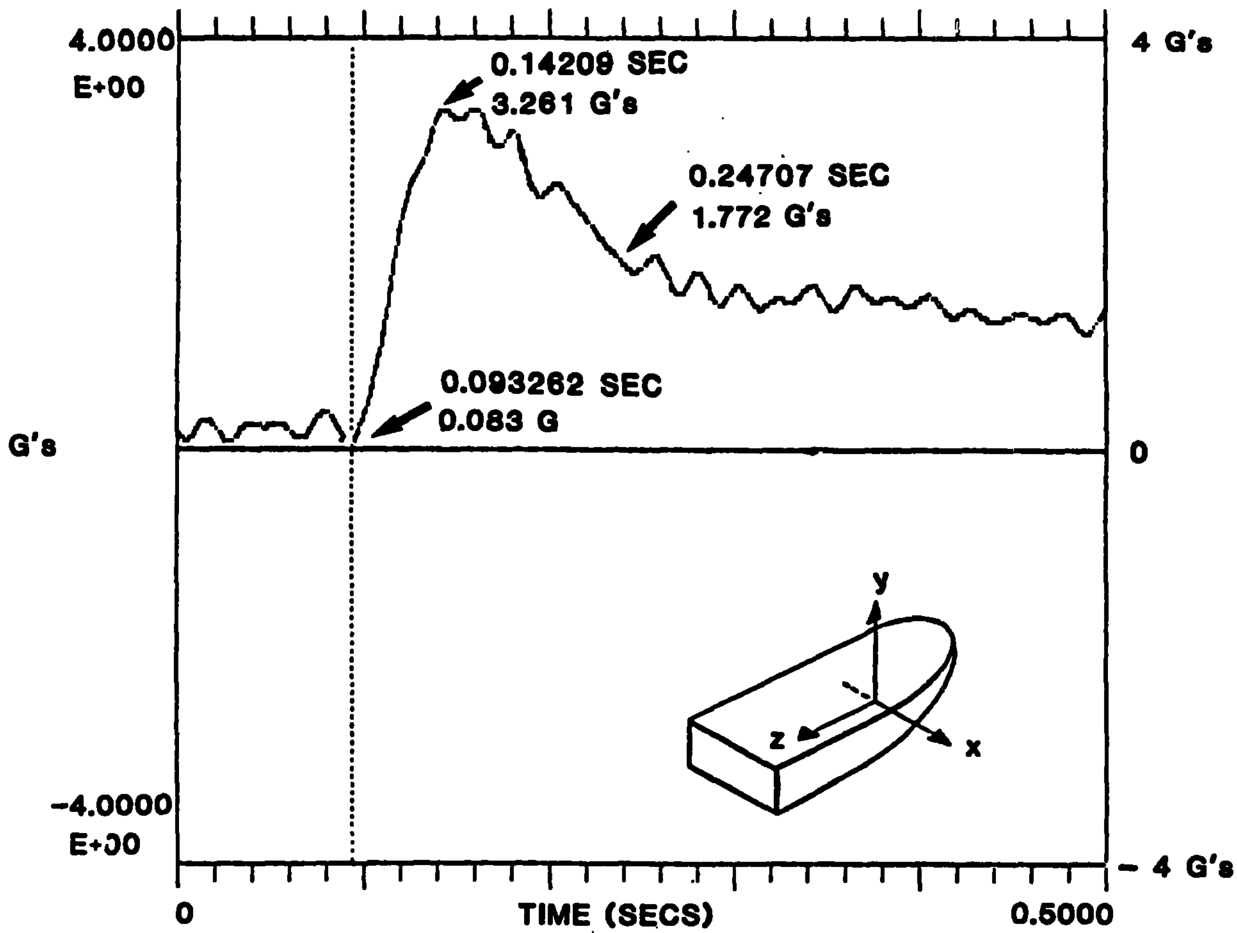


Figure 3. Acceleration of the Maximum Cabin Vertical Shock (Frame 4) Filtered to 50 Hz; 2800 rpm, Starboard Bow Sea [5.1]

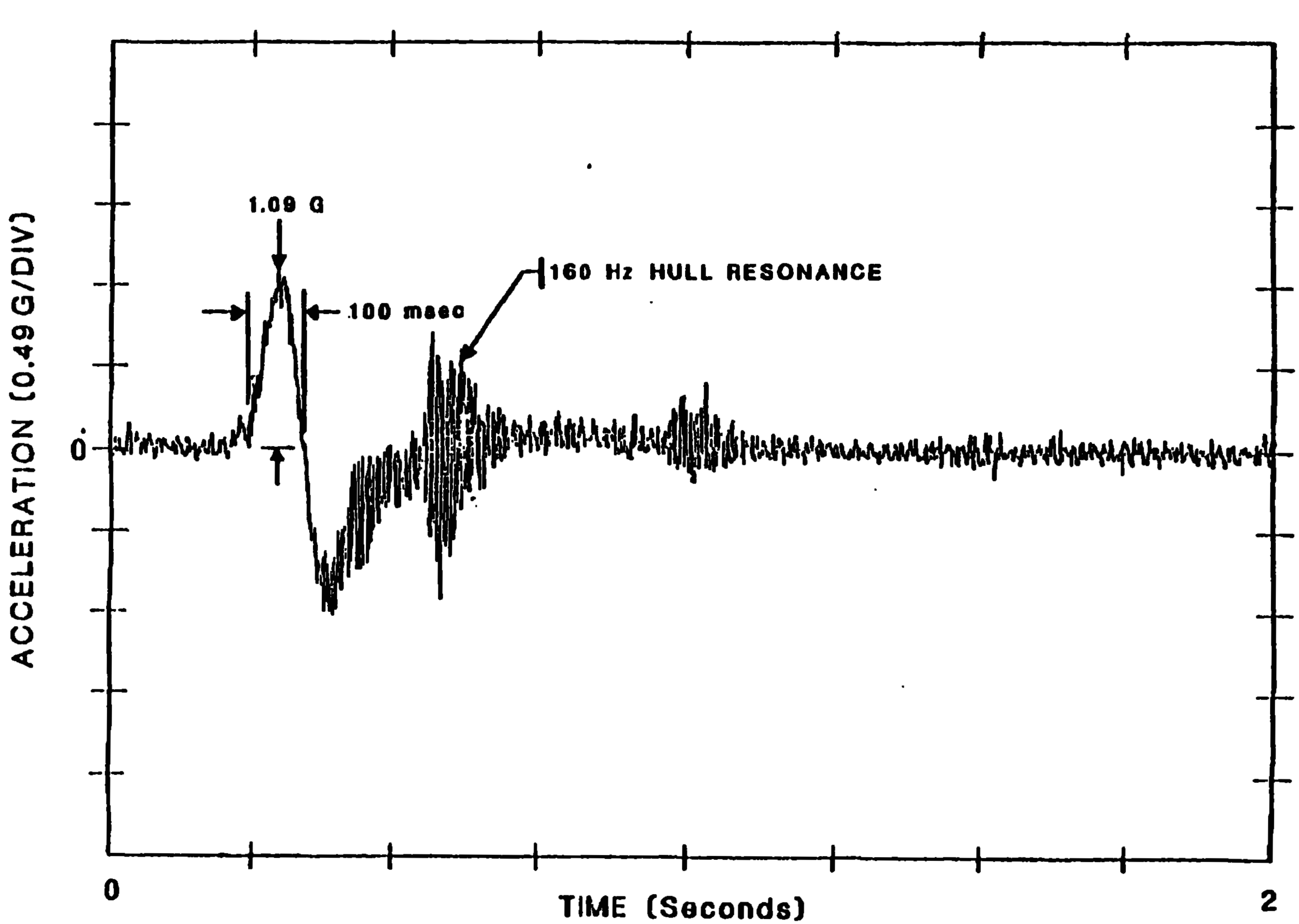


Figure 4. Pier Bump Test, Bow Longitudinal Impact Acceleration vs Time, Bow-On Condition [5.1]

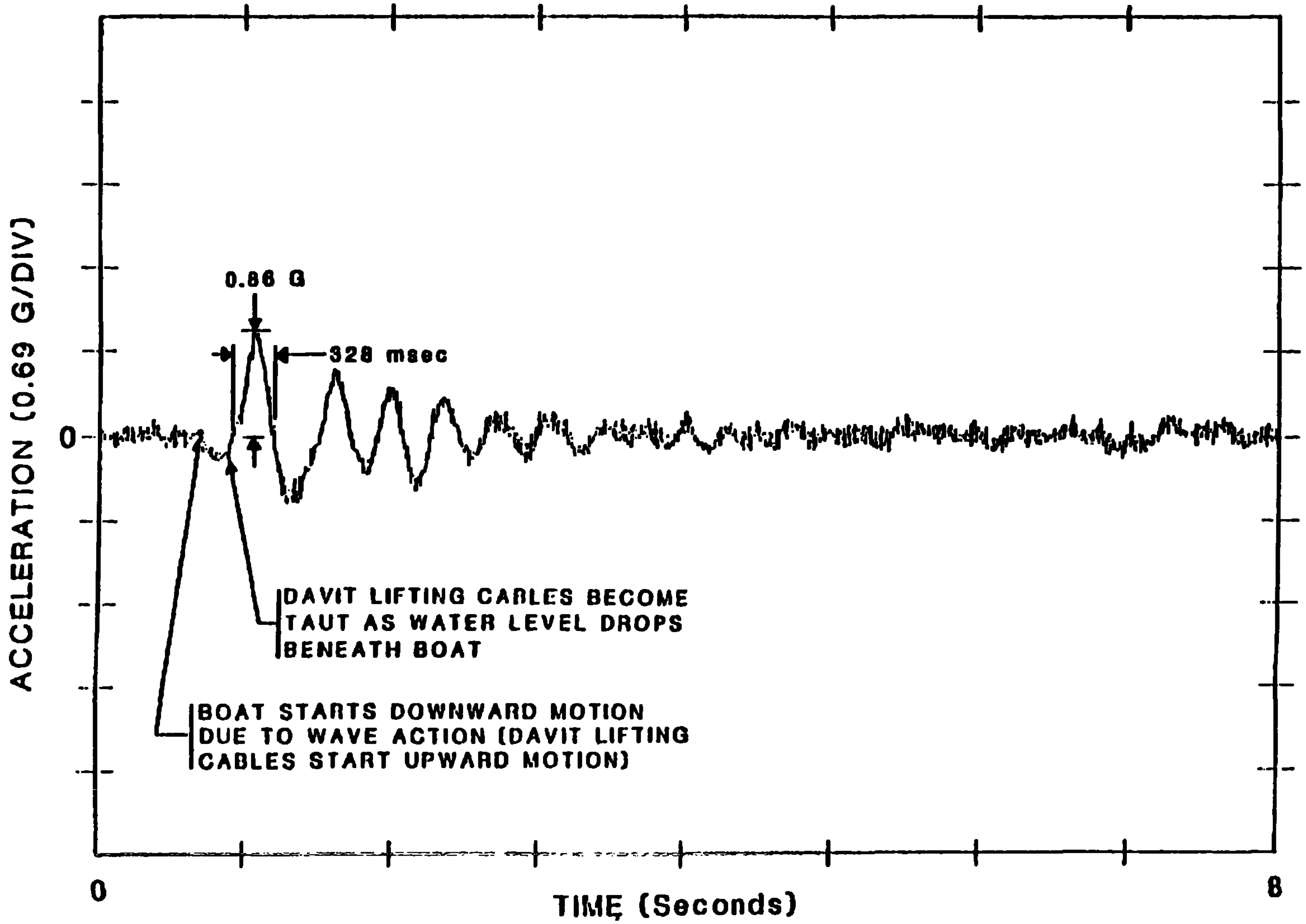


Figure 5. Bow Vertical Acceleration During Davit Lift with Wave Action [5.1]

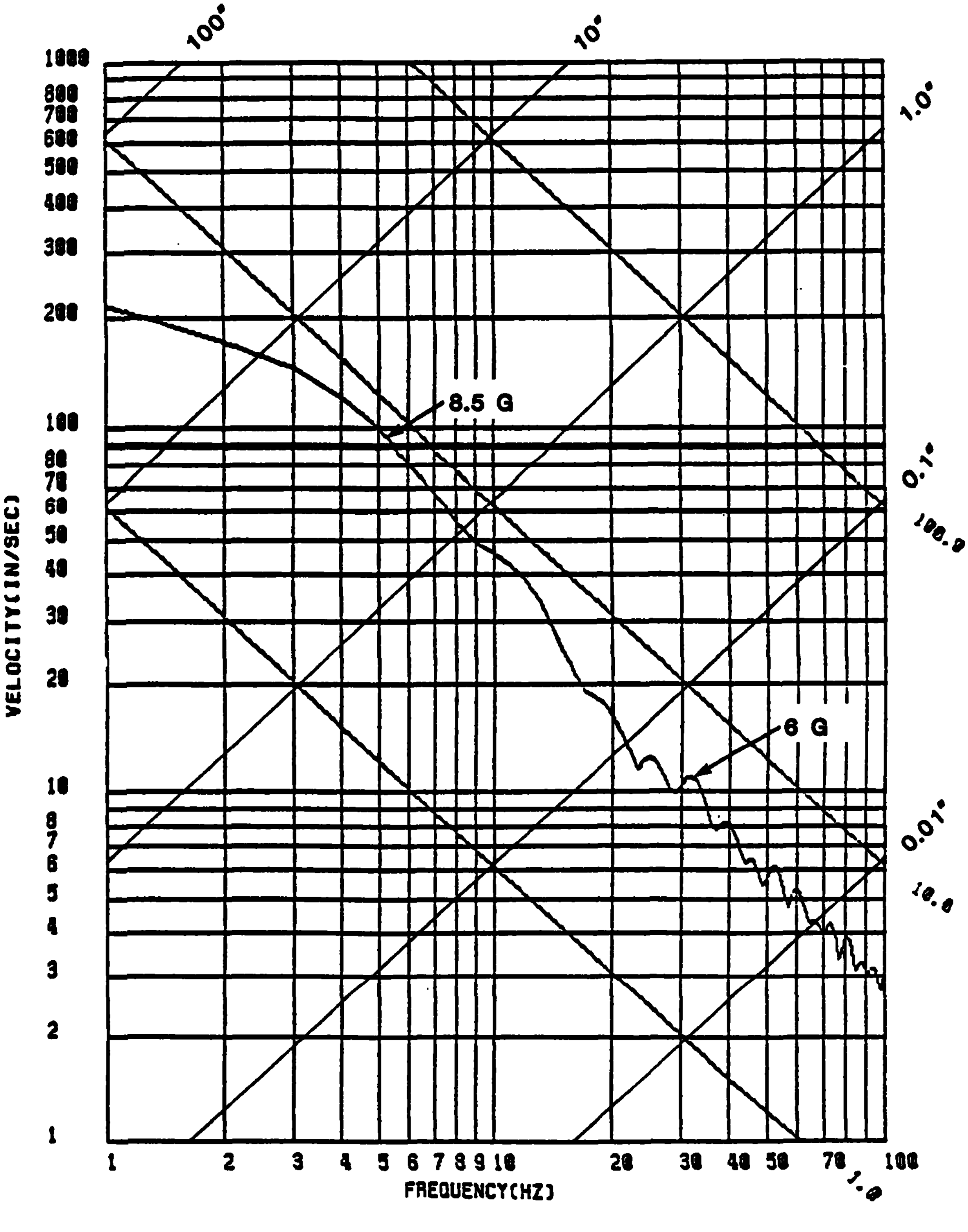


Figure 6. Vertical Shock Spectrum of the Maximum Bow Motion (Figure 2) Measured on Frame 2

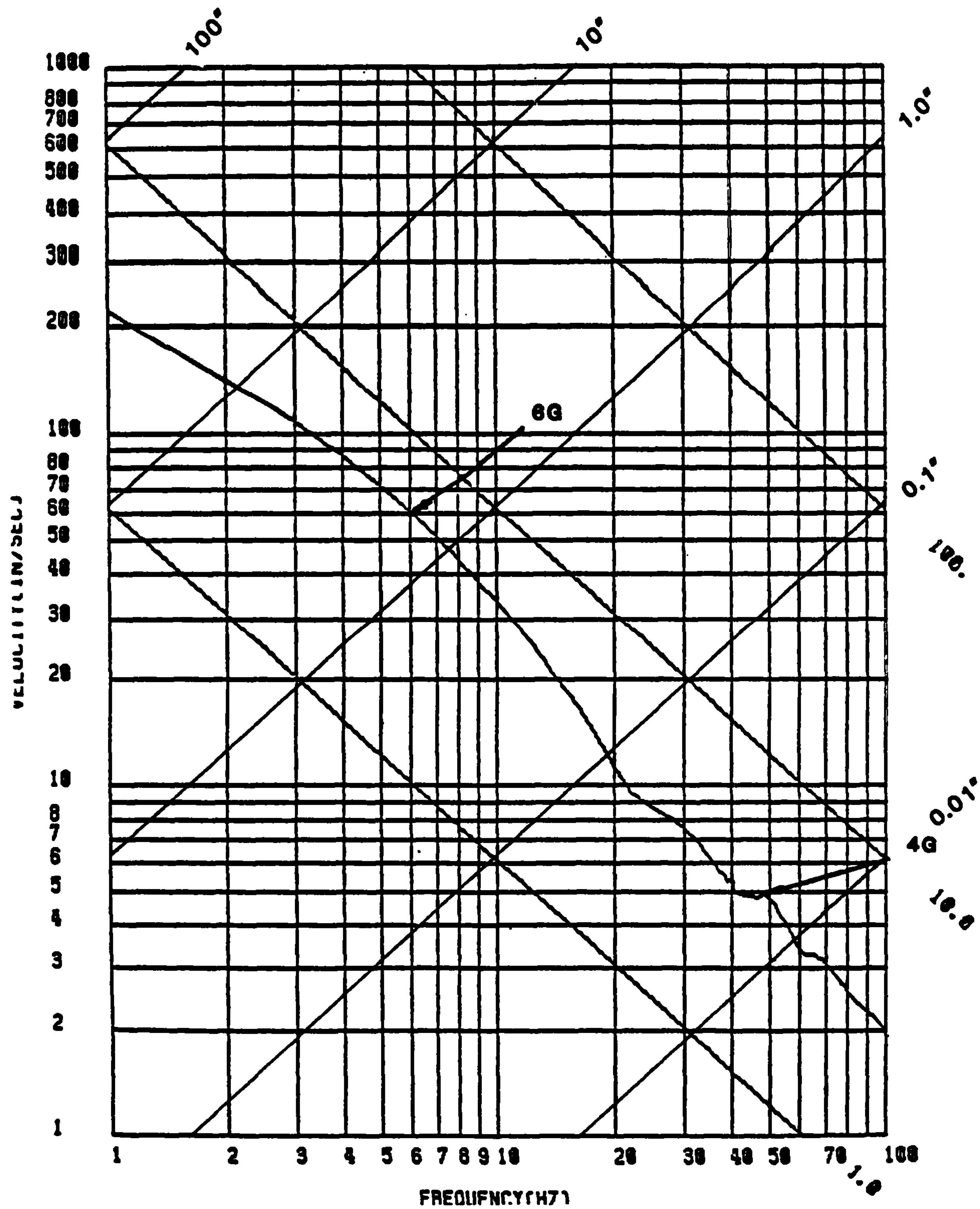


Figure 7. Vertical Shock Spectrum of the Maximum Cabin Motion (Figure 3) Measured on Frame 4

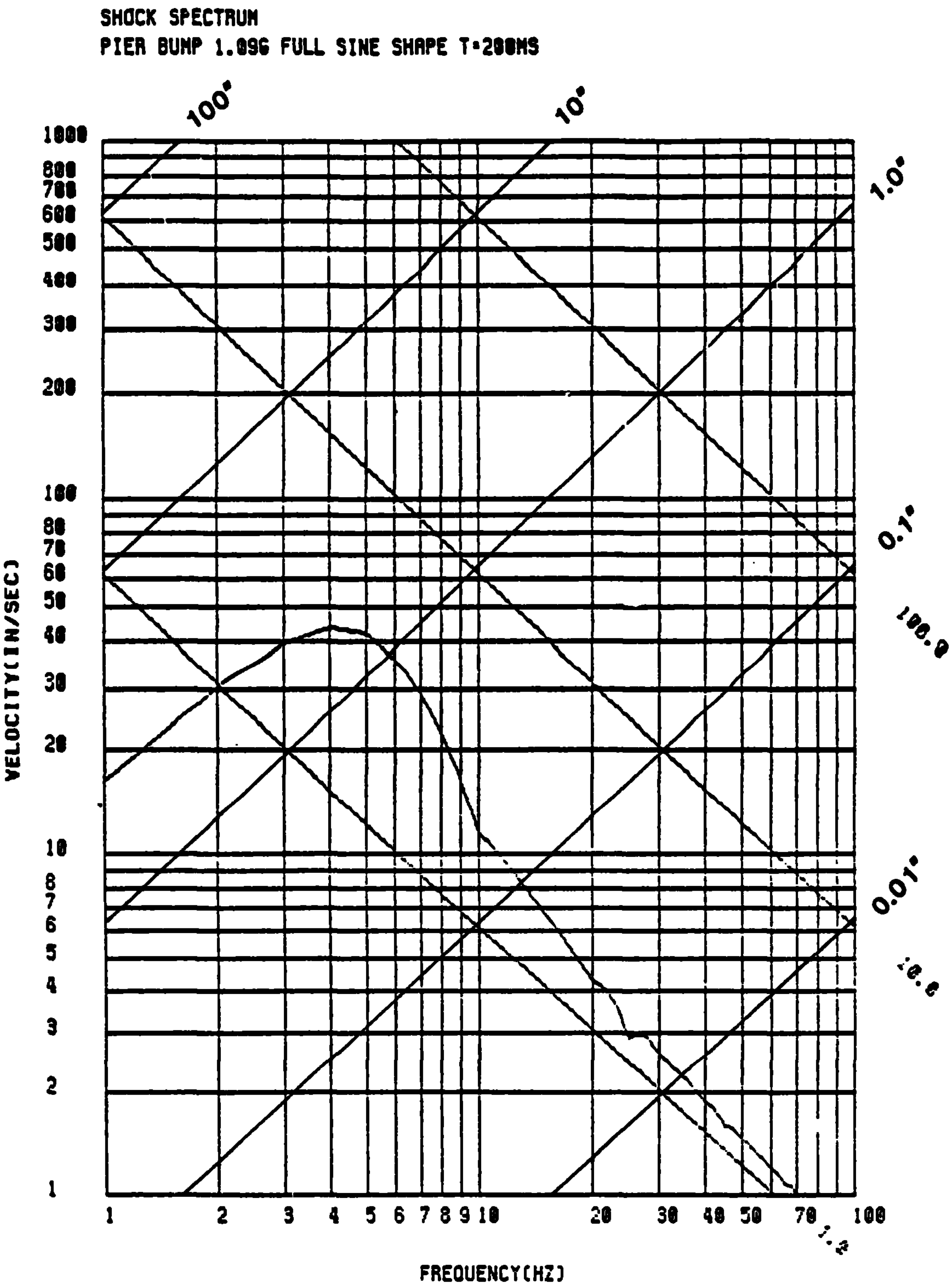


Figure 8. Lateral Shock Spectrum from the Pier Bump Test (Figure 4)

VERTICAL AND LATERAL DESIGN SPECTRA

LEGEND:

VELOCITY = ft/sec
ACCELERATION = g's

DISPLACEMENT = ft
FREQUENCY = HERTZ

1g = 32.2 ft/sec.
1 Hertz = 1/sec.

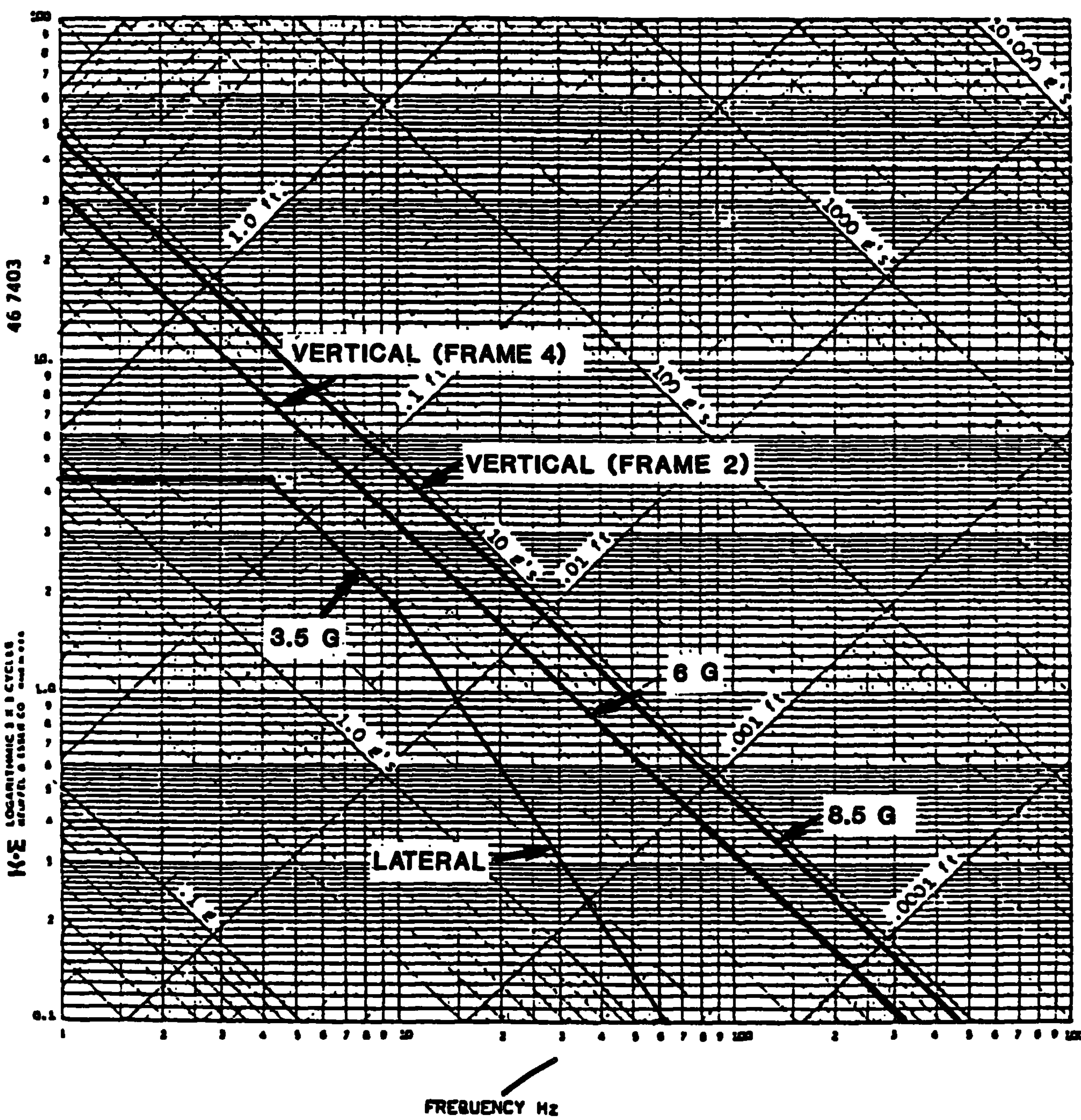


Figure 9. Vertical Design Spectrum Curve and Lateral Design Spectrum Curve for the Rough Seas Case and Pier Bump Test, Respectively

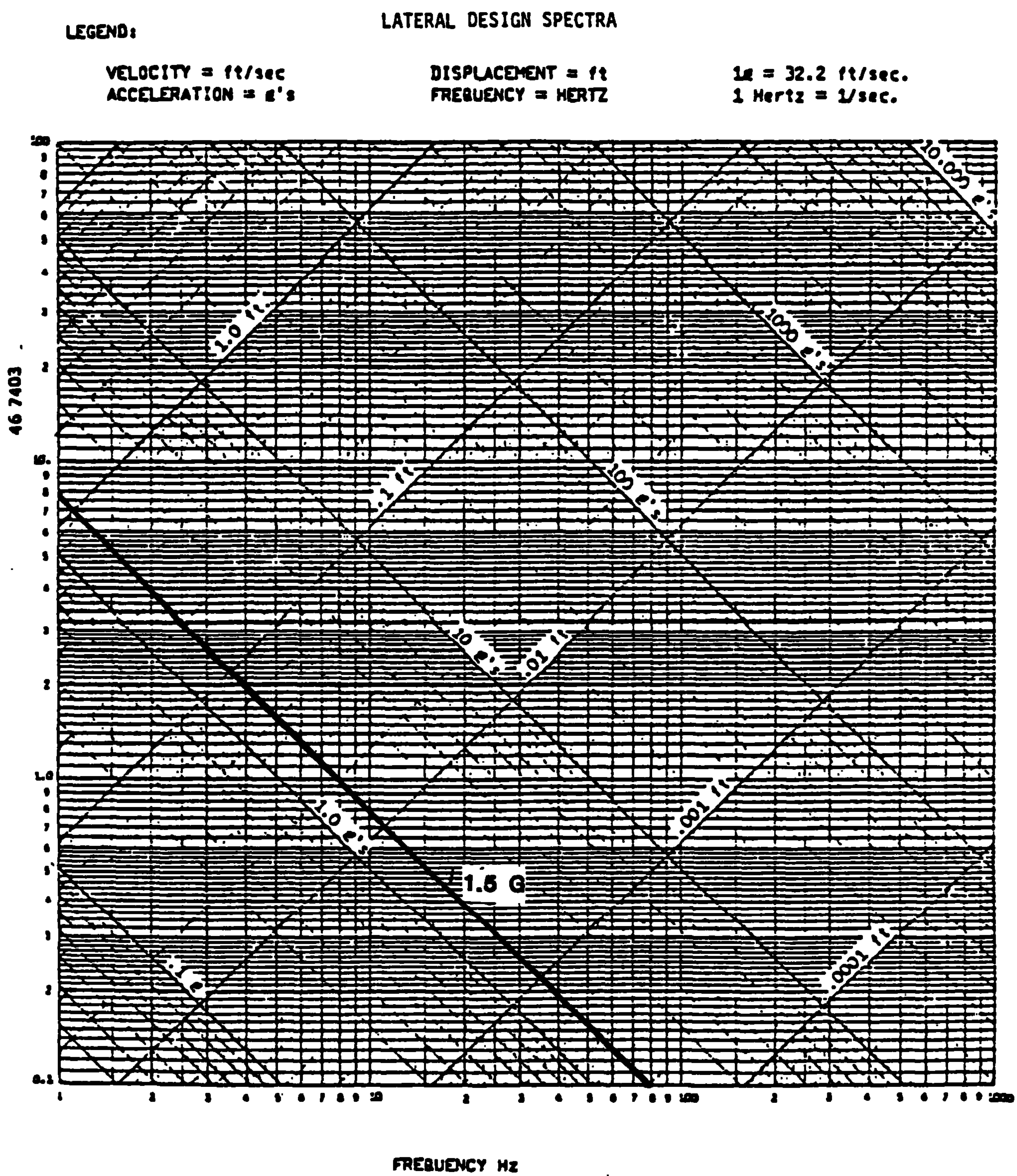


Figure 10. Lateral Design Spectrum Curve for Rough Seas

3.4 Recommended Test Motions

Most vibration and shock test machines do not have the amplitude required to completely simulate the shock environment of the survey launch in the laboratory. However, some pulses can approximate the actual motion. It was found that a half sine pulse or a full sine pulse of the proper duration could be used. Spectrum response curves for the pulses listed below were studied.

(1) 6 g half sine pulse with a 4 Hz frequency and a duration of 125 ms

(2) 6 g full sine pulse with a 4 Hz frequency and a duration of 250 ms

(3) 4 g half sine pulse with a 4 Hz frequency and a duration of 125 ms

(4) 4 g full sine pulse with a 4 Hz frequency and a duration of 250 ms.

These responses are plotted on Figures 11 through 14, respectively. Spectrum values are also listed on Tables 1 through 4. These motions can be approximated in the laboratory using seismic testing equipment [5.3] available at some commercial laboratories. Drop testers may also be used to develop the nalf sine pulse. Motions described as (1) and (2) are recommended for simulation of survival conditions; motions described as (3) and (4) are recommended for simulation of Operational conditions. At high frequencies, the spectrum reduces to 4 g's also. Graphs of these shock spectrum curves and tabulated values are attached. As seen from the attached curves the 4 g half sine pulse more closely approximates the shock spectra determined from measured launch motion than the full sine pulse and, therefore, is preferred.

As a result of these analyses, two shock requirments are recommended: one for operational conditions and one for survival conditions. Operational requirements are defined to mean that shock level for which there is no system performance degradation and no human intervention required for continued system operation. Survival requirements are defined to mean that shock level which may cause momentary degradation of the system without permanent system damage.

Operational Requirement: Subject the system or components to either a full or half acceleration sine pulse with a maximum of 4 g amplitude and a 4 Hz frequency (a duration of 250 or 125 ms, respectively). The equipment should be subjected to a total of 50 pulses with at least a 1-second rest between pulses.

Survival Requirement: Subject the system or components to either a full or half acceleration sine pulse with a maximum of 6 g amplitude and a 4 Hz frequency (a duration of 250 or 125 ms, respectively). The equipment should be subjected to a total of 100 pulses with at least a 1-second rest between pulses.

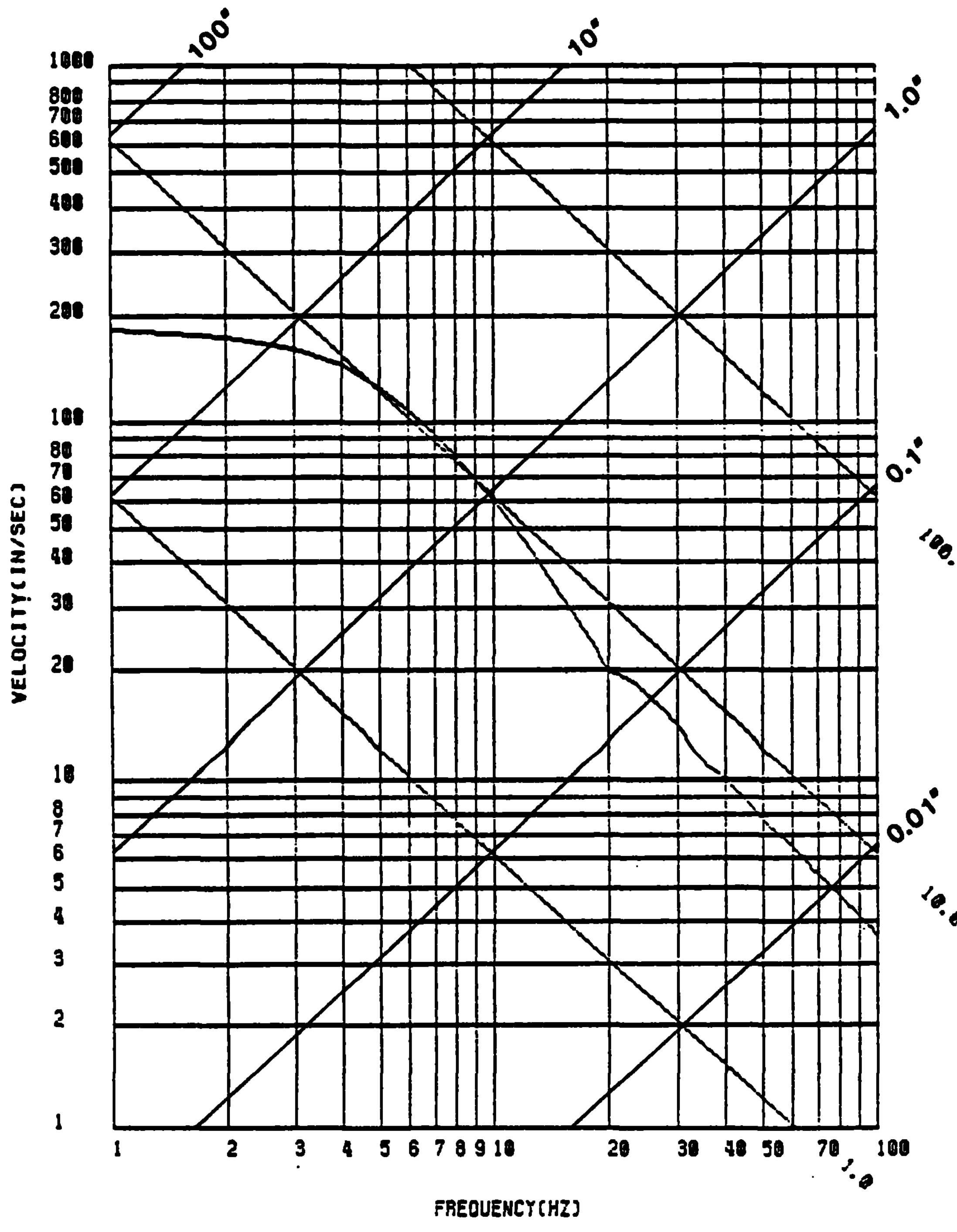


Figure 11. Shock Spectrum; 6g 4 Hz Half Sine Pulse

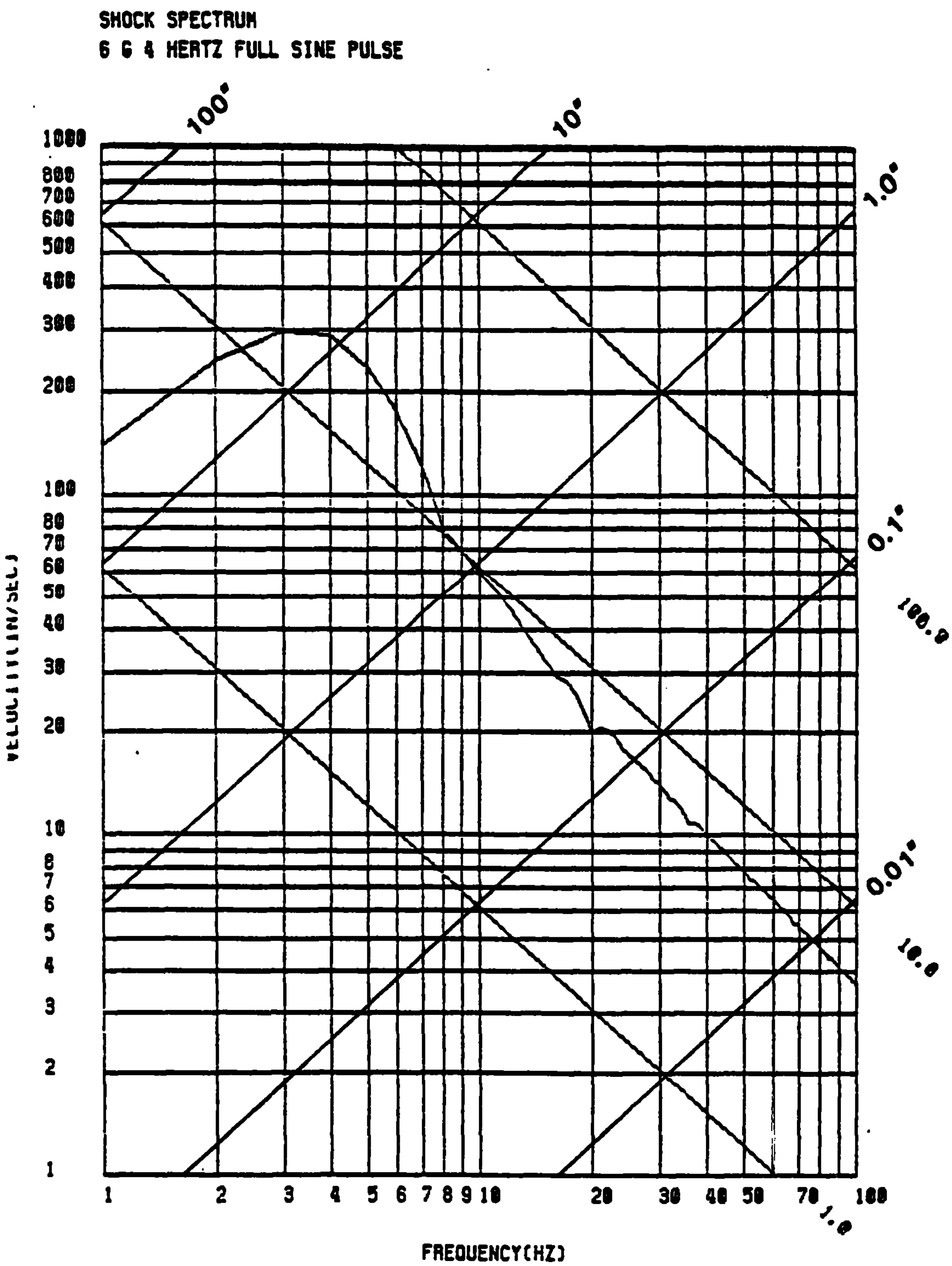


Figure 12. Shock Spectrum; 6g 4 Hz Full Sine Pulse

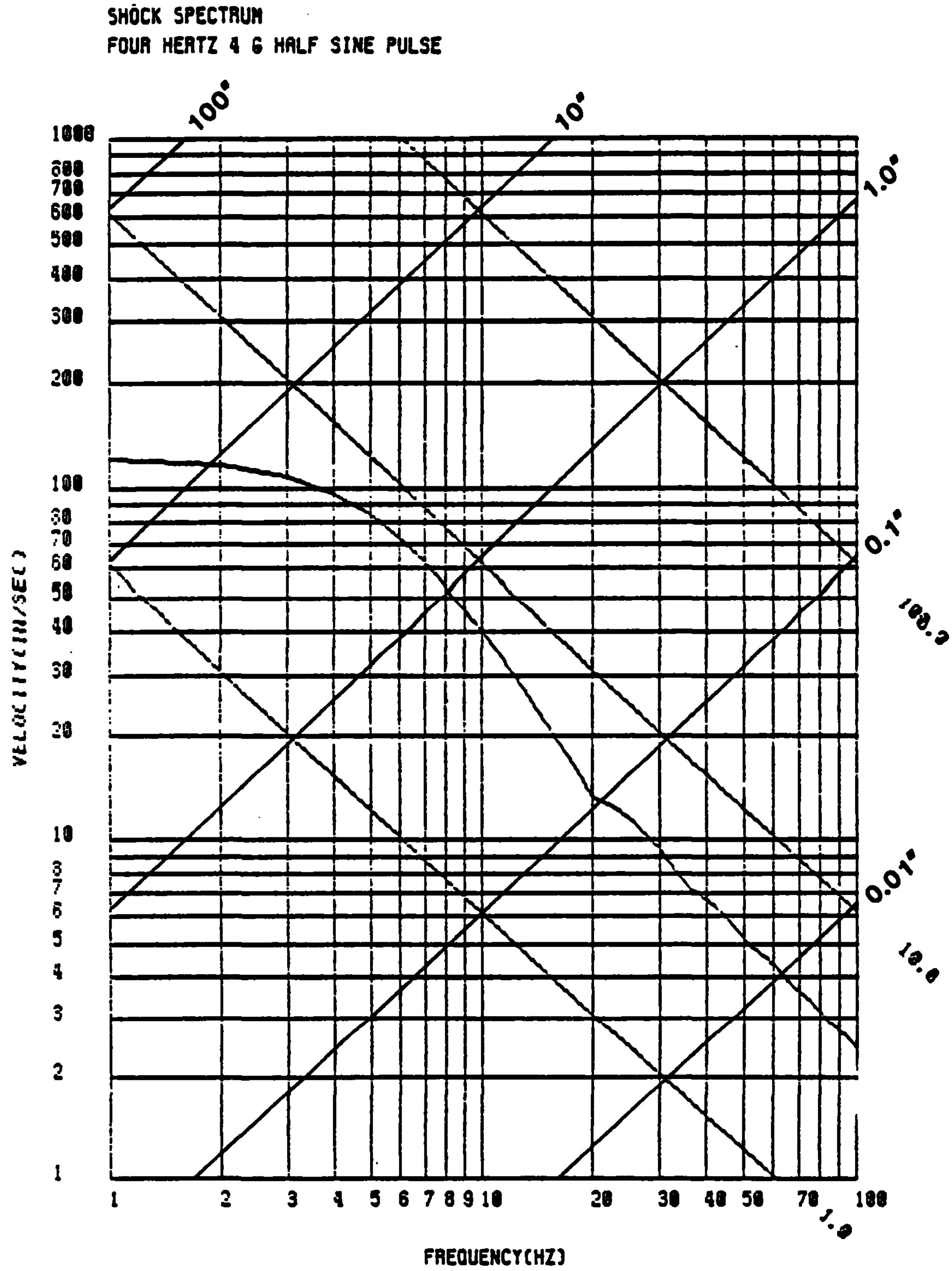


Figure 13. Shock Spectrum; 4g 4 Hz Half Sine Pulse

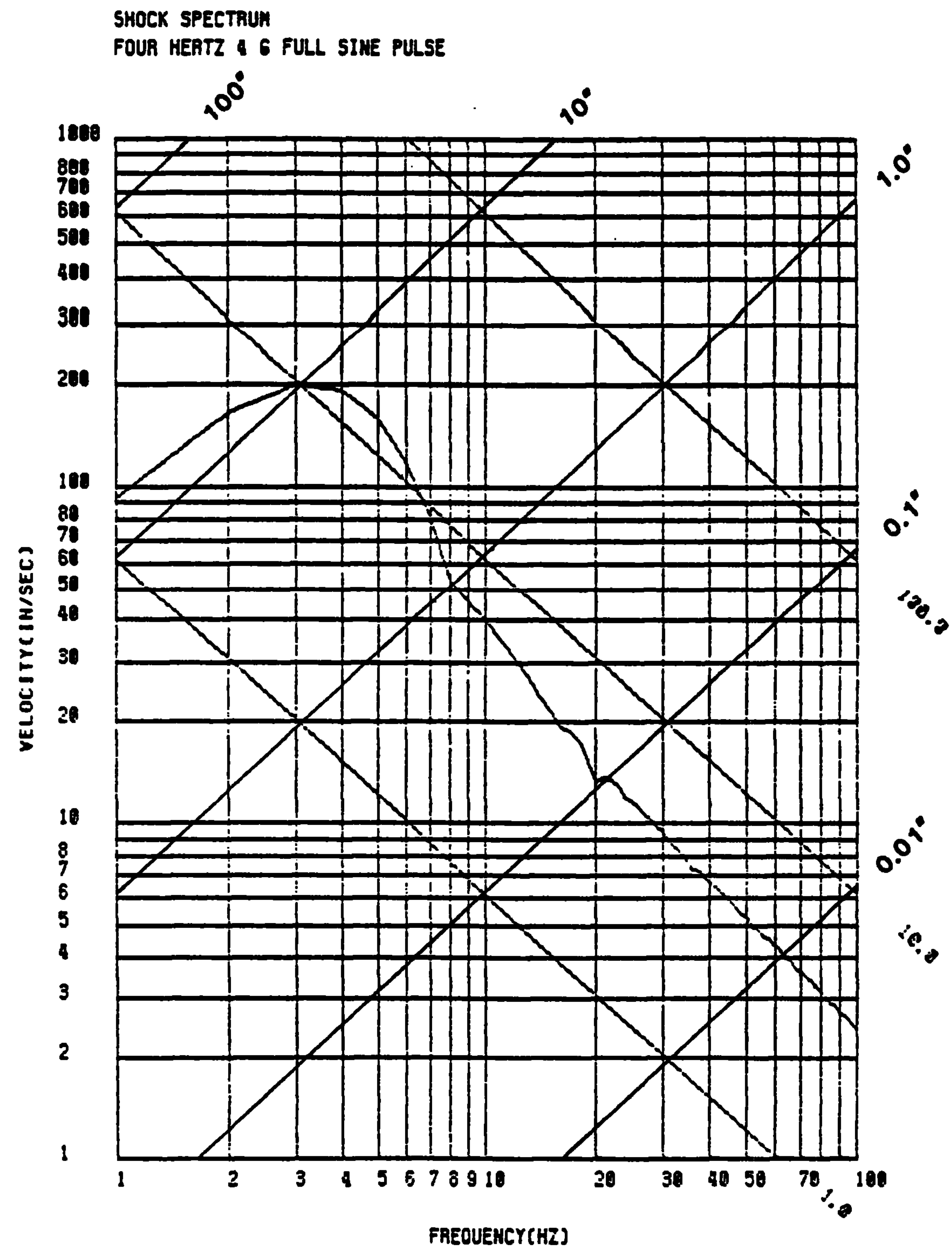


Figure 14. Shock Spectrum; 4g 4 Hz Full Sine Pulse

Table 1. Shock Spectra - 6g 4 Hz Half Sine Pulse

SHOCK SPECTRUM OUTPUT FREQUENCY, Hz	VELOCITY, FT/SEC	ACCELERATION, G
1.0	15.134	2.953
2.0	14.479	5.651
3.0	13.434	7.864
4.0	12.063	9.415
5.0	10.506	10.250
6.0	9.027	10.569
7.0	7.737	10.568
8.0	6.649	10.380
9.0	5.742	10.084
10.0	4.990	9.737
11.0	4.362	9.363
12.0	3.838	8.988
13.0	3.397	8.617
14.0	3.022	8.257
15.0	2.705	7.918
16.0	2.433	7.595
17.0	2.198	7.290
18.0	1.993	7.001
19.0	1.816	6.732
20.0	1.660	6.478
21.0	1.632	6.689
22.0	1.592	6.834
23.0	1.546	6.937
24.0	1.494	6.997
25.0	1.440	7.025
26.0	1.385	7.025
27.0	1.330	7.005
28.0	1.276	6.972
29.0	1.222	6.917
30.0	1.172	6.862
31.0	1.123	6.792
32.0	1.075	6.714
33.0	1.031	6.637
34.0	0.988	6.554
35.0	0.947	6.468
36.0	0.908	6.379
37.0	0.892	6.438
38.0	0.875	6.491
39.0	0.857	6.525
40.0	0.838	6.541
41.0	0.819	6.555
42.0	0.800	6.559
43.0	0.781	6.553
44.0	0.762	6.539
45.0	0.742	6.518

Table 1. Shock Spectra - 6g 4 Hz Half Sine Pulse (Continued)

SHOCK SPECTRUM OUTPUT

FREQUENCY, Hz	VELOCITY, FT/SEC	ACCELERATION, G
46.0	0.723	6.492
47.0	0.705	6.461
48.0	0.686	6.425
49.0	0.668	6.385
50.0	0.650	6.338
51.0	0.633	6.296
52.0	0.616	6.254
53.0	0.608	6.283
54.0	0.598	6.304
55.0	0.589	6.318
56.0	0.579	6.325
57.0	0.569	6.324
58.0	0.559	6.326
59.0	0.549	6.325
60.0	0.540	8.312
61.0	0.529	6.303
62.0	0.519	6.277
63.0	0.510	6.267
64.0	0.500	6.248
65.0	0.490	6.259
66.0	0.481	6.238
67.0	0.472	
68.0	0.462	6.129
69.0	0.457	6.178
70.0	0.451	6.201
71.0	0.445	6.197
72.0	0.439	6.166
73.0	0.433	6.174
74.0	0.427	6.166
75.0	0.421	6.157
76.0	0.415	6.137
77.0	0.409	6.138
78.0	0.403	6.131
79.0	0.397	6.118
80.0	0.390	5.094
81.0	0.385	6.100
82.0	0.378	6.097
83.0	0.373	6.068
84.0	0.367	6.010
85.0	0.364	6.050
86.0	0.359	6.063
87.0	0.355	6.044
88.0	0.351	6.033
89.0	0.347	6.023
90.0	0.343	6.029

Table 1. Shock Spectra - 6g 4 Hz Half Sine Pulse (Concluded)

SHOCK SPECTRUM OUTPUT

FREQUENCY, Hz	VELOCITY, FT/SEC	ACCELERATION, G
91.0	0.338	6.007
92.0	0.335	6.015
93.0	0.330	5.988
94.0	0.327	5.994
95.0	0.322	5.964
96.0	0.319	5.968
97.0	0.314	5.951
98.0	0.312	5.960
99.0	0.307	5.921
100.0	0.302	5.900

Table 2. Shock Spectra - 6g 4 Hz Full Sine Pulse

SHOCK SPECTRUM OUTPUT

FREQUENCY, Hz	VELOCITY, FT/SEC	ACCELERATION, G
1.0	11.583	2.260
2.0	20.477	7.991
3.0	24.822	14.331
4.0	24.125	18.830
5.0	19.744	19.263
6.0	14.606	17.101
7.0	10.132	13.840
8.0	6.649	10.330
9.0	5.742	10.094
10.0	4.990	9.737
11.0	4.362	9.363
12.0	3.838	8.988
13.0	3.397	9.617
14.0	3.022	8.257
15.0	2.705	7.918
16.0	2.433	7.595
17.0	2.353	7.807
18.0	2.169	7.617
19.0	1.927	7.145
20.0	1.660	6.478
21.0	1.716	7.031
22.0	1.691	7.260
23.0	1.611	7.229
24.0	1.494	6.997
25.0	1.440	7.025
26.0	1.385	7.025
27.0	1.330	7.005
28.0	1.276	6.972
29.0	1.222	6.917
30.0	1.172	6.862
31.0	1.123	6.792
32.0	1.075	6.714
33.0	1.053	6.781
34.0	1.015	6.735
35.0	0.965	6.593
36.0	0.908	6.379
37.0	0.909	6.560
38.0	0.895	6.636
39.0	0.871	6.631
40.0	0.838	6.541
41.0	0.819	6.555
42.0	0.800	6.559
43.0	0.781	6.553
44.0	0.762	6.539
45.0	0.742	6.518

Table 2. Shock Spectra - 6g 4 Hz Full Sine Pulse (Continued)

FREQUENCY, Hz	SHOCK SPECTRUM OUTPUT VELOCITY, FT/SEC	ACCELERATION, G
46.0	0.723	6.492
47.0	0.705	6.461
48.0	0.686	6.425
49.0	0.675	6.456
50.0	0.659	6.432
51.0	0.639	6.356
52.0	0.616	6.254
53.0	0.613	6.336
54.0	0.605	6.377
55.0	0.594	6.374
56.0	0.579	6.325
57.0	0.569	6.324
58.0	0.559	6.326
59.0	0.549	6.325
60.0	0.540	6.318
61.0	0.529	6.303
62.0	0.519	6.277
63.0	0.510	6.267
64.0	0.500	6.248
65.0	0.493	6.217
66.0	0.484	6.193
67.0	0.474	6.169
68.0	0.462	6.129
69.0	0.459	6.151
70.0	0.454	6.164
71.0	0.447	6.164
72.0	0.439	6.166
73.0	0.433	6.174
74.0	0.427	6.166
75.0	0.421	6.157
76.0	0.415	6.157
77.0	0.409	6.138
78.0	0.403	6.131
79.0	0.397	6.118
80.0	0.390	6.094
81.0	0.386	6.086
82.0	0.381	6.050
83.0	0.375	6.045
84.0	0.367	6.010
85.0	0.365	6.030
86.0	0.361	6.026
87.0	0.356	6.032
88.0	0.351	6.033
89.0	0.347	6.023
90.0	0.343	6.029

Table 2. Shock Spectra - 6g 4 Hz Full Sine Pulse (Concluded)

SHOCK SPECTRUM OUTPUT

FREQUENCY, Hz	VELOCITY, FT/SEC	ACCELERATION, G
91.0	0.338	6.007
92.0	0.335	6.015
93.0	0.330	5.988
94.0	0.327	5.994
95.0	0.322	5.964
96.0	0.319	5.968
97.0	0.314	5.951
98.0	0.312	5.960
99.0	0.307	5.921
100.0	0.302	5.900

Table 3. Shock Spectra - 4g 4 Hz Full Sine Pulse

FREQUENCY, Hz	SHOCK SPECTRUM OUTPUT VELOCITY, FT/SEC	ACCELERATION, G
1.0	7.722	1.507
2.0	13.651	5.327
3.0	16.548	9.687
4.0	16.083	12.553
5.0	13.163	12.842
6.0	9.738	11.401
7.0	6.755	9.227
8.0	4.433	6.920
9.0	3.828	6.723
10.0	3.327	6.491
11.0	2.908	6.242
12.0	2.559	5.992
13.0	2.265	5.745
14.0	2.015	5.505
15.0	1.804	5.279
16.0	1.622	5.063
17.0	1.569	5.205
18.0	1.446	5.078
19.0	1.285	4.763
20.0	1.107	4.319
21.0	1.144	4.687
22.0	1.127	4.840
23.0	1.074	4.820
24.0	0.996	4.665
25.0	0.960	4.683
26.0	0.923	4.683
27.0	0.886	4.670
28.0	0.851	4.648
29.0	0.815	4.611
30.0	0.782	4.575
31.0	0.749	4.528
32.0	0.717	4.476
33.0	0.702	4.521
34.0	0.677	4.490
35.0	0.644	4.395
36.0	0.605	4.253
37.0	0.606	4.373
38.0	0.597	4.424
39.0	0.581	4.421
40.0	0.559	4.361
41.0	0.546	4.370
42.0	0.534	4.373
43.0	0.521	4.369
44.0	0.508	4.359
45.0	0.495	4.345

Table 3. Shock Spectra - 4g 4 Hz Full Sine Pulse (Continued)

SHOCK SPECTRUM OUTPUT FREQUENCY, Hz	VELOCITY, FT/SEC	ACCELERATION, G
46.0	0.482	4.328
47.0	0.470	4.307
48.0	0.457	4.284
49.0	0.450	4.304
50.0	0.440	4.288
51.0	0.426	4.237
52.0	0.411	4.170
53.0	0.408	4.224
54.0	0.403	4.252
55.0	0.396	4.249
56.0	0.386	4.217
57.0	0.379	4.216
58.0	0.373	4.217
59.0	0.366	4.217
60.0	0.360	4.212
61.0	0.353	4.202
62.0	0.346	4.185
63.0	0.340	4.178
64.0	0.334	4.165
65.0	0.329	4.172
66.0	0.323	4.159
67.0	0.316	4.129
68.0	0.308	4.086
69.0	0.306	4.118
70.0	0.303	4.134
71.0	0.298	4.131
72.0	0.293	4.111
73.0	0.289	4.116
74.0	0.285	4.111
75.0	0.280	4.105
76.0	0.277	4.105
77.0	0.272	4.092
78.0	0.269	4.088
79.0	0.265	4.078
80.0	0.260	4.063
81.0	0.257	4.067
82.0	0.254	4.065
83.0	0.250	4.045
84.0	0.244	4.007
85.0	0.243	4.034
86.0	0.241	4.042
87.0	0.237	4.029
88.0	0.234	4.022
89.0	0.231	4.015
90.0	0.229	4.019

Table 3. Shock Spectra - 4g 4 Hz Full Sine Pulse (Concluded)

SHOCK SPECTRUM OUTPUT FREQUENCY, Hz	VELOCITY, FT/SEC	ACCELERATION, G
91.0	0.226	4.004
92.0	0.223	4.010
93.0	0.220	3.992
94.0	0.218	3.996
95.0	0.214	3.976
96.0	0.212	3.979
97.0	0.210	3.968
98.0	0.208	3.973
99.0	0.204	3.948
100.0	0.202	3.933

Table 4. Shock Spectra - 4g 4 Hz Half Sine Pulse

FREQUENCY, Hz	SHOCK SPECTRUM OUTPUT VELOCITY, FT/SEC	ACCELERATION, G
1.0	10.089	1.969
2.0	9.653	3.767
3.0	8.957	5.243
4.0	8.042	6.277
5.0	7.004	6.833
6.0	6.018	7.046
7.0	5.158	7.046
8.0	4.433	6.920
9.0	3.828	6.723
10.0	3.327	6.491
11.0	2.908	6.242
12.0	2.559	5.992
13.0	2.265	5.745
14.0	2.015	5.505
15.0	1.804	5.279
16.0	1.622	5.063
17.0	1.465	4.860
18.0	1.329	4.667
19.0	1.211	4.488
20.0	1.107	4.319
21.0	1.088	4.460
22.0	1.061	4.556
23.0	1.030	4.624
24.0	0.996	4.665
25.0	0.960	4.683
26.0	0.923	4.683
27.0	0.886	4.670
28.0	0.851	4.648
29.0	0.815	4.611
30.0	0.782	4.575
31.0	0.749	4.528
32.0	0.717	4.476
33.0	0.687	4.425
34.0	0.659	4.370
35.0	0.631	4.312
36.0	0.605	4.253
37.0	0.594	4.292
38.0	0.584	4.328
39.0	0.572	4.350
40.0	0.559	4.361
41.0	0.546	4.370
42.0	0.534	4.373
43.0	0.521	4.369
44.0	0.508	4.359
45.0	0.495	4.345

Table 4. Shock Spectra - 4g 4 Hz Half Sine Pulse (Continued)

SHOCK SPECTRUM OUTPUT

FREQUENCY, Hz	VELOCITY, FT/SEC	ACCELERATION, G
46.0	0.482	4.328
47.0	0.470	4.307
48.0	0.457	4.284
49.0	0.445	4.256
50.0	0.433	4.226
51.0	0.422	4.197
52.0	0.411	4.170
53.0	0.405	4.189
54.0	0.399	4.203
55.0	0.392	4.212
56.0	0.386	4.217
57.0	0.379	4.216
58.0	0.373	4.217
59.0	0.366	4.217
60.0	0.360	4.212
61.0	0.353	4.202
62.0	0.346	4.185
63.0	0.340	4.178
64.0	0.334	4.165
65.0	0.327	4.144
66.0	0.321	4.128
67.0	0.315	4.113
68.0	0.308	4.086
69.0	0.305	4.101
70.0	0.301	4.109
71.0	0.297	4.109
72.0	0.293	4.111
73.0	0.289	4.116
74.0	0.285	4.111
75.0	0.280	4.105
76.0	0.277	4.105
77.0	0.272	4.092
78.0	0.269	4.088
79.0	0.265	4.078
80.0	0.260	4.063
81.0	0.257	4.057
82.0	0.252	4.033
83.0	0.249	4.030
84.0	0.244	4.007
85.0	0.242	4.020
86.0	0.239	4.017
87.0	0.237	4.021
88.0	0.234	4.022
89.0	0.231	4.015
90.0	0.229	4.019

Table 4. Shock Spectra - 4g 4 Hz Half Sine Pulse (Concluded)

SHOCK SPECTRUM OUTPUT FREQUENCY, Hz	VELOCITY, FT/SEC	ACCELERATION, G
91.0	0.226	4.004
92.0	0.223	4.010
93.0	0.220	3.992
94.0	0.218	3.996
95.0	0.214	3.976
96.0	0.212	3.979
97.0	0.209	3.957
98.0	0.207	3.958
99.0	0.204	3.938
100.0	0.202	3.933

3.5 Shock Characteristics of System Components

Commercial components have not been designed for significant shock loads. However, most equipment has been designed to withstand shipping dynamic loads. The characteristics of three typical components were investigated to determine if these typical units could be expected to withstand the shock environment of the survey launch. It is understood that no decision concerning procurement has been made. The units studied are as follows:

(1) Textronix 4107 Computer Terminal
(2) Micropolis Corp. Disk Drive
(3) Kennedy Tape Drive

In all cases, vendors claimed to have conducted shock test for shipping loads. However, specific information concerning the type of shock pulse applied to the component could not be obtained.

Both the Textronix and Micropolis have been tested to 20 g. This acceleration may have been obtained from a drop with small displacements. Thus, low frequency modes in the equipment may not have been excited. Because of this concern, shock spectrum curves of high frequency half sine pulses were calculated at the request of NOAA. These response curves were developed for half sine pulses with frequencies of 4, 10, 25, and 50 Hz, with a 1 g magnitude (Figures 15 through 18). From these curves it can be seen that the shock loads to low frequency subcomponents of a component in the system even with a peak shock of 20 g can be much less than 6 g if the duration of the pulse is short.

It may be possible that commercial equipment will survive the environment of the launch without modification. However specific data on tests previously conducted is required before an engineering evaluation can be made.

3.6 Safety of Personnel

With regard to crew safety, the following recommendation is made:

Safety: In order to safeguard personnel from injury from adrift equipment, it is recommended that holddown devices (bolts, etc.) be designed for 15 g's in the vertical direction and 7.5 g's in the lateral direction. It is also recommended that personnel be protected from possible implosion of cathode ray tubes that could fail during shock loading.

4.0 CONCLUSIONS

(1) Shock motion of the launch from rough seas is characterized by large displacements (> 3 feet) and low frequency (2 Hz).

(2) Shock spectra of the measured launch motion peak about 6 g at 6 Hz and reduces to about 4 g at 20 Hz (Figure 7) for frame location 4.

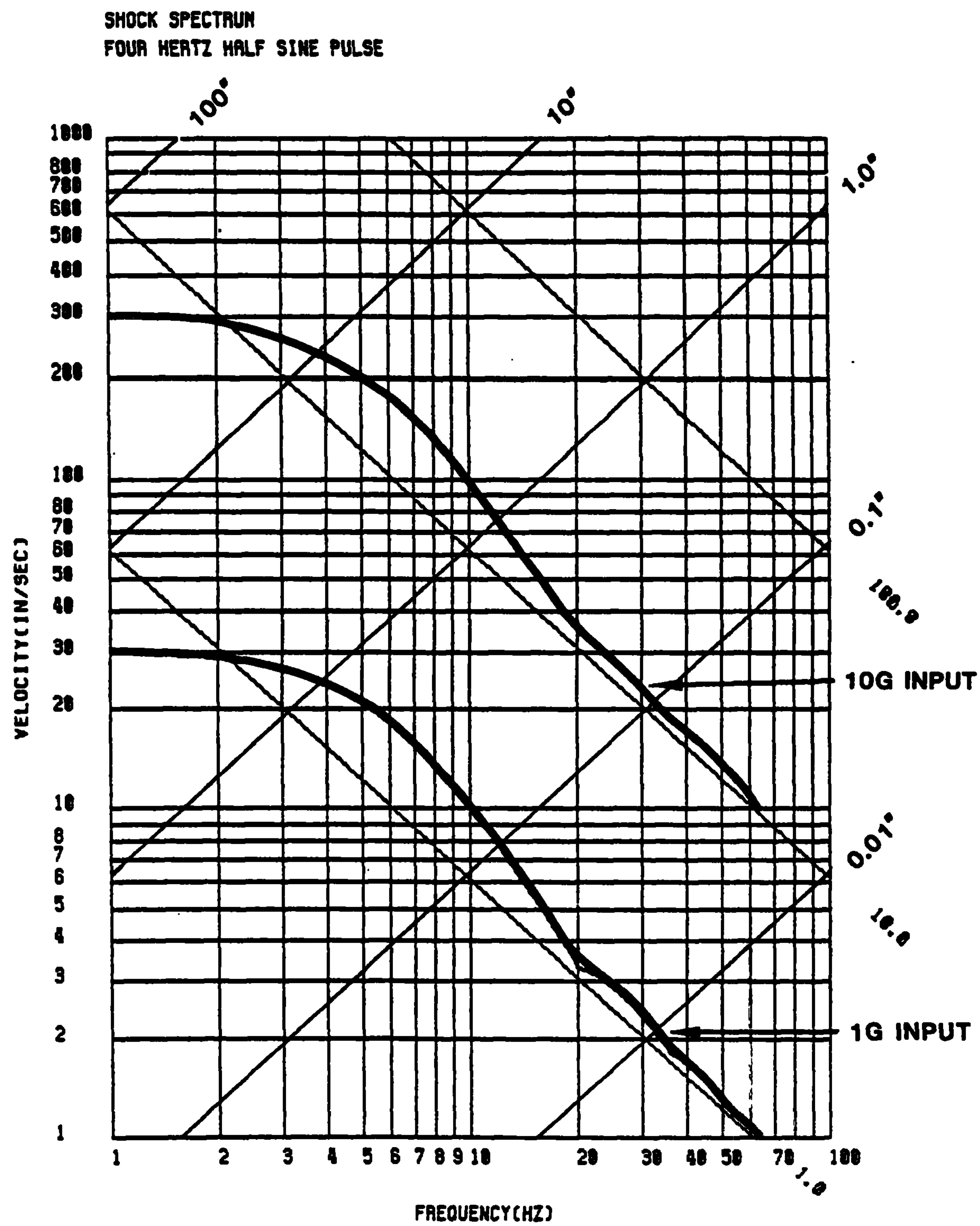


Figure 15. Shock Spectrum; 1g and 10g 4 Hz Half Sine Pulse

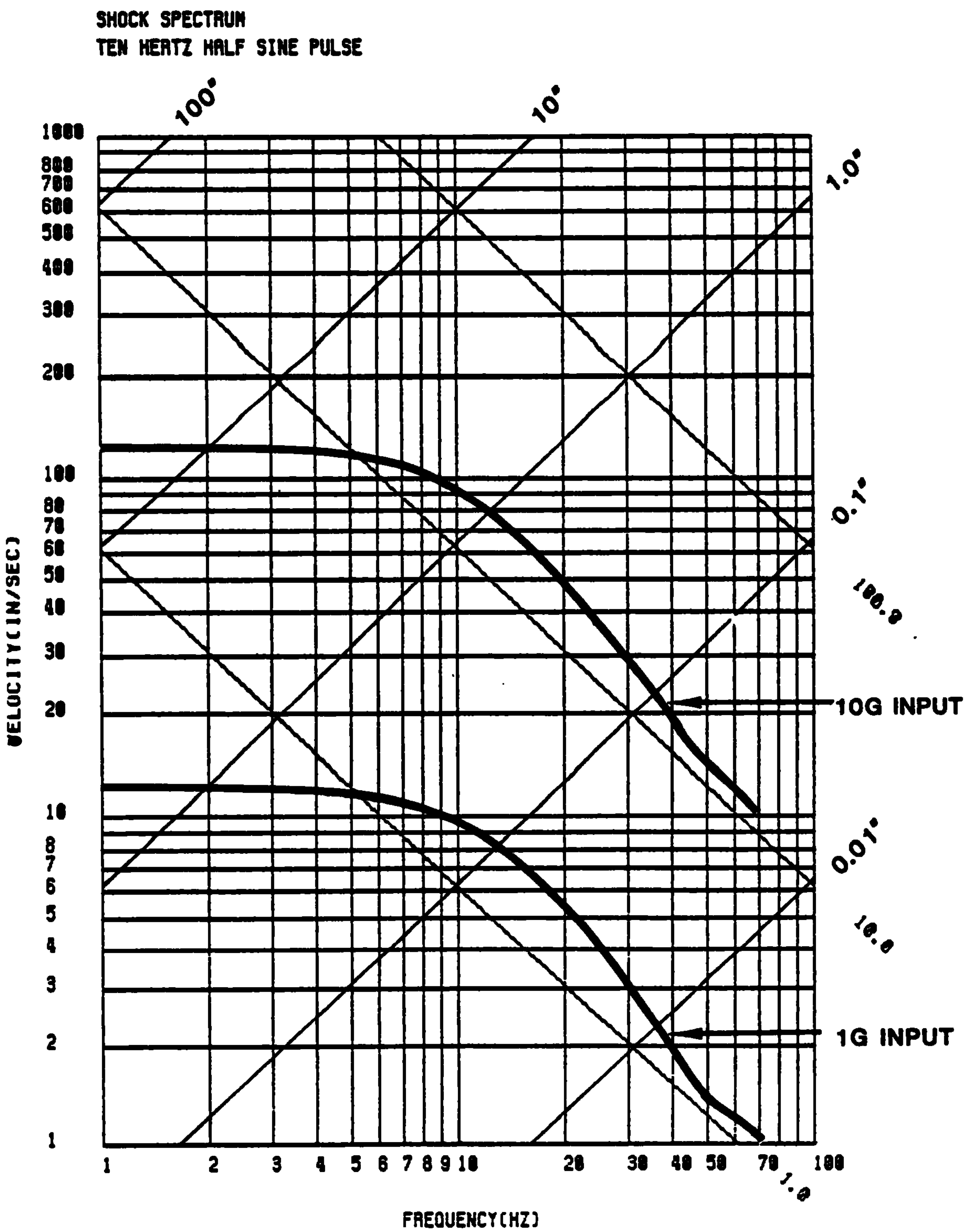


Figure 16. Shock Spectrum; 1g and 10g 10 Hz Half Sine Pulse

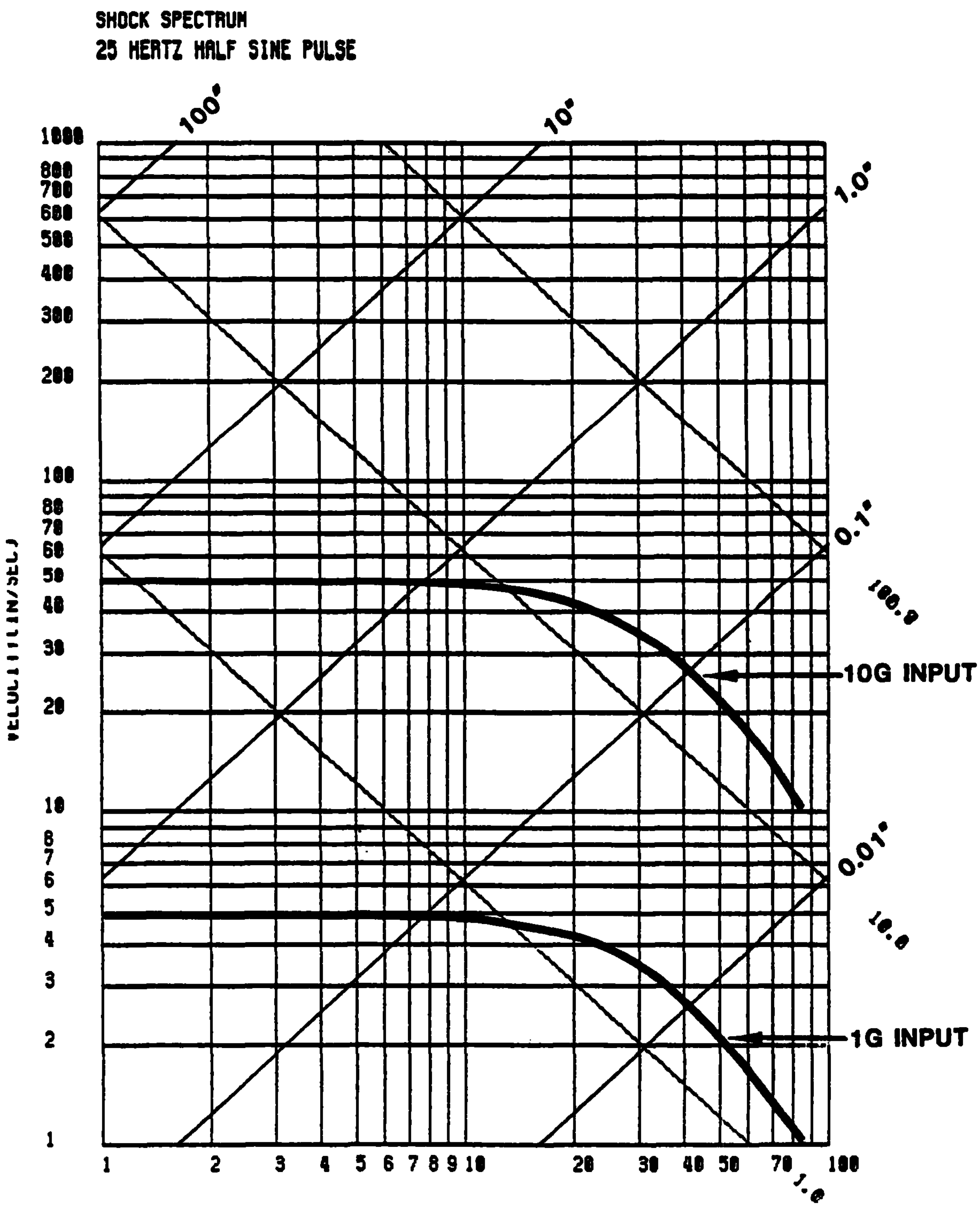


Figure 17. Shock Spectrum; 1g and 10g 25 Hz Half Sine Pulse

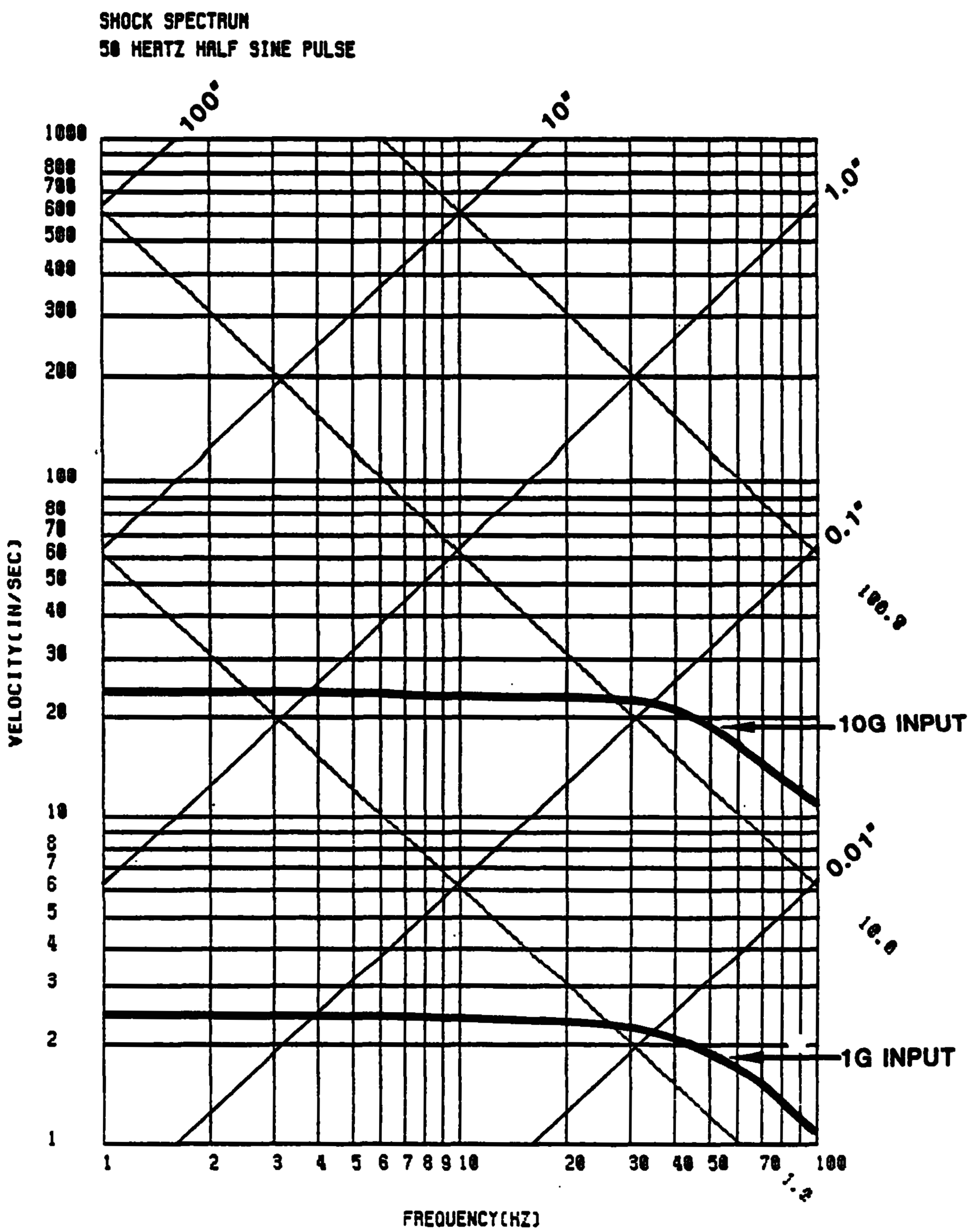


Figure 18. Shock Spectrum; 1g and 10g 50 Hz Half Sine Pulse

At frame location 2 these shock spectra peaks are about 8.5 g at 6 Hz and 6 g at 32 Hz (Figure 6).

(3) For design in the vertical direction, a 6 g shock response curve is recommended for frame location 4, and 8.5 g for frame location 2.

(4) Laboratory testing of system components using either a seismic tester or a drop tester is feasible.

(5) Sufficient information from potential vendors could not be obtained for a complete engineering evaluation; therefore, the laboratory testing is recommended.

(6) In order to safeguard personnel from injury from equipment that may come adrift from shock, a 15 g vertical and 7.5 g lateral design of holddown devices is recommended. Also protection from implosion of the cathode ray tube of the computer terminal is recommended.

5.0 REFERENCES

5.1 J.W. Lewis, "NOAA 29′ SURVEY LAUNCH - SHOCK AND ENVIRONMENTAL TEST," Naval System Combat Systems Engineering Station Report No. 60-132, Draft, August 1984.

5.2 "AEROFLEX ISOLATORS - CATALOG & SELECTION GUIDE," Aeroflex International Inc., Plainview, Long Island, N.Y. 11803.

5.3 "EARTHQUAKE TESTING - Long Stroke Seismic Simulator," Wyle Laboratories, Huntsville, Alabama 35807.

Appendix A

SHOCK SPECTRUM CURVES

In 1941, Biot (Reference A.1) defined what he called the earthquake spectrum. In doing so, he introduced the concept of what it is now called the response (or shock) spectrum. In 1949 Blake and Walsh (Reference A.2) applied the Biot concept and earthquake spectra to the mechanical shock problem, resulting in response quantity generally labeled the shock spectrum.

There are many ways of applying a shock spectrum in the literature. For example, Fung (Reference A.3) applies the shock spectrum in analysis used for considering the response of ICBMs in hardened silos. The definition used here is due to O'Hara (Reference A.4) because it is most suitable for ship shock problems.

The shock spectrum is a plot of the maximum absolute values of the relative displacements of a set of damped (in general) single-degree-of-freedom oscillators with negligible mass which have been subjected to a shock motion versus the natural frequencies of the oscillators. In some cases this plot may be constructed with scaling factors ω or $\omega^2/_0g$ (ω is the circular natural frequency, rad/sec) to give units of velocity or equivalent static acceleration, respectively. These shock spectra utilize relative response quantities since the stress and/or strain distribution in the system components naturally depends on relative displacements.

It should be made clear that the spectrum gives only the maximum response of the system of a complex input. Phase and time characteristics of the response are lost. Furthermore, it will be shown that the maximum response of a system is a function of only the natural frequency for a given input motion.

Naval shock design is based only on shock from a base motion transient, as induced by an underwater explosion. Airblast, on the other hand, loads the structure directly. Although spectrum concepts can be used for both types of load, only foundation transient inputs will be considered.

A.1 BASIC EQUATIONS

The equation of the shock spectrum can be developed in two ways (see Figure A.1). One may use absolute motions or, alternately, use the relative motion of the mass, m, with respect to the foundation. The most useful derivation is in terms of the relative motion,

$$x(t) = y(t) - Z(t), \qquad \text{(A.1)}$$

which will be used in this section.

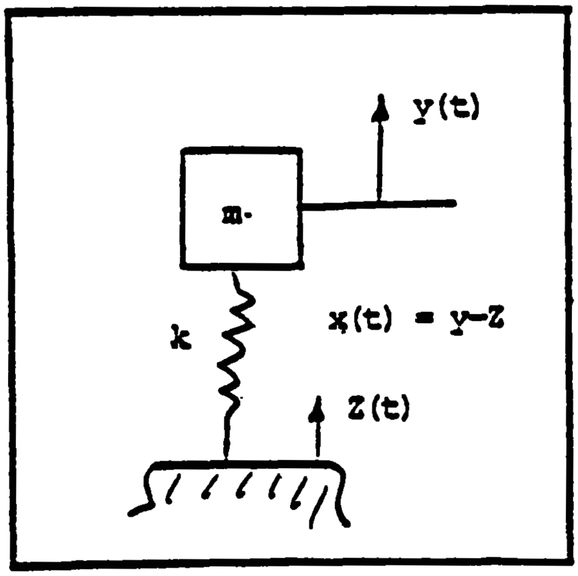


Figure A.1. Coordinate System

Damping to some degree is present in all structures. This damping is almost always approximated by assuming a linear viscous damping form. Even the linear case makes the equations more complex and difficult to follow. Therefore, damping will not be considered in the derivation. However, the basic equations with damping are included.

At time $t = 0$, assume that the system which is initially at rest is subjected to the foundation motion $Z(t)$. For this case, the equation of motion can be written,

$$m\ddot{y}(t) + k\left[y(t) - Z(t)\right] = 0 \tag{A.2}$$

with initial conditions

$$y(0) - \dot{y}(0) = 0 \tag{A.3}$$

Substituting equation (A.1), the equation of motion in terms of the relative displacement x is obtained.

$$m\ddot{x} + kx = - m\ddot{Z} \tag{A.4}$$

or since $\omega^2 = k/m$,

$$\ddot{x} + \omega^2 x = - \ddot{Z} \tag{A.5}$$

with initial conditions

$$x(0) = \dot{x}(0) = 0 \tag{A.6}$$

The solution to equation (A.5) is

$$x(t) = -\frac{1}{\omega} \int_0^t \ddot{Z}(\tau)\sin \omega(t - \tau)d\tau \tag{A.7}$$

The maximum relative motion D is found by obtaining the maximum value of the integral for all t.

The dynamic load on the system is

$$F = m\ddot{y} = kx \tag{A.8}$$

or

$$F = -\frac{k}{\omega} \int_0^t \ddot{Z}(\tau)\sin \omega(t - \tau)d\tau \tag{A.9}$$

This force can be related to the G-load as follows:

$$G = F/mg = -\frac{k}{mg\omega} \int_0^t \ddot{Z}(\tau)\sin \omega(t - \tau)d\tau \tag{A.10}$$

or

$$G = -\frac{\omega}{g} \int_0^t \ddot{Z}(\tau)\sin \omega(t - \tau)d\tau \tag{A.11}$$

For design, only the maximum dynamic load in the supporting member need be considered.

$$G(\omega) = \left[\frac{\omega}{g} \int_0^t \ddot{Z}(\tau)\sin \omega(t - \tau)d\tau\right]_{\substack{\text{maximum} \\ \text{overall } t}} \tag{A.12}$$

This spectrum integral, or Duhamel's integral, is a function of the system natural frequency, ω, only for a given foundation input. The maximum dynamic load acting on the system is obtained as follows.

$$F = G(\omega)W \tag{A.13}$$

where G is based on equation (A.12) and is a function of the system natural frequency ω.

A.2 INFLUENCE OF DAMPING

If linear viscous damping is considered, the equation of motion can be written, in terms of the relative motion, x, as

$$m\ddot{x} + c\dot{x} + kx = -m\ddot{Z} \tag{A.14}$$

Dividing by m, Equation A.14 becomes

$$\ddot{x} + 2\omega\zeta\dot{x} + \omega^2 x = -\ddot{Z} \tag{A.15}$$

where

$$\zeta = \frac{c}{2\omega m} = \frac{c}{c_c} \tag{A.16}$$

and

$$\omega = \sqrt{\frac{k}{m}} \tag{A.17}$$

The solution to Equation A.15 is

$$x = -\frac{1}{\omega\sqrt{1-\zeta^2}} \int_0^t \ddot{Z}(\tau)e^{-\zeta\omega(t-\tau)} \sin\left[\omega\sqrt{1-\zeta^2}(t-\tau)\right] d\tau_{\;max} \tag{A.18}$$

The spectrum displacement is

$$D = \frac{1}{\omega\sqrt{1-\zeta^2}} \int_0^t \ddot{Z}(\tau)e^{-\zeta\omega(t-\tau)} \sin\left[\omega\sqrt{1-\zeta^2}(t-\tau)\right] d\tau_{\;\text{max on } t} \tag{A.19}$$

If $\zeta \rightarrow o$, Equation A.18 reduces to Equation A.12.

Often, the response spectrum is plotted as a function of the critical damping ration, ζ. In the earthquake response spectrum curves ζ is significant. For the shock spectrum, ζ is usually not significant because peak responses normally occur early in time. Thus damping does have a significant effect on the calculated shock spectrum.

A.3 INPUT AND OUTPUT UNITS

Units of the spectrum integral may be presented in terms of acceleration (Equation A.12), velocity or displacement. The mathematical relationships between units are simple and the physical significance of these output units, which is important, is more complex.

In addition to the output of the spectrum integral, the input is presented in terms of acceleration velocity or displacement. Integration by parts can be used to change these input motion units of the spectrum integral.

A.3.1 Output Units

The shock spectra can be converted from one unit to another through the natural frequency, ω . Assume that D is the maximum relative displacement between t-- mass of a single-degree-of-freedom system. Then

$$V = \omega D \tag{A.20}$$

$$A = \omega V = \omega^2 D \tag{A.21}$$

$$G = \frac{A}{g} = \frac{V\omega}{g} = \frac{\omega^2 D}{g} \tag{A.22}$$

The physical significance of each of these spectra is as follows.

D - Spectrum displacement -- is the maximum relative motion between the mass, m, and foundation. Shock forces can be found by multiplying D, times the spring stiffness, k.

V - Spectrum velocity -- can be considered as the initial velocity of a single-degree-of-freedom at rest for t < o, which yields the correct relative displacement.

A,G - Spectrum acceleration -- can be considered as the effective maximum acceleration of the mass, m. The dynamic force can be determined from GW.

These three spectrum units can be presented on one graph as shown on Figure 10.

A.4 REFERENCES

A.1 M.A. Biot, "A Mechanical Analyzer for the Prediction of Earthquake Stresses," Bulletin of the Seismological Society of America, April 1941.

A.2 R. Blake and J.P. Walsh, "The Equivalent Static Acceleration of Shock Moons," Proceedings of the Society for Experimental Stress Analysis, Vol. IV, No. 2, 1949.

A.3 Y. Fung, "Shock Loading and Response Spectra," Proceedings of the Colloquium on Shock and Structural Response, American Society of Mechanical Engineers, 1960.

A.4 G.J. O'Hara, "Shock Spectra and Design Shock Spectra," NRL Report 5386, November 1959.

Appendix B

CALCULATIONS

B.1 APPROXIMATE ANALYSIS OF BOW DISPLACEMENT

With reference to Figure 2.0, the maximum acceleration pulse measured in the bow of the 29 foot survey launch can be approximated using Figure B.1.

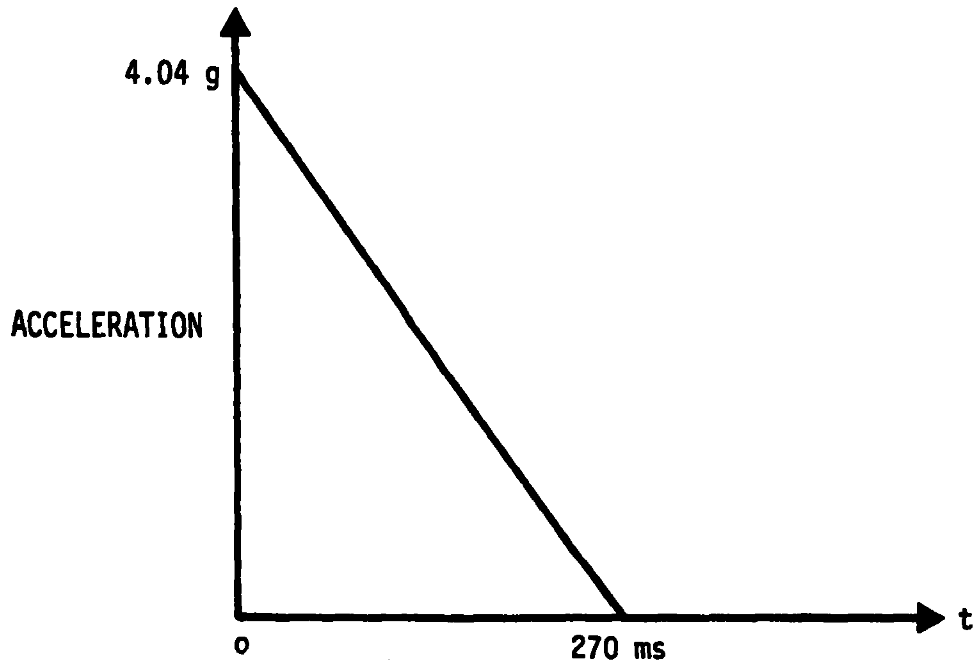


Figure B.1.

$$\ddot{Z} = 4.04g - 4.04g\,\frac{t}{270},\ g \qquad 0 \leq t \leq 270 \text{ ms}$$

$$\ddot{Z} = 0 \qquad t > 270 \text{ ms}$$

B.1.1 Velocity change

If t is in seconds.

$$\frac{dv}{dt} = 4.04\left(1 - \frac{t}{0.270}\right)(32.2),\ \text{ft/sec}^2$$

$$\Delta v = 4.04\left(t - \frac{t^2}{0.540}\right)(32.2) = 17.6 \text{ ft/sec @ 270 ms}$$

B.1.2 <u>Displacement</u>

$$\frac{ds}{dt} = 130.1\left(t - \frac{t^2}{.540}\right)$$

$$s = 130.1\left(\frac{t^2}{2} - \frac{t^3}{1.620}\right),\ t\ \text{sec.}$$

$$s = 3.161\ \text{ft.}$$

B.1.3 <u>Drop Height to obtain Δv</u>

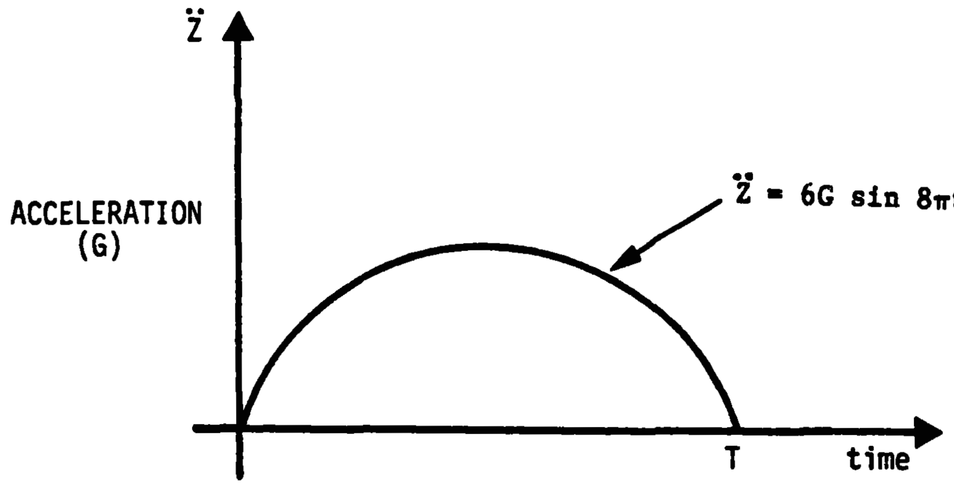
$$\Delta v = \sqrt{2gh}$$

$$h = \frac{\Delta v^2}{2g} = \frac{(17.6)^2}{(2)(32.2)} = 4.81\ \text{ft.}$$

which is close to the displacement of the bow during the pulse.

B.2 CHARACTERISTICS OF A HALF SINE PULSE

$f = 4$ Hz $\qquad A_{max} = 6G \qquad T = \frac{1}{2f} = \frac{1}{8} \qquad T = 125$ ms



Maximum Velocity Change

$$\frac{d\dot{z}}{dt} = \ddot{Z} = 6G \sin 8\pi t$$

$$\dot{z} = \int_o^t 6G \sin 8\pi t \, dt = -\frac{6G}{8\pi} \cos 8\pi t \Big|_o^t$$

$$\dot{z} = \frac{6G}{8}\left[1 - \cos 8\pi t\right]$$

$$\dot{z})_{max} = \frac{12G}{8\pi} = 15.36 \text{ ft/sec}$$

Displacement at T

$$z = \frac{6G}{8\pi}\left[t - \frac{1}{8\pi} \sin 8\pi t\right]_o^t$$

$$z)_{max} = \frac{6G}{64\pi} = .96 \text{ ft. @ .125 sec.}$$