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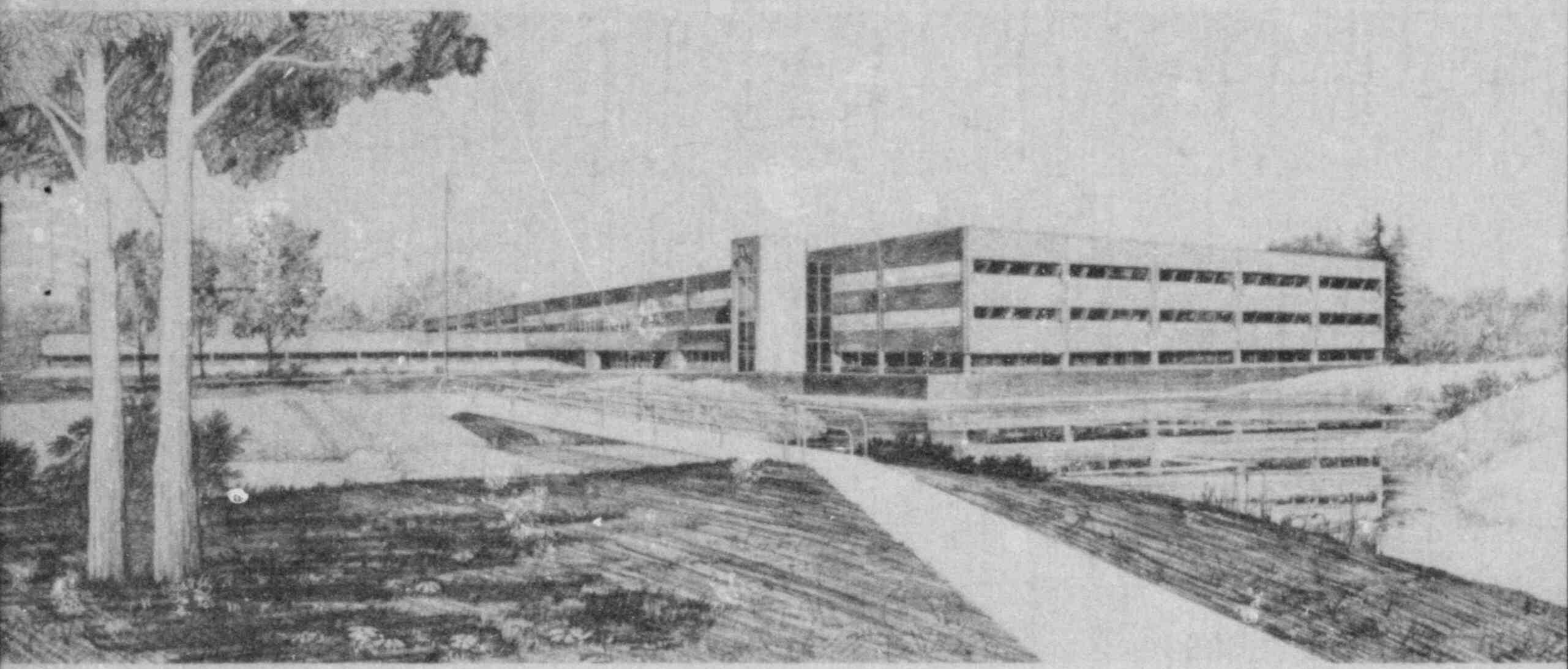

Idaho National Engineering Laboratory
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Tests to Determine How Support Type and Excitation Source Influence Pipe Damping

James G. Arendts
Arthur G. Ware

September 1984

Prepared for the
U.S. Nuclear Regulatory Commission
Under DOE Contract No. DE-AC07-76IDO1570

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FIN No. A6316

ABSTRACT

A series of vibration tests was performed on the second configuration of the NRC/EPRI/ANCO piping system at the ANCO Engineers test facility. Excitation was provided by a hydraulic shaker at three different locations/directions using both random and swept-sine-excitation methods. For random excitation, the frequency-response-function, complex-exponential-curve-fit method was used to compute damping values. For swept-sine tests, half-power-bandwidth techniques were used for damping determination. Damping for the lowest three modes was 1 to 3% of critical damping and decreased as frequency increased. A Rayleigh damping curve fit approximated the data well. We conclude as a result of these investigations that type of excitation (random versus swept sine) and type of support (rigid strut, mechanical snubber, hydraulic snubber, rigid strut with gap) has little influence on damping.

FIN No. A6316—Parameters Influencing Damping

SUMMARY

The United States Nuclear Regulatory Commission and the Electric Power Research Institute jointly sponsored construction of two laboratory piping systems at the ANCO Engineers facility in Culver City, California. EG&G Idaho, Inc. used the second of these systems to obtain piping system damping data using different supports and methods of excitation.

The 6-in. carbon steel piping system was approximately 50 ft long with two 3-in. branch lines. It was supported at five locations and excited using a single electrohydraulic shaker. Both random and swept-sine methods were used for excitation. A variable support attached near the shaker location allowed four different configurations to be tested: a rigid strut, a mechanical snubber, a hydraulic snubber, and a rigid strut with a gap.

Data were recorded for the lowest nine significant modes. Damping for the first three modes ranged from 1 to 3% of critical damping and decreased as frequency increased. The random excitation produced a slightly higher average overall damping than did the swept sine, but the effect did not appear significant. Changing the variable support also produced only a small change in the damping of the system. A metal fatigue break in one of the branch lines, which occurred during test cycling, gives the warning that although higher damping levels may be appropriate for calculating primary stress levels, lower-level operational transients with damping levels of only 1 to 3% can produce fatigue failures.

ACKNOWLEDGMENTS

We acknowledge our NRC Technical Monitor, John O'Brien, for his encouragement, financial support, and review of this report. Gary Thinnes assisted with equipment setup and initial testing. The ANCO staff provided piping excitation, recorded some of the data on the ANCO data acquisition system, and monitored excitation levels.

CONTENTS

TESTS TO DETERMINE HOW SUPPORT TYPE AND EXCITATION SOURCE INFLUENCE PIPE DAMPING

INTRODUCTION

The United States Nuclear Regulatory Commission (NRC) and the Electric Power Research Institute (EPRI) jointly sponsored a piping research project at the ANCO Engineers test facility in Culver City, California.[1,2] Two piping systems were constructed and vibration tested to determine system damping, to determine system safety margins, and to obtain a data base for benchmarking structural computer codes. A summary of the overall test plan and objectives, as well as preliminary results from the first piping configuration, have been reported in References 1 and 2.

As part of the NRC/EG&G Idaho pipe damping study program,[3] EG&G Idaho personnel collected, reduced, and analyzed data from the second piping configuration. This system consisted of a 6-in.-diameter line with two 3-in.-diameter branch lines. The system was vibrated with a hydraulic shaker, and data were collected and reduced using the EG&G GenRad modal analyzer. Additional data were collected for EG&G by ANCO on the ANCO data acquisition and computer system.

The objectives of the EG&G tests were to obtain damping data from the ANCO piping system when supported by a rigid strut, mechanical and hydraulic snubbers, and a rigid strut with a gap, using random and swept-sine methods for excitation. Further, the damping results computed using the frequency-response-function (FRF), complex-exponential-curve-fit and half-power-bandwidth methods can be used for comparison with results obtained using other damping calculational methods when those results become available.

TEST DESCRIPTION

This section describes the piping system, the matrix of tests conducted, the excitation, and the data collection and reduction methods. For a more complete description of the piping system, supports, and the ANCO instrumentation and data collection system, Reference 2 should be read.

Piping System

A schematic of the NRC/EPRI/ANCO piping system is shown in Figure 1. The piping was uninsulated SA-106 Grade B carbon steel, pressurized to 1150 psi. The main line was approximately 50 ft long and consisted of 6-in., Schedule 40 piping with 8-in., Schedule 40 piping at each end. The two 3-in., Schedule 40 branch lines, each approximately 20 ft long, were connected to the main lines by welded tee joints.

The system was supported by five sleds, labeled S1 through S5 in Figure 1. All sleds were locked in place for this test series to permit single-point excitation. Additional supports consisting of a rigid strut and a variable support were located at sled S2. The variable support was changed to permit four configurations: a rigid strut, a mechanical snubber, a hydraulic snubber, and a rigid strut with a gap. Details of these supports are listed in Reference 2.

The hydraulic-shaker excitation was applied in the Y direction at location 1 and in both X and Y directions at location 2. Response data (accelerations) used for calculating the results reported here were recorded at response locations 1 and 2 as shown on Figure 1.

Test Matrix

The original test matrix consisted of 24 tests, including both high- and low-level excitation, for each shaker location using random and swept-sine methods. The testing began using the mechanical snubber as the variable support with high-level, swept-sine excitation applied at location 1Y. During this testing, one of the 3-in. branch lines experienced a fatigue failure. The break was repaired and testing was continued at lower stress levels. Thus only 12 tests were carried out for each shaker location for the remainder of the testing.

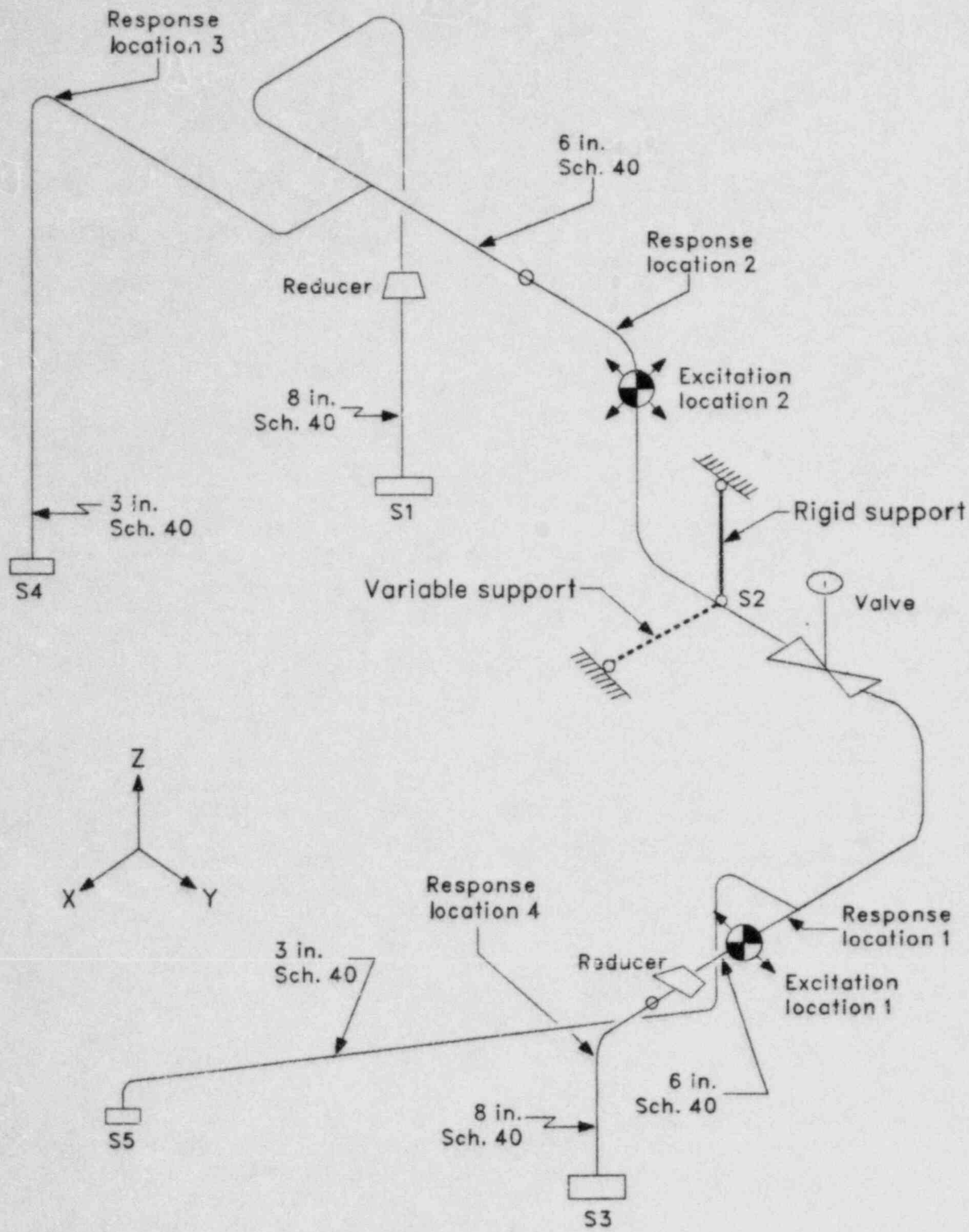


Figure 1. Piping system schematic diagram.

The test matrix, as actually carried out, is shown in Table 1. Three tests for each shaker location and variable support configuration were carried out—one random, a swept sine about the lowest four modes, and a swept sine about the higher five modes. Both high and low swept-sine excitation tests were carried out for the mechanical snubber configuration with shaker excitation 1Y. Tests 11 and 12 for the 1Y excitation location are therefore designated as 11(L), 11(H), 12(L), 12(H) to denote high and low excitation levels.

Table 1. Test matrix

Excitation Location	Test Number	Excitation Type	Variable Support	Excitation Level: High	Excitation Level: Low
1Y	3	Random	Rigid strut		X
	5	Swept sine	Rigid strut		X
	6	Swept sine	Rigid strut		X
	9	Random	Mechanical snubber		X
	11	Swept sine	Mechanical snubber	X	X
	12	Swept sine	Mechanical snubber	X	X
	15	Random	Hydraulic snubber		X
	17	Swept sine	Hydraulic snubber		X
	18	Swept sine	Hydraulic snubber		X
	21	Random	Rigid strut with gap		X
	23	Swept sine	Rigid strut with gap		X
	24	Swept sine	Rigid strut with gap		X
2X	3	Random	Rigid strut		X
	5	Swept sine	Rigid strut		X
	6	Swept sine	Rigid strut		X
	9	Random	Mechanical snubber		X
	11	Swept sine	Mechanical snubber		X
	12	Swept sine	Mechanical snubber		X
	15	Random	Hydraulic snubber		X
	17	Swept sine	Hydraulic snubber		X
	18	Swept sine	Hydraulic snubber		X
	21	Random	Rigid strut with gap		X
	23	Swept sine	Rigid strut with gap		X
	24	Swept sine	Rigid strut with gap		X
2Y	3	Random	Rigid strut		X
	5	Swept sine	Rigid strut		X
	6	Swept sine	Rigid strut		X
	9	Random	Mechanical snubber		X
	11	Swept sine	Mechanical snubber		X
	12	Swept sine	Mechanical snubber		X
	15	Random	Hydraulic snubber		X
	17	Swept sine	Hydraulic snubber		X
	18	Swept sine	Hydraulic snubber		X
	21	Random	Rigid strut with gap		X
	23	Swept sine	Rigid strut with gap		X
	24	Swept sine	Rigid strut with gap		X

Excitation

Force excitation was applied to the system using a single electrohydraulic actuator. For excitation location 1, the actuator cylinder was rigidly fixed to ground. For location 2, the actuator was suspended from an overhead framework, the excitation force being developed by reaction of the actuator mass and an additional mass attached to the base of the actuator. In both cases, excitation force was transmitted to the piping via the actuator piston, double universal joint link, load cell, and pipe clamp.

For random excitation, constant-input power spectra were desired. However, recorded input spectra indicate significant power drops for frequency bands spanning the major structural resonances. Significant input power roll-off was noted for frequencies greater than approximately 30 Hz.

For swept-sine excitation, a constant-amplitude, sine-actuator-displacement signal was slowly swept through two frequency ranges: 5 to 12 Hz and 14 to 22 Hz. The sweep rate for both ranges was approximately 1 Hz/min.

Recorded Data

For random-excitation tests, a total of 14 output transducers and one input force load cell were monitored; FRFs were determined and stored on magnetic disk for each output transducer. In addition, representative time-domain samples were obtained and stored on magnetic tape. The output transducers consisted of nine accelerometers [three sets of three (X, Y, Z)] at response locations 1, 2, and 3, two displacement transducers (X, Y) near response location 2, and three strain gauges (axial piping strain) at response location 4. For the damping results reported here, only the four accelerometer FRFs determined for response locations 1Y and 2 (X, Y, Z) were used.

For swept-sine tests, the three accelerometers at response location 2 and the input force transducer were monitored. Thus, three FRFs were obtained and stored on magnetic disk for each swept-sine test.

Data Reduction

For FRFs derived from random excitation, the curve-fit method (complex exponential) was used to derive resonant frequency and damping values for major modes in the frequency range 5 to 22 Hz because resolution of the base-band FRFs (0.10 Hz) was not great enough to use half-power bandwidth methods. In the case of swept-sine-derived FRFs, resolution was significantly greater (0.03 Hz), which enabled use of the half-power bandwidth method.

Response Level

Preliminary computer model simulation of the tests indicated that maximum response stresses for the main piping run would occur at response location 4. Thus, strain gauges in place at this location were monitored during subsequent tests.

The initial high-level, swept-sine-test excitation was scaled such that maximum stress intensity approximately equaled 36,000 psi. However, this excitation level resulted in branch line (S4) stresses significantly greater than yield, which soon resulted in fatigue failure of an elbow in this branch line. After repair of the elbow, excitation magnitude for all tests was reduced so that yielding in the branch line was avoided. This restriction limited maximum stresses in the main piping run to be approximately equal to 18,000 psi for all tests after the failure. Measured yield strength was 43,200 psia or above in all sections of the 6-in. piping.[2]

TEST RESULTS

Natural frequencies for the lowest nine significant modes are listed in Table 2. The frequencies for these modes range from 6.2 Hz to 21.5 Hz.

Damping values for each of these modes are listed in Tables 3, 4, and 5 for shaker locations 1Y, 2X, and 2Y, respectively. The values reported are the averages of the X, Y, and Z direction responses of the accelerometer readings. From evaluation of the damping data in the X, Y, and Z directions, there was no indication that the damping could be considered dependent on response direction. The effects of several parameters were evaluated using these tables as reported below.

Table 2. Natural frequencies for lowest nine significant modes

Mode	Frequency (Hz)
1	6.2
2	6.5
3	8.0
4	11.0
5	14.7
6	15.0
7	16.0
8	20.6
9	21.5

Frequency Effect

Plots of damping versus frequency are shown for each test case in Figures 2, 3, and 4. In the majority of the tests, there appears to be a definite relation that damping decreases as frequency increases. The first three modes are generally in the 1 to 2 % of critical damping range, the fourth through eighth modes are mainly in the 0.7 to 1.0 % range, while the ninth mode's range is about 0.4 to 0.5 %. This frequency trend will be further demonstrated by the graphs in the following sections.

Excitation Direction Effect

The damping values for each mode were averaged and are listed in Table 6 as a function of excitation direction. The values are plotted in Figures 5a, b, and c, along with a Rayleigh least squares curve fit of the data. The equation of the Rayleigh fit is

$$\zeta = A/f + Bf$$

where

ζ = % of critical damping

f = frequency (Hz)

A, B = Rayleigh constants.

The curves for the three directions are compared in Figure 5d. There is virtually no difference in the 2X and 2Y data, while the 1Y data is slightly smaller in the lower modes, and greater in the higher modes.

Support Effect

The random-excitation damping values for each mode were averaged and are listed in Table 7 for each type of support. The values are plotted in Figure 6 along with a Rayleigh curve fit for each support type. Mode 6 for the mechanical snubber and rigid strut with gap, and Mode 8 for the mechanical snubber, are higher than the trend of the remainder of the data. However, these modes are not higher than the rest of the data for the swept-sine-excitation values listed in Table 8. For this case, Mode 5 of the lower excitation mechanical snubber data is higher than the trend (Figure 7). Curve fits are compared in Figures 8 and 9 for the random and swept-sine data, respectively. The curves for these supports are nearly identical. Thus it is concluded that no support effect can be discerned from these tests.

Excitation Method Effect

To compare the random versus swept-sine methods of excitation, the results for each excitation location and support were compared using Table 9. The averages, using only those modes for which both random and swept-sine results were available, were computed to form this table. In 11 of the 13 cases, the random results were greater than the swept-sine results. This is probably an indication that better frequency resolution was obtained with the swept-sine data. In all but three cases, the damping differed by less than 30%. Because the damping values themselves were very low, the differences in percentage of critical damping computed using the two methods were also low, generally less than 0.5% of critical damping. Averages obtained using the data in Tables 7 and 8 are listed in Table 10 and Rayleigh curve fits are shown in Figure 10.

Excitation Amplitude Effect

For excitation direction 1Y, the piping system was vibrated at a lower and a higher amplitude. For four out of five modes, the low-excitation damping was greater than that of the high-excitation damping (Table 3). However, from the curve fit in Figure 7b, the difference is not significant.

Table 3. Shaker excitation 1Y damping results

Test Number	Random (R) or Swept Sine (SS)	Support Type	Damping (% of critical) for Mode 1	2	3	4	5	6	7	8	9
3	R	Rigid strut	1.56	1.72	0.91	1.02	0.73	0.62	0.90	0.66	0.38
5-6	SS	Rigid strut	—	1.09	0.87	0.89	—	—	0.61	0.55	0.32
9	R	Mechanical snubber	1.57	1.27	0.97	0.92	1.03	—	1.04	0.82	0.37
11-12(L)[a]	SS	Mechanical snubber	1.09	0.86	1.04	—	1.69	—	0.55	0.99	0.57
11-12(H)[a]	SS	Mechanical	1.28	0.84	0.83	1.50	0.64	—	—	0.50	—
15	R	Hydraulic snubber	2.14	—	0.92	1.01	0.48	0.99	0.97	0.71	0.29
17-18	SS	Hydraulic snubber	1.56	—	—	—	—	—	—	0.74	—
21	R	Rigid strut with gap	—	1.07	1.13	1.04	1.11	1.37	0.96	1.28	0.68
23-24	SS	Rigid strut with gap	—	—	0.67	0.77	—	0.44	—	0.56	0.49

a. L = lower-level excitation, H = higher-level excitation.

Table 4. Shaker excitation 2X damping results

Test Number	Random (R) or Swept Sine (SS)	Support Type	Damping (% of critical) for Mode								
			1	2	3	4	5	6	7	8	9
3	R	Rigid strut	—	—	1.49	—	—	—	0.57	0.53	0.45
5-6	SS	Rigid strut	—	0.99	1.19	—	0.87	0.41	0.76	0.75	0.73
9	R	Mechanical snubber	—	1.60	2.89	—	—	—	0.68	1.37	0.38
11-12	SS	Mechanical snubber	—	—	0.80	0.51	1.39	0.88	1.05	0.53	0.34
15	R	Hydraulic snubber	1.08	2.06	1.74	—	1.03	—	0.58	0.62	0.67
17-18	SS	Hydraulic snubber	1.64	—	1.66	—	0.68	—	0.61	—	0.56
21	R	Rigid strut with gap	2.04	1.77	2.04	—	—	—	0.60	0.63	0.34
23-24	SS	Rigid strut with gap	1.15	1.17	—	0.89	0.57	—	0.71	0.72	0.48

Table 5. Shaker excitation 2Y damping results

Test Number	Random (R) or Swept Sine (SS)	Support Type	Damping (% of critical) for Mode								
			1	2	3	4	5	6	7	8	9
3	R	Rigid strut	1.80	—	1.19	1.31	1.10	0.71	0.85	0.75	0.36
5-6	SS	Rigid strut	—	1.38	1.69	0.92	0.57	—	1.08	0.58	—
9	R	Mechanical snubber	—	1.12	1.81	0.51	—	1.37	0.47	1.42	0.27
11-12	SS	Mechanical snubber	1.60	1.07	1.83	0.62	—	0.72	0.43	0.87	0.64
15	R	Hydraulic snubber	2.57	1.80	2.19	0.46	—	—	0.82	0.96	0.27
17-18	SS	Hydraulic snubber	1.52	1.00	0.99	—	—	0.64	0.76	0.81	—
21	R	Rigid strut with gap	0.99	1.15	0.89	0.58	1.03	—	0.75	0.71	0.29
23-24	SS	Rigid strut with gap	—	1.41	1.41	1.21	—	0.79	0.48	0.51	0.53

Table 6. Damping (% of critical) as a function of excitation direction

Mode	Excitation Direction 1Y	2X	2Y	Mode	Excitation Direction 1Y	2X	2Y
1	1.53	1.48	1.70	6	0.86	0.65	0.85
2	1.14	1.52	1.28	7	0.84	0.70	0.71
3	0.92	1.69	1.49	8	0.76	0.74	0.81
4	1.02	0.70	0.80	9	0.44	0.49	0.39
5	0.95	0.91	0.90				

Table 7. Comparison of damping (% of critical) for each support type (random excitation)

Mode	Rigid Strut	Mechanical Snubber	Hydraulic Snubber	Rigid Strut with Gap
1	1.68	1.57	1.93	1.23
2	1.72	1.33	1.93	1.42
3	1.20	1.89	1.49	1.53
4	1.16	0.72	0.74	1.13
5	0.92	0.73	0.66	1.07
6	0.67	1.37	0.99	1.37
7	0.77	0.73	0.79	0.77
8	0.65	1.20	0.76	0.87
9	0.40	0.34	0.41	0.44

Table 8. Comparison of damping (% of critical) for each support type (swept-sine excitation)

Mode	Rigid Strut	Mechanical Snubber[a] (L)	Mechanical Snubber[a] (H)	Hydraulic Snubber	Rigid Strut with Gap
1	—	1.35	1.44	1.57	1.15
2	1.15	0.97	0.96	1.00	1.29
3	1.25	1.22	1.15	1.33	1.04
4	0.91	0.57	0.88	—	0.96
5	0.72	1.54	1.02	0.68	0.57
6	0.41	0.80	0.80	0.64	0.62
7	0.82	0.68	0.74	0.69	0.60
8	0.63	0.80	0.63	0.78	0.60
9	0.53	0.52	0.49	0.56	0.50

a. L = lower-level excitation, H = higher-level excitation.

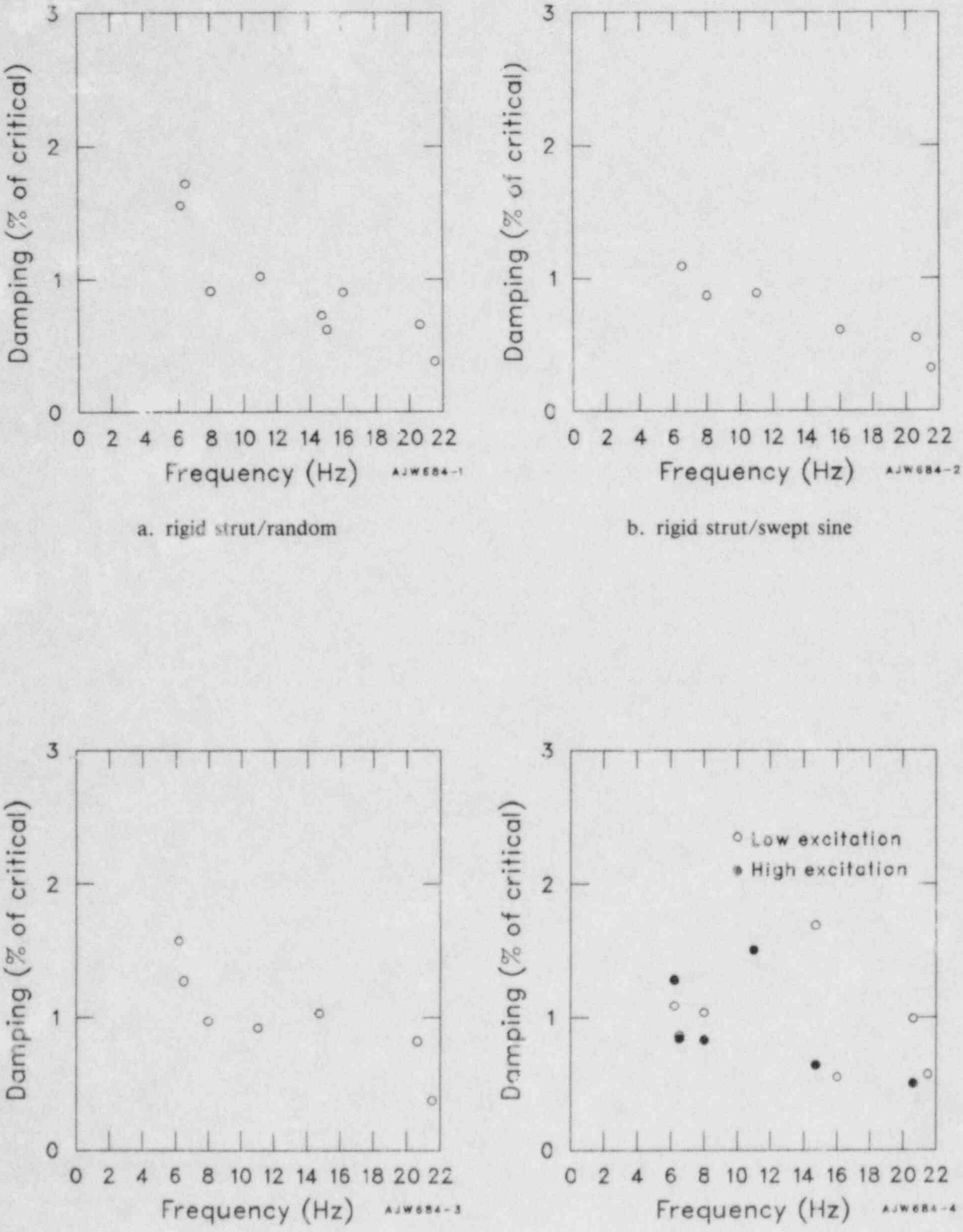
Table 9. Comparison of random versus swept-sine damping values

Excitation Location	Support	Damping (% of critical) Random (R)	Swept Sine (SS)	R/SS
1Y	Rigid strut	0.93	0.72	1.29
	Mechanical snubber (L)[a]	1.01	0.97	1.04
	Mechanical snubber (H)[a]	1.10	0.93	1.18
	Hydraulic snubber	1.43	1.15	1.24
	Rigid strut with gap	1.10	0.59	1.86
2X	Rigid strut	1.02	0.86	1.15
	Mechanical snubber	1.33	0.68	1.96
	Hydraulic snubber	1.03	1.12	0.92
	Rigid strut with gap	1.08	0.85	1.27
2Y	Rigid strut	1.04	0.97	1.07
	Mechanical snubber	1.00	0.88	1.13
	Hydraulic snubber	1.65	1.02	1.62
	Rigid strut with gap	0.71	0.92	0.77

a. L = lower-level excitation, H = higher-level excitation.

Table 10. Averages of random and swept-sine damping (% of critical) results

	Excitation Method			Excitation Method	
Mode	Random	Swept Sine	Mode	Random	Swept Sine
1	1.60	1.38	6	1.10	0.65
2	1.60	1.07	7	0.77	0.71
3	1.53	1.20	8	0.87	0.69
4	0.94	0.83	9	0.40	0.52
5	0.85	0.91			



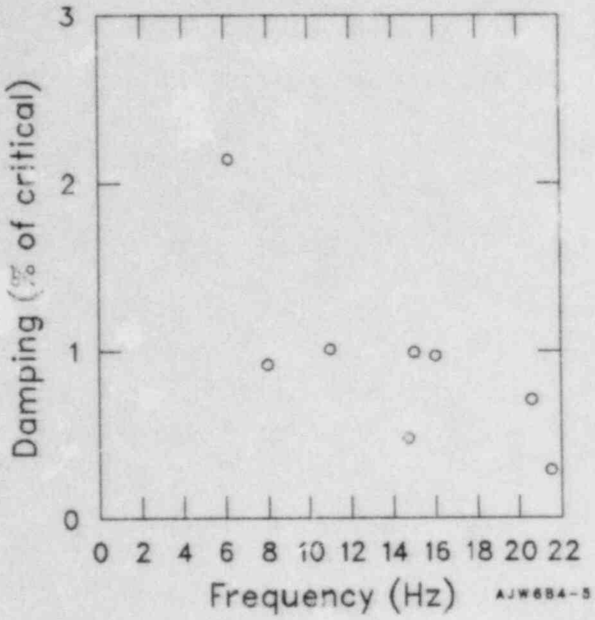
a. rigid strut/random

b. rigid strut/swept sine

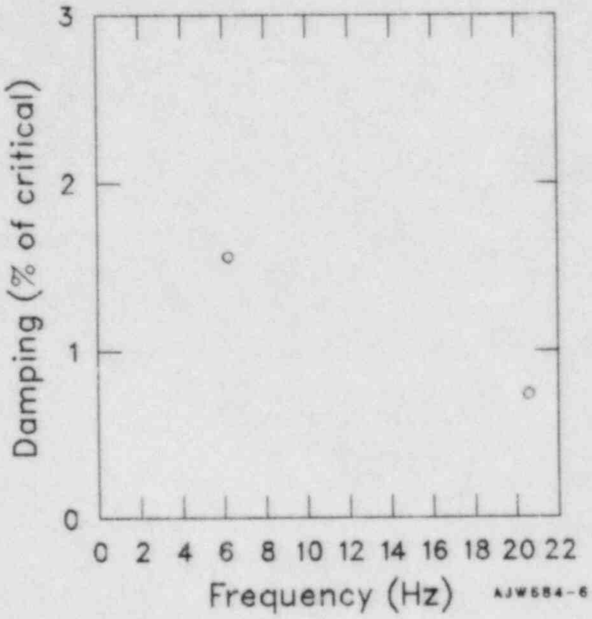
c. mechanical snubber/random

d. mechanical snubber/swept sine

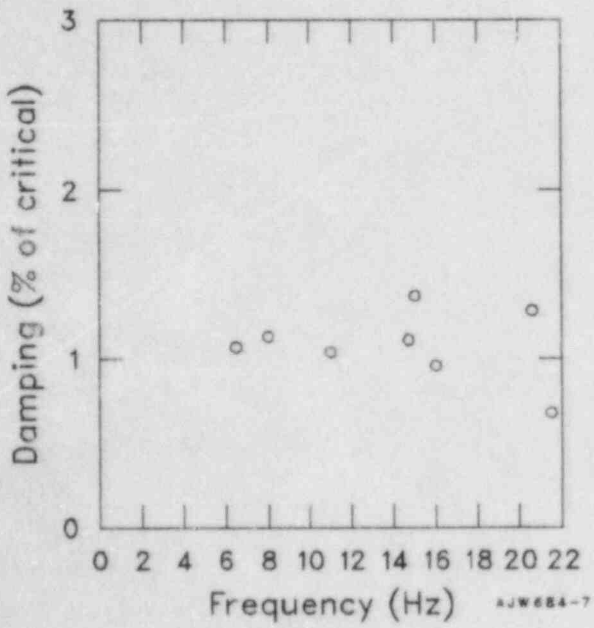
Figure 2. Shaker excitation location 1Y results.



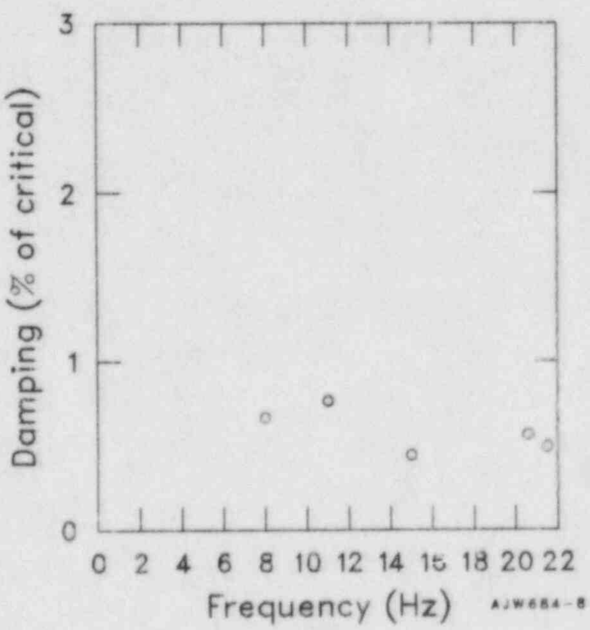
e. hydraulic snubber/random



f. hydraulic snubber/swept sine

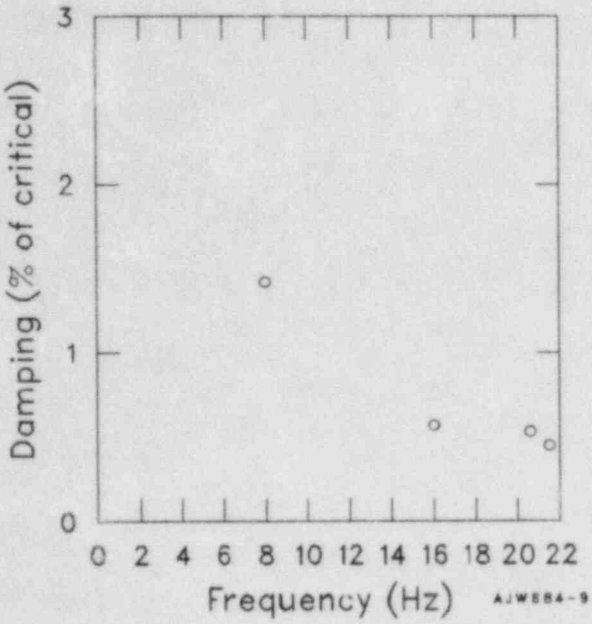


g. rigid strut with gap/random

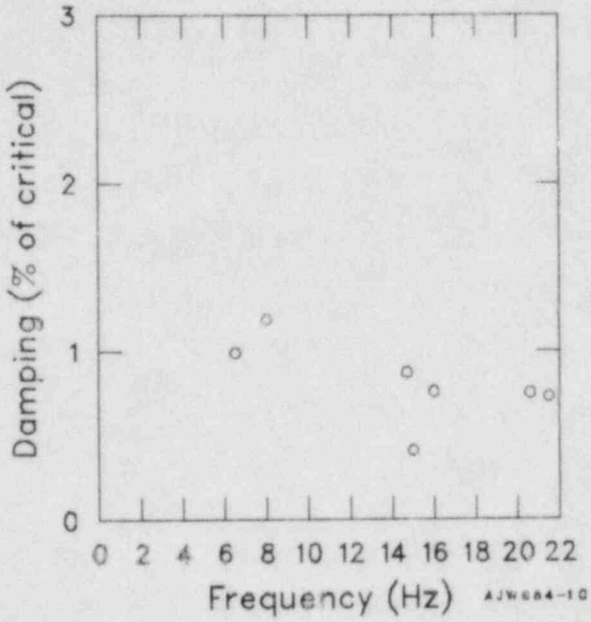


h. rigid strut with gap/swept sine

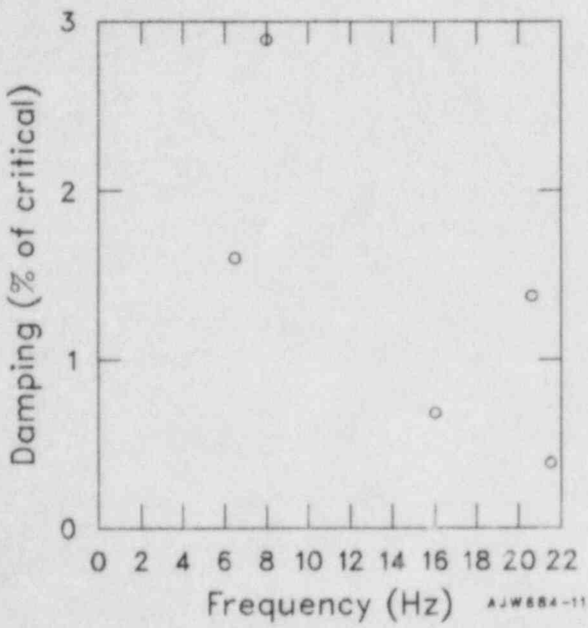
Figure 2. (continued).



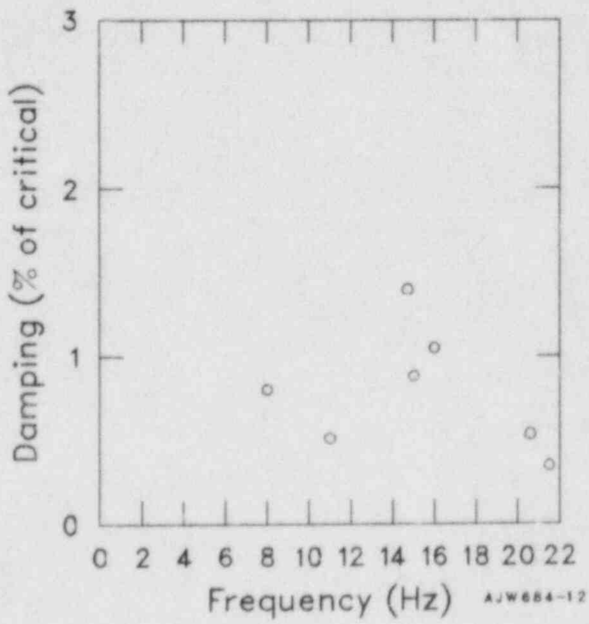
a. rigid strut/random



b. rigid strut/swept sine

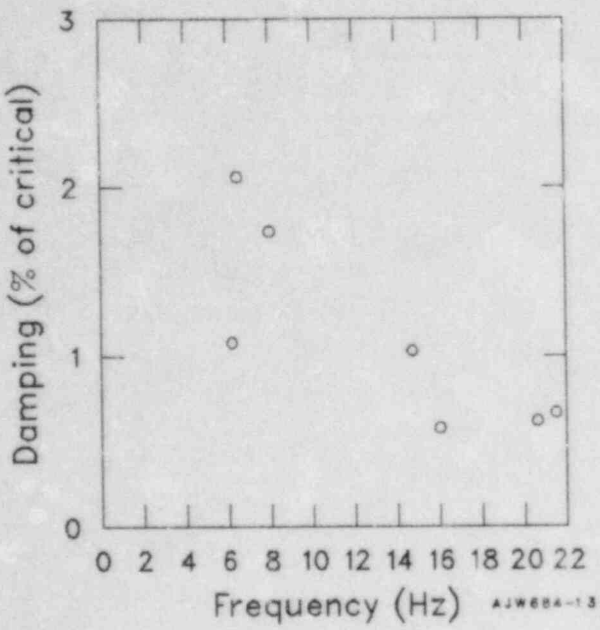


c. mechanical snubber/random

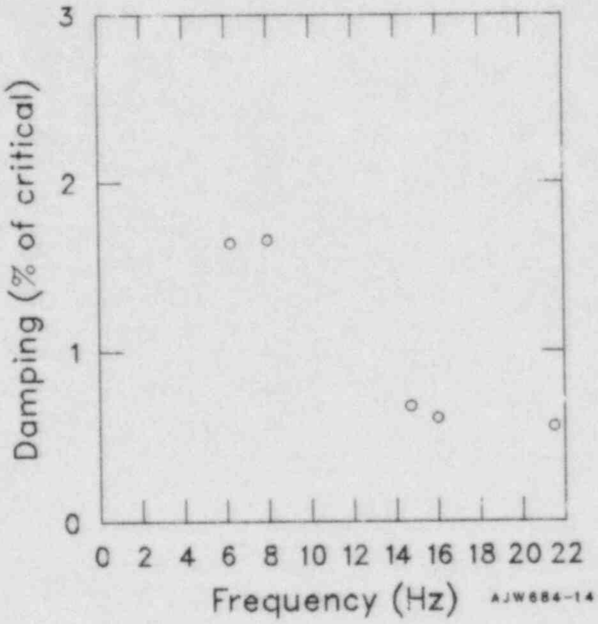


d. mechanical snubber/swept sine

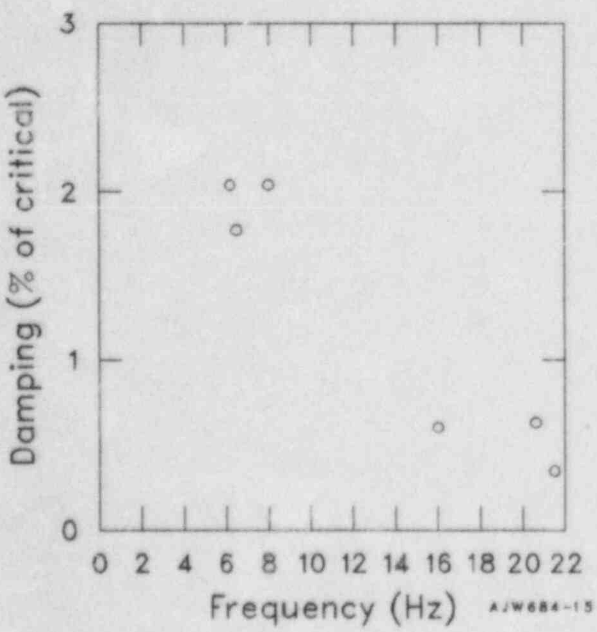
Figure 3. Shaker location 2X results.



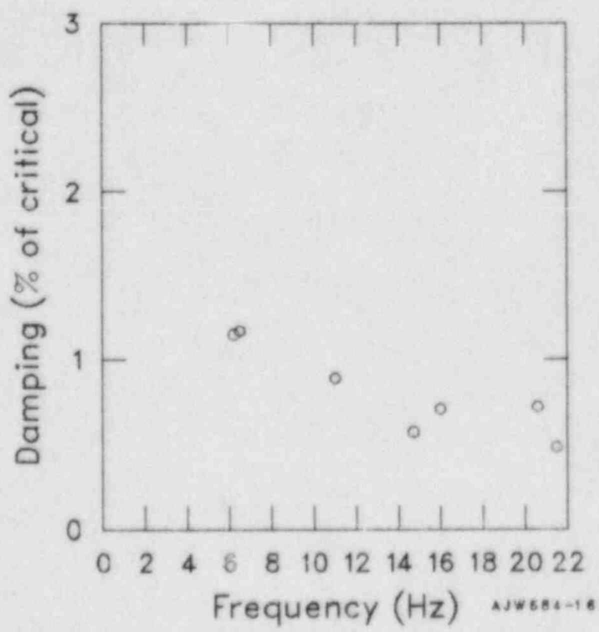
e. hydraulic snubber/random



f. hydraulic snubber/swept sine

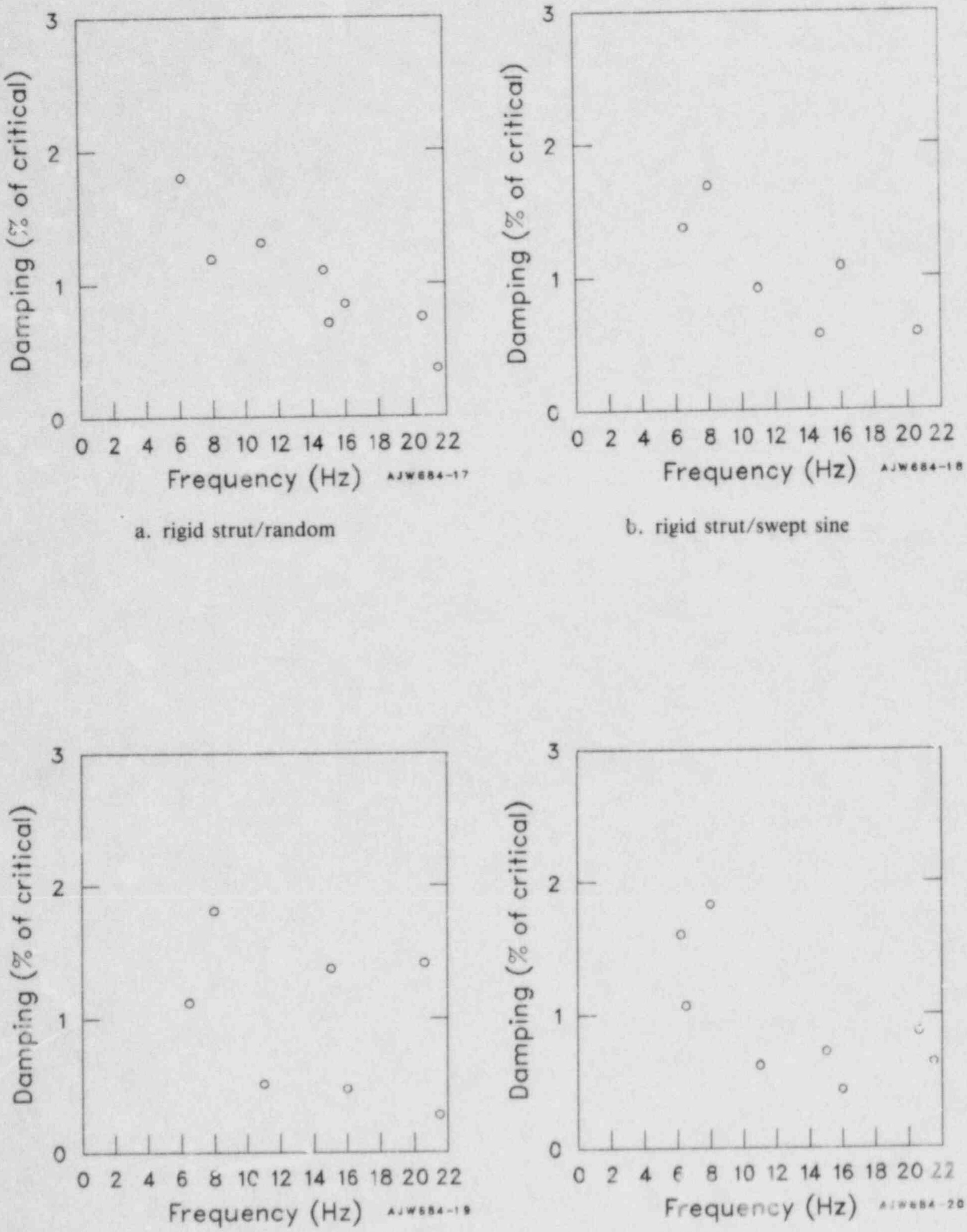


g. rigid strut with gap/random



h. rigid strut with gap/swept sine

Figure 3. (continued).



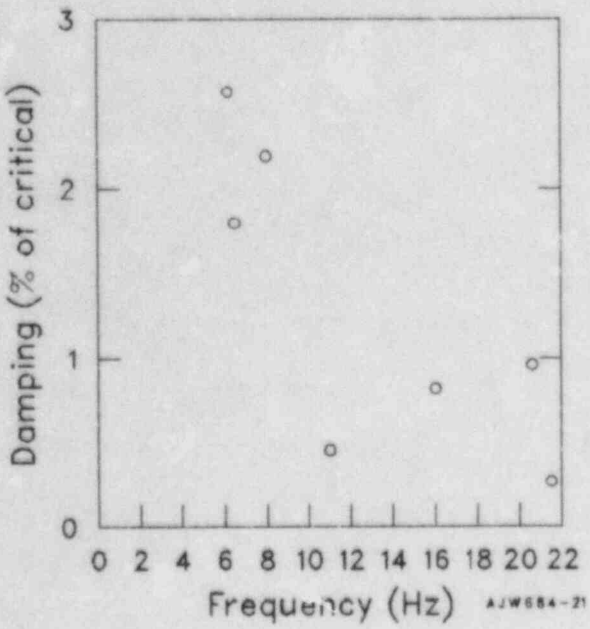
a. rigid strut/random

b. rigid strut/swept sine

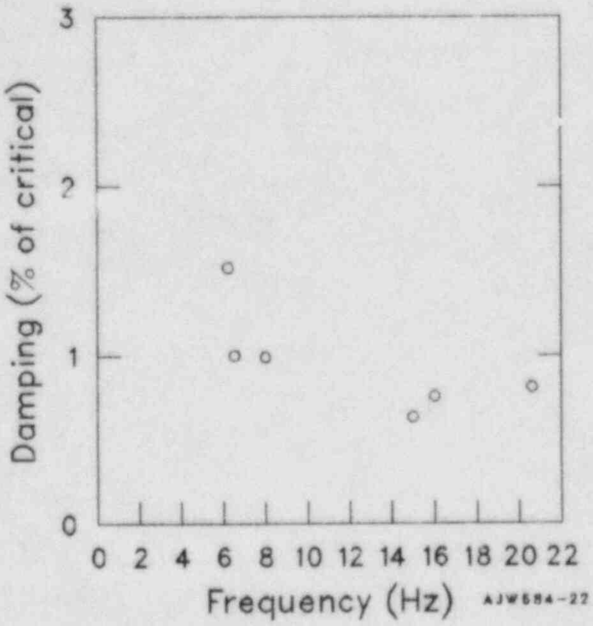
c. mechanical snubber/random

d. mechanical snubber/swept sine

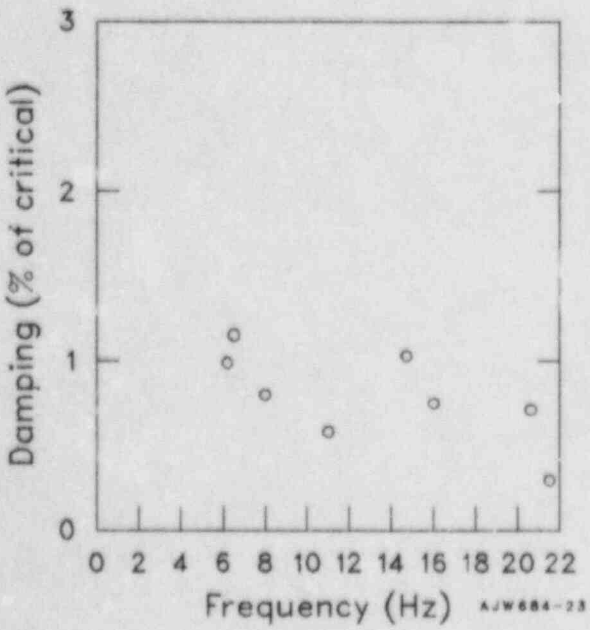
Figure 4. Shaker location 2Y results.



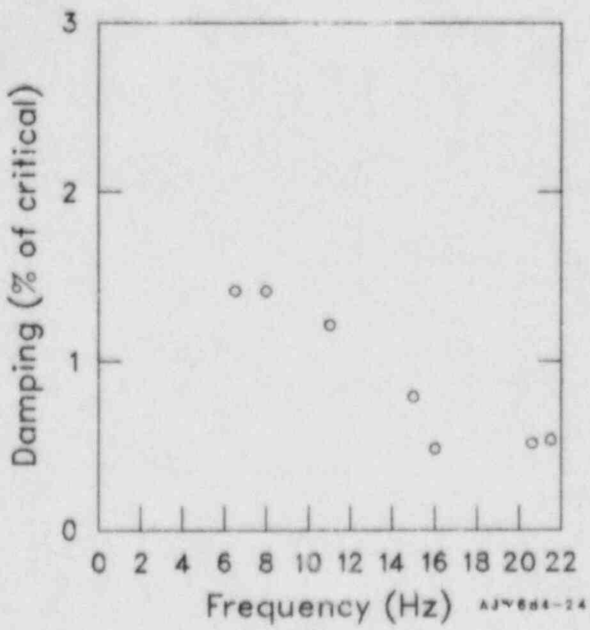
e. hydraulic snubber/random



f. hydraulic snubber/swept sine

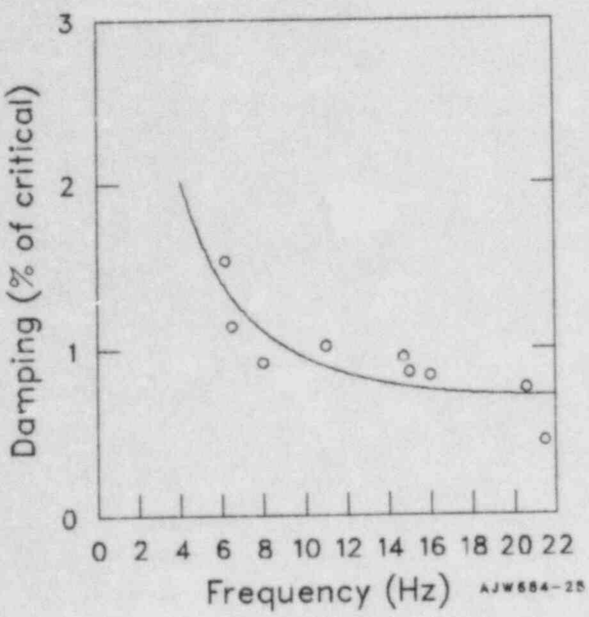


g. rigid strut with gap/random

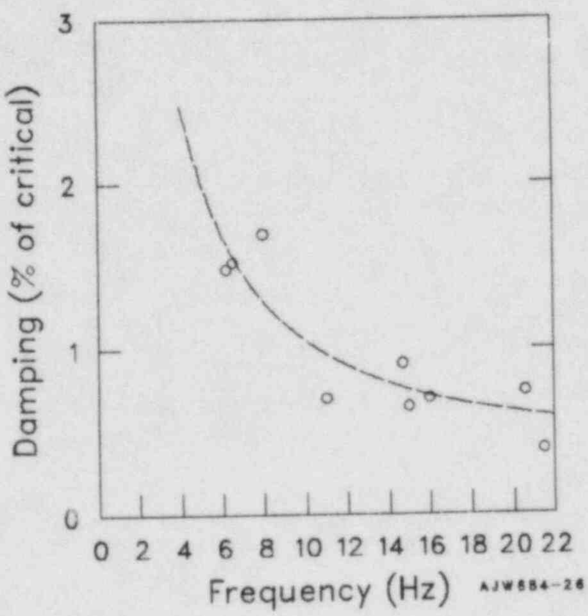


h. rigid strut with gap/swept sine

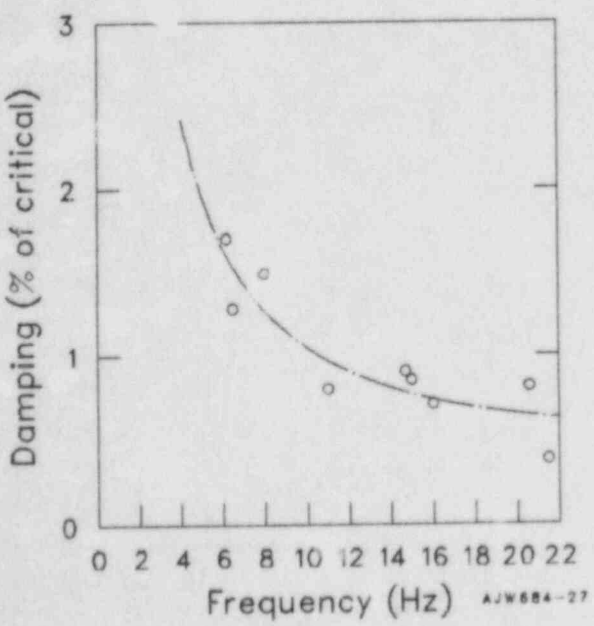
Figure 4. (continued).



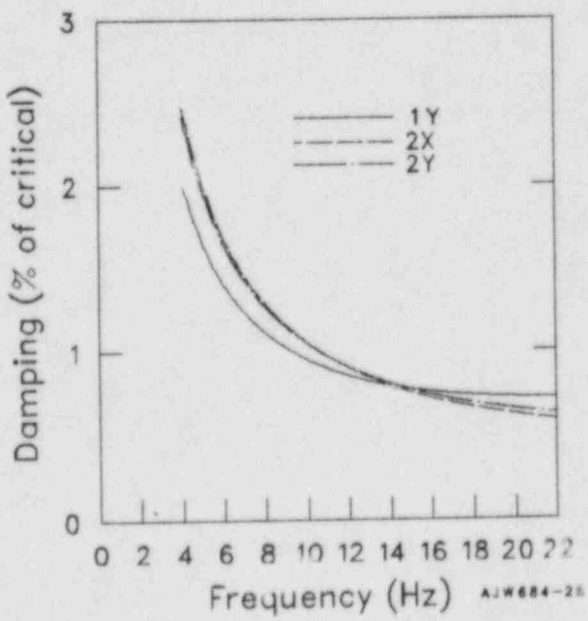
a. 1Y results



b. 2X results

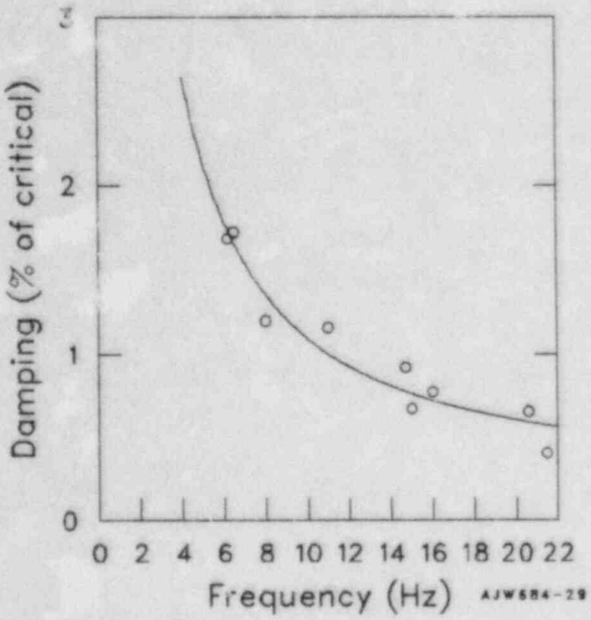


c. 2Y results

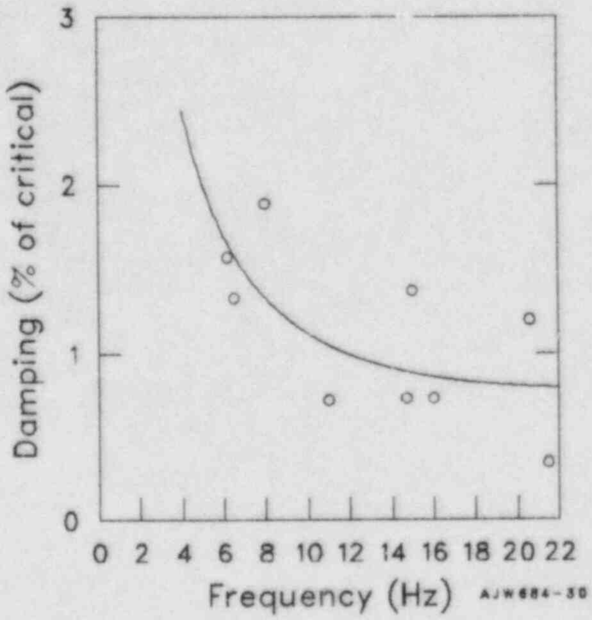


d. all excitation results

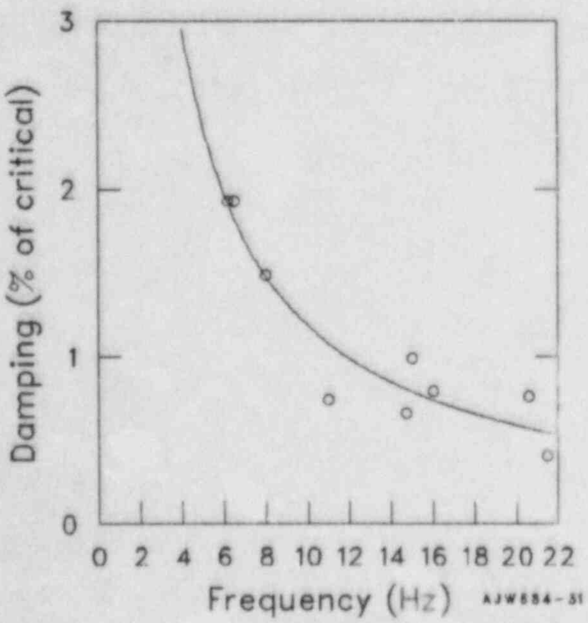
Figure 5. Comparison of excitation direction results.



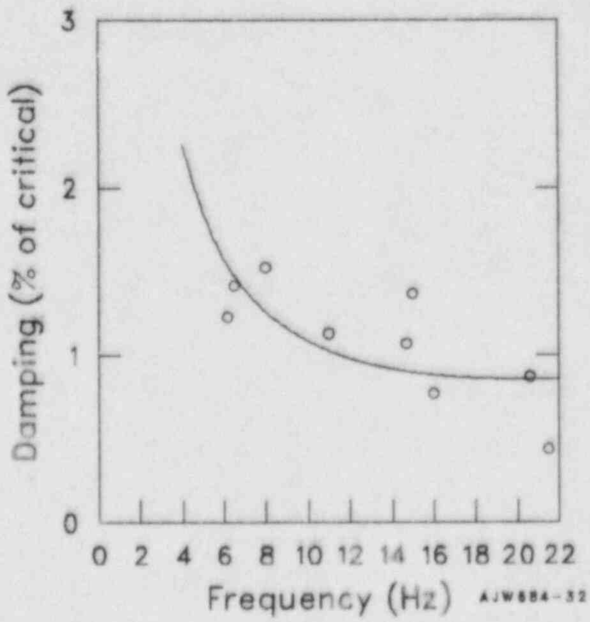
a. rigid strut



b. mechanical snubber

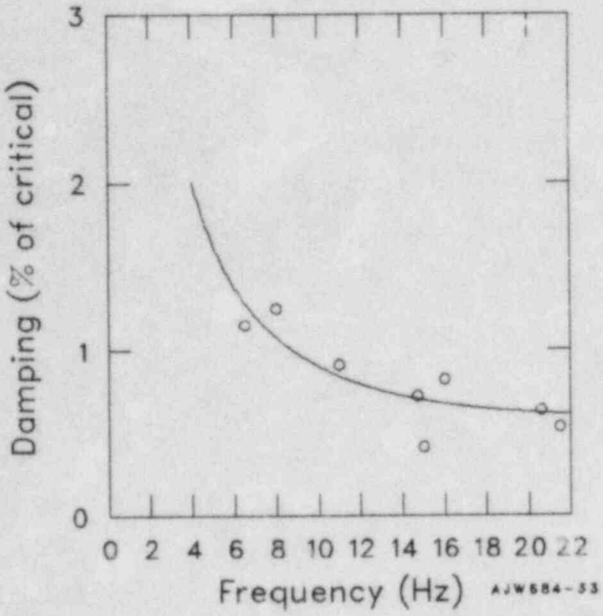


c. hydraulic snubber

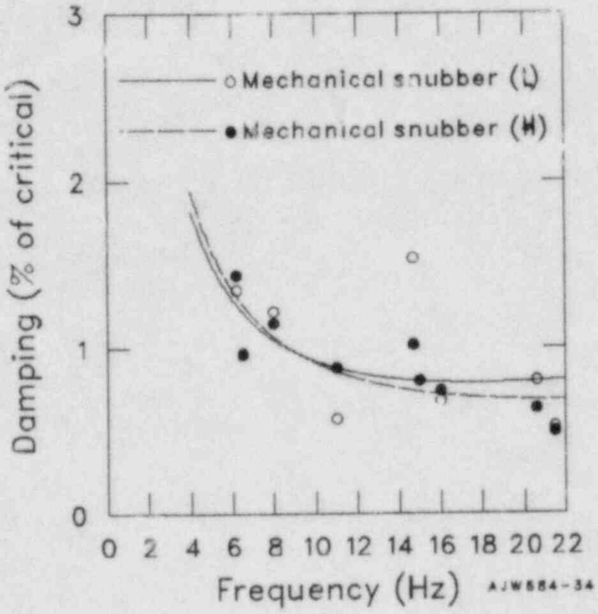


d. rigid strut with gap

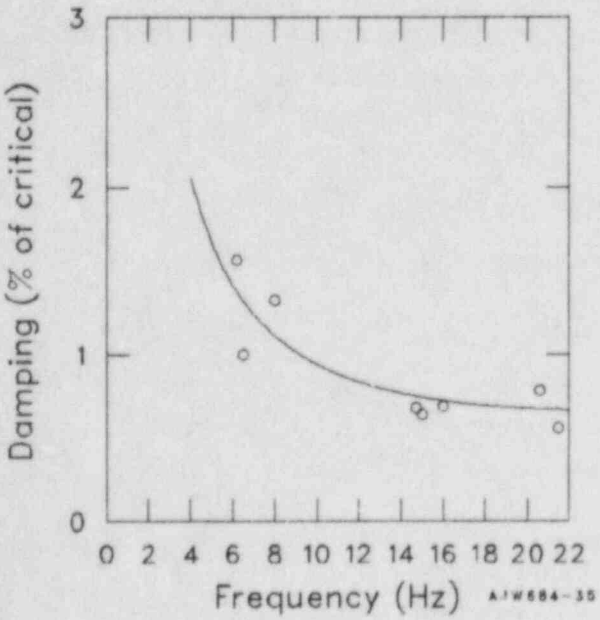
Figure 6. Support effect (random excitation).



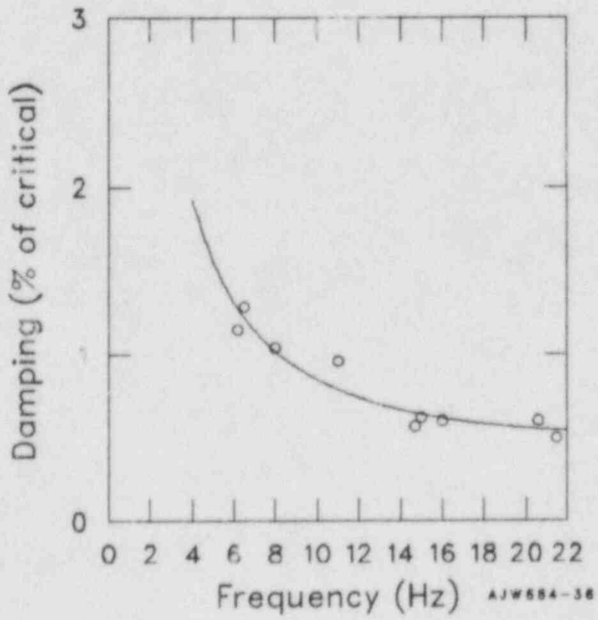
a. rigid strut



b. mechanical snubber



c. hydraulic snubber



d. rigid strut with gap

Figure 7. Support effect (swept-sine excitation).

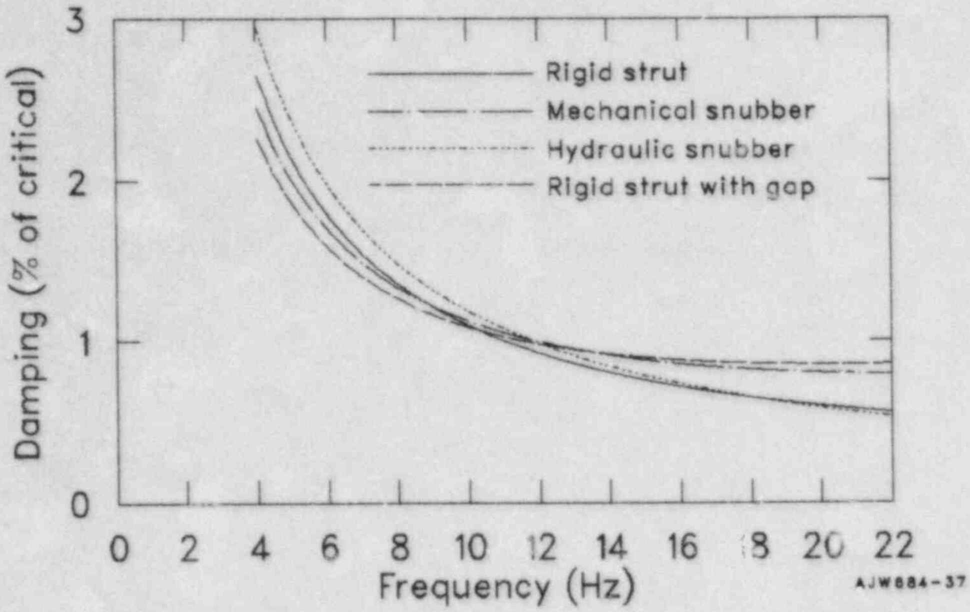


Figure 8. Support effect (random excitation).

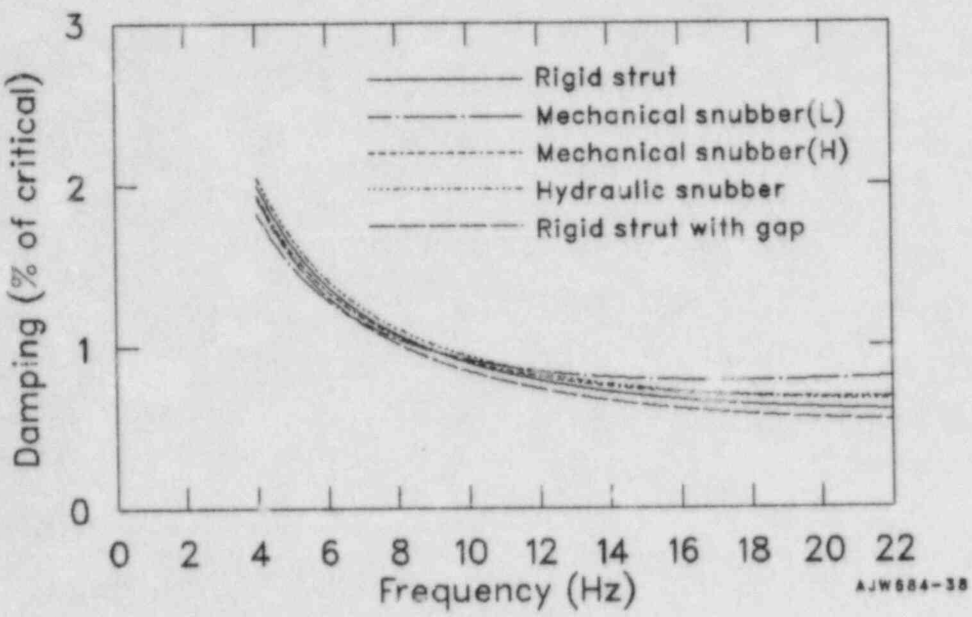


Figure 9. Support effect (swept-sine excitation).

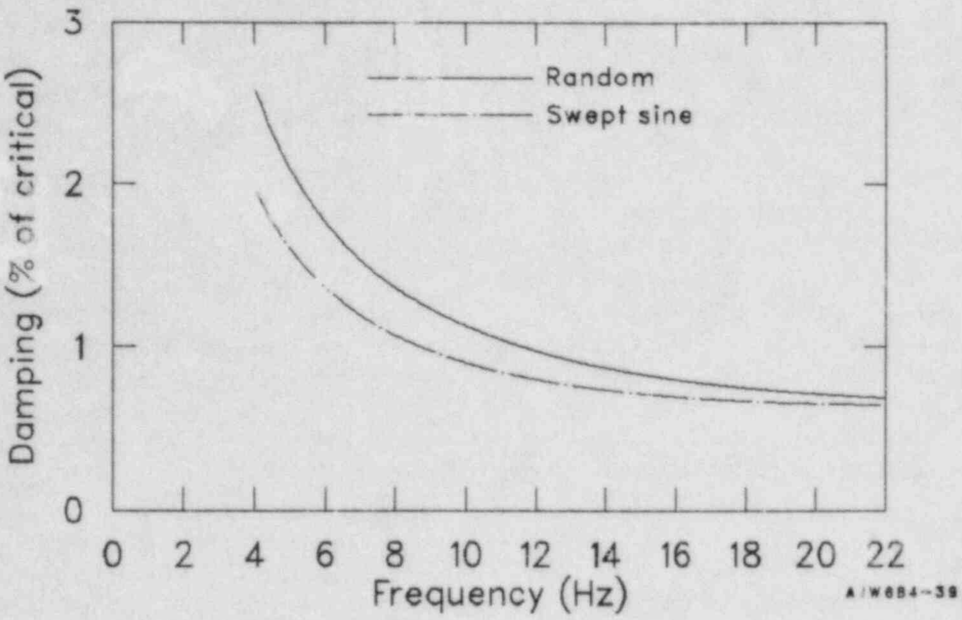


Figure 10. Excitation effect.

CONCLUSIONS

From the test data reported here, the following conclusions have been reached:

1. The damping values were inversely proportional to frequency.

2. A Rayleigh damping curve fit approximated the data well.

3. Individual damping values ranged from 3.05 % of critical damping for Mode 1 (6.2 Hz) down to 0.15 % for Mode 9 (21.5 Hz). The average from the curve fits was approximately 1.5 % at 6 Hz to 0.8 % at 22 Hz. From snapback test results using the log-decrement-damping calculational method, ANCO reported 1 to 2% of critical damping for the first mode at comparable stress levels.[2]

4. The effect of excitation location and direction was small. This was consistent with the results of the Heissdampfreaktor (HDR) piping vibration tests in the Federal Republic of Germany.[4]

5. The effect of changing the variable support was small

6. The random-excitation results were generally, but not significantly, higher than the swept-sine results (probably due to increased resolution of the swept-sine data).

7. The lower-excitation damping was greater in four of five modes than the higher-excitation damping for the one configuration tested. However, the overall curve fits showed no significant difference. In previous tests, a pattern of decreasing damping at low strain levels, constant damping at intermediate strain levels, and increasing damping at strain levels at and above yield stress was observed.[5] The low- and high-range mechanical snubber tests appear to be consistent with the previous intermediate-range tests where damping did not change with amplitude.

Conclusions 1 and 2 support the results of Reference 4 that showed for a number of piping systems the damping values were inversely proportional to frequency and that a Rayleigh damping curve can be used as a good approximation to the data. The damping values were consistent with those reported by ANCO using snapback tests. These numerical values were, however, lower than those of similar sized piping systems reported in Reference 4. This may have been due to different excitation levels or support configurations. The lack of any noticeable effect on damping with change of excitation direction or location was consistent with previous results, and can probably be generalized to any system. The variable support was only one of the multiple supports in the piping system and showed that for supports with small clearances, damping was unaffected by changing the support. If sufficient care is taken to achieve the required data-reduction frequency resolution, both random and swept-sine excitation methods result in approximately the same damping using the complex-exponential and half-power damping computational methods, respectively. The results were also in agreement with the ANCO snapback data. The excitation levels in the higher- and lower-excitation-level mechanical snubber tests appear to be at an intermediate stress level, where in previous tests damping was fairly constant with strain level. Previous tests showed significant nonlinearities may occur at very low (0 to 100 μ strain) or high (at or above yield strain) response levels.

Another consideration arising from this test series is that prolonged cyclic testing can produce fatigue failures in the piping. For this reason, snapback testing is advantageous in that only a few fatigue cycles are introduced into the piping. Although at seismic levels producing high-amplitude strain and response the damping level might reach 5% of critical or even higher, the damping level for this piping system during operating transients would only be 1 to 2%. Therefore, for design purposes, a higher damping value would be reasonable for computing primary stresses that would be controlled by the seismic restraints (struts and snubbers), while a lower damping value would be appropriate for fatigue analysis.

REFERENCES

1. Y. K. Tang, and H. T. Tang, "Dynamic Tests of Three-Dimensional Piping Systems—A NRC/EPRI Joint Test Program," *Proceedings of the U.S. Nuclear Regulatory Commission Eleventh Water Reactor Safety Research Information Meeting*, NUREG/CP-0048, Vol. 5, pp. 189-205, January 1984.

2. G. E. Howard et al., *Laboratory Studies: Dynamic Response of Prototypical Piping Systems*, ANCO Engineers, Inc., Report 1182.13, June 1984.

3. A. G. Ware, *Parameters That Influence Damping in Nuclear Power Plant Piping Systems*, NUREG/CR-3022, EGG-2232, November 1982.

4. A. G. Ware, *A Survey of Experimentally Determined Damping Values in Nuclear Power Plant Piping Systems*, NUREG/CR-2406, EGG-2143, November 1981.

5. A. G. Ware and G. L. Thinnes, *Damping Test Results for Straight Sections of 3-inch and 8-inch Unpressurized Pipes*, NUREG/CR-3722, EGG-2305, April 1984.

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