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INFORMAL REPORT

A SURVEY OF CABLE TRAY AND CONDUIT DAMPING RESEARCH

C. B. Slaughterbeck
A. G. Ware

Prepared for the

U.S. NUCLEAR REGULATORY COMMISSION

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ABSTRACT

This paper examines current knowledge on cable tray system and conduit damping values. Current design conventions with regard to damping values are discussed, and recent experimental results are presented. Representative damping values for heavily loaded and unloaded cable trays, and for conduits are included.

SUMMARY

Cable tray and conduit systems support and route the electrical and instrument cables necessary for the operation of a nuclear power plant. Since this electrical system is required to safely shut down the plant in case of a severe earthquake, these systems must be designed to withstand the Operating Basis Earthquake (OBE) and the Safe Shutdown Earthquake (SSE).

Cable tray systems consist of cables, trays, conduits, and supports. Since each system is unique, it is difficult to assign precise damping values for seismic design. Regulatory Guide 1.61 specifies values of 4% and 7% of critical damping for the OBE and SSE respectively, for bolted steel structures. Currently, these are the only standard values available. Use of higher values must be supported by experimental data in order to seismically qualify the plant. The Regulatory Guide values are widely believed to be highly conservative, especially for loaded trays.

Cable tray systems designed with these damping factors tend to be very stiff, leading to other problems with the system. Recently, research has been done to determine new, less conservative, damping values for various cable tray systems. These include a program by Bechtel and ANCO Engineers investigating cable trays and conduit damping, a program by URS/John Blume to investigate cable tray damping, and a Tennessee Valley Authority (TVA) research effort to quantify conduit damping.

Preliminary Bechtel/ANCO results indicate 20% of critical damping for fully loaded trays and 7% of critical for unloaded trays and conduits are appropriate representations of the test data at accelerations levels >0.35 gs. The URS/John Blume tests indicate 25% of critical damping for heavily loaded cable trays, 10% of critical for heavily loaded trays with sprayed-on fire retardant, and 5% of critical for conduit and lightly loaded cable tray raceways at acceleration levels >0.7 gs. Preliminary TVA results support 5% of critical damping for steel conduits, 7% of critical for 4 to 5-in. aluminum conduits, and possible higher damping for smaller diameter aluminum conduits. Final recommendations should wait for

the conclusion of the Bechtel/ANCO and TVA programs, but based on tests to date, the Bechtel recommendation for heavily loaded and unloaded cable trays, the URS/John Blume recommendation for cable tray raceways with sprayed-on fire retardant, 5% of critical damping for steel conduits, and 7% of damping for aluminum conduits would give appropriate representations of the test data.

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A SURVEY OF CABLE TRAY AND CONDUIT DAMPING RESEARCH

CABLE TRAY SYSTEMS

Cable tray systems support and route the electrical and instrument cables necessary for the operation of a nuclear power plant. A typical plant may have miles of cable trays. A cable tray system consists of the cables themselves, conduits which route groups of cables into the larger capacity trays, the trays, and a support system. Figure 1 is a sketch of a small part of a cable tray system.

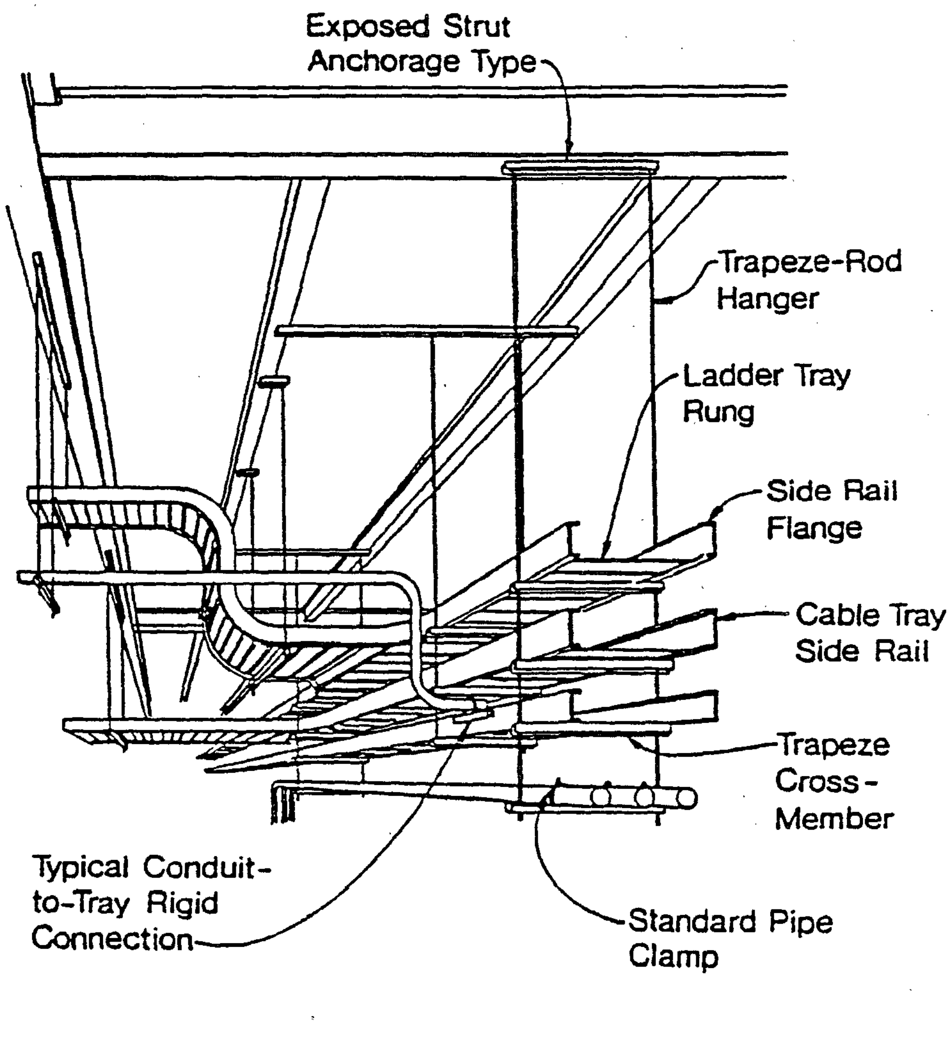
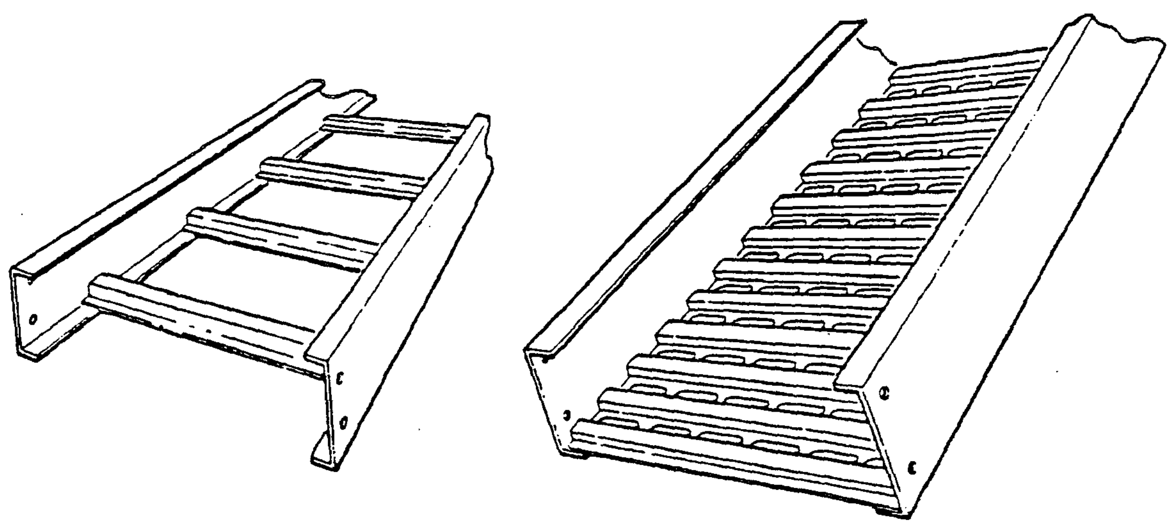


Figure 1. Cable Tray System[1]

Cable trays are available in three types; solid bottom, trough, and ladder. Each type may be either open or closed on top. The trays are constructed of steel or aluminum. The most common tray is a steel ladder type, open on top. This is the most flexible and weakest type, but it is also more versatile than other trays. The trays are generally between 6 and 36 in. wide, and between 4 and 6 in. deep. They run horizontally and vertically (between floors), and may be stacked or single. If stacked, the minimum vertical spacing between trays is one foot.[2,3] Figure 2 shows two types of cable trays.



ladder type

trough type

Figure 2. Cable Trays[4]

Support systems vary widely, as the trays can be suspended from the ceiling, supported from the floor, or clamped to a cantilever strut attached to the wall. The supports may be bolted or welded structures, or a combination of the two. Some include bracing for stiffness, while others aim for the most flexible design. A variety of connectors and anchor plates is also used. Several authors refer to a certain support configuration as "standard", but there is no consensus among authors as to the most common type. Figure 3 shows various support configurations.

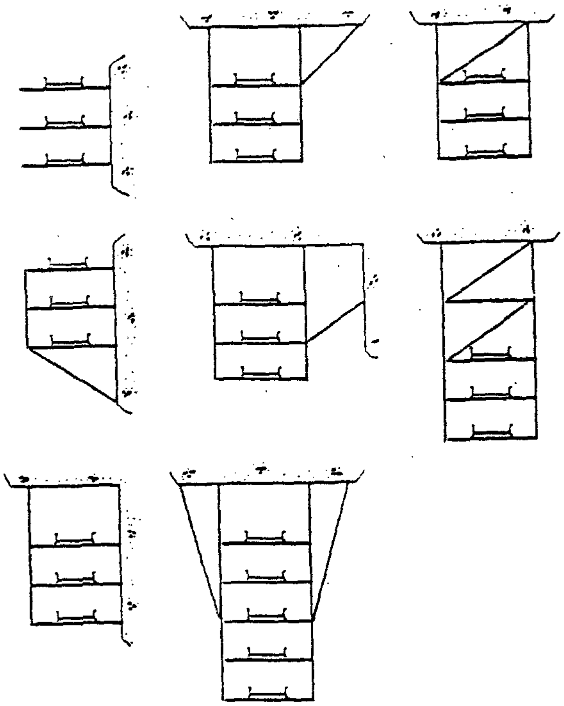


Figure 3. Cable Tray Support Systems[2]

The electrical conduits are made of aluminum or steel, and range in size from about 1 to 10 in. in diameter. Conduits are sometimes attached to the trays, routing cables in, and sometimes run parallel to the trays, on a different level of the same support system. In either case, conduit damping characteristics must be considered to determine the system damping values.

The cables are standard electric and instrument cables, with a maximum weight of around 70 lbs/ft in a fully loaded tray.[3]

The elevations, lengths, and sizes of cable tray system components are determined by the nuclear power plant they are designed for. The buildings, reactor system and secondary systems are designed first, and the cable tray systems must meet the requirements of the plant. There are numerous methods of design, and numerous combinations of system components that will meet the plant specifications.

DAMPING

Damping is a measure of energy dissipation in a vibrating system. Material damping occurs in the structural material, due to internal losses. System damping, a much larger factor in cable tray damping, is a function of the system design. The joint design, system connections to the wall, floor, and ceiling, splices in the trays, and the cable load all can be influencing factors.

Damping for materials and systems is expressed as the percent of critical damping or as a decimal damping factor, critical damping being one. A system with high damping will withstand vibrations better than a system with low damping, and thus can be designed less rigorously. In the case of cable trays, using a weaker material or smaller cross section can represent considerable construction savings for a nuclear power plant.

The two methods most commonly used to calculate damping are the logarithmic decay method and the half power method. The reader is referred to Reference 5 for details of these methods and more information on damping.

DESIGN OF CABLE TRAY SYSTEMS

Cable tray systems themselves are not essential to the operation of a nuclear power plant. However, they support the electrical and instrument cables that are necessary to initiate and maintain a safe shutdown of the plant. As such, they must be designed to withstand both the Operating Basis Earthquake (OBE) and the Safe Shutdown Earthquake (SSE) as specified by the United States Nuclear Regulatory Commission (USNRC). Modes of failure to design against include common flexure, buckling, web crippling, and excessive deformation.[2] Currently, Regulatory Guide (RG) 1.61[6] provides the only standard guidelines for damping values. These values are shown in Table 1.

TABLE 1. DAMPING VALUES[6]
(Percent of Critical Damping)

Material	OBE	SSE
Welded steel structures	2	4
Bolted steel structures	4	7
Piping systems, diameter > 12 in.	2	3
Piping systems, diameter $\leq$ 12 in.	1	2

These damping values were adopted on the recommendation of Newmark, Blume, and Kapur.[6] It is now widely believed that these values are overly conservative. Cable trays, especially when full loaded, can be expected to have much higher damping values than those in Table 1.

Design Methods and Associated Damping Values

Design methods for cable tray systems vary widely from project to project. Several methods will be covered briefly here. The references for each method cover the procedure more thoroughly and may include examples.

One of the common design methods is to design the system as "stiff" as possible. In other words, put in so many supports that the vibrations caused by an earthquake wouldn't propagate at all. This view was especially popular before any work on cable tray damping was done. It is the most conservative method. Unfortunately, it leads to other system problems which will be discussed later. Shahin, et al. assume a system is rigid if the natural frequency of the system is greater than 33 Hz. In other cases, they quote a damping value of 5% of critical being used.[2] According to Duke Power Company, cable tray systems can be considered rigid if they are supported every 6 ft 8 in. or less longitudinally.[3]

Several design methods involve reducing a system to a mathematical model. Thulin explains a method to reduce the system to a stick model with lumped masses.[7] The model is then "mathematically excited" and analyzed. Thulin's damping values are given in the data section of this paper, since they were experimentally determined.

Samara and Drag advocate a similar method.[8] The tray is again modeled with lumped masses, but the model is then subjected to unit spectra and multiplied by a "spectral factor." This "spectral factor" is the magnitude of the response spectrum for a certain direction at a certain frequency. Eigenvalue analysis is also utilized in the process. No damping values are given.

Krause and Kremer use a combination of dynamic analysis and experimental testing.[9] They assumed a damping value of 4% of critical for the steel components, then performed tests to determine the effect of increasing input accelerations on cable damping. A graph of their data is included in the experimental results section of this report.

Many other design methods depend on time history analysis or the use of computer models. Most of these methods assume a damping factor of around 5% of critical.

The damping values in RG 1.61 and the assumed values in the above mentioned design methods are all meant to be conservative. However, having unnecessary supports causes other problems. More maintenance is required simply because there are more components that may have problems. This can expose workers to additional radiation. Also, large, complicated cable tray systems leave less room for piping and duct systems necessary for the operation of the plant. Response of certain tray systems to actual earthquakes indicates that very flexible systems may better withstand the seismic loadings.

There are several ways to design a system to have high damping. These include various kinds of viscoelastic layers or interface lubrication. These methods can, however, cause other problems and probably wouldn't be suitable for cable tray design. Bolted joints have higher damping values than welded joints, since they are allowed more slip. Thus, a cable tray system with bolted joints, and other connections that allow some slip, would be expected to have more damping ability than a welded system.[10]

Dixon et al., a group of mechanical engineers at Clemson University, have studied a concept for a new type of cable tray hanger.[3] The new hanger is flexible, eliminating the need for excessive bracing. The analysis was performed at the request of Duke Power Company, who provided Clemson with average cable tray data. The concept requires much further analysis, but shows promise for the future simpler design of cable tray systems.

EXPERIMENTAL RESULTS

Interest in cable tray damping work has grown in recent years. Two major test programs, one performed by ANCO, for Bechtel Power Corporation and several electrical utilities, and the other performed by URS/John Blume and Associates, for the Seismic Evaluation Program owners group (SEP) have published results, and tests are continuing. Tennessee Valley Authority (TVA) is currently testing electrical conduits. Also, results from a few small scale experiments can be found in various papers. The small scale results will be presented first, followed by a discussion of and results from the major test programs.

Thulin Results

As mentioned previously, F.A. Thulin, Jr. provides a table of damping values in his paper, "Constructing Mathematical Models of Cable Tray and Support Systems to Determine Seismic Response in Nuclear Plants.[7]" He does not give much background on the experiment, saying only that the values are the result of tests on "typical cable trays." They represent first mode average natural frequencies, and were calculated using both the decay-rate and half-power methods. Thulin's damping ratios are reproduced in Table 2.

TABLE 2: AVERAGE CABLE TRAY DAMPING RATIOS[7]
(Thulin, ratios in percent of critical damping)

		Bare (5.8 kg/m)		Weights (75.7 kg/m)		Cables (74.0 kg/m)	
Span (m)	Direction	Freq. (Hz)	Damping (%)	Freq. (Hz)	Damping (%)	Freq. (Hz)	Damping (%)
2.62	Transverse	24	1	7	6	9	21
2.62	Vertical	36	2	11	4	11	13
5.25	Transverse	12	4	4	7	4	8

Krause and Kremer Results

According to Krause and Kremer, the steel construction of cable tray systems and the cables' interaction influence damping. They assumed 4% of critical damping for the steel, but tested the damping due to variations in input acceleration. This was necessary because cable damping effects are mass proportional, and increase as the cable vibrations increase. Krause and Kremer's graph of results is reproduced below. They used a cable load of 70 kg/m.

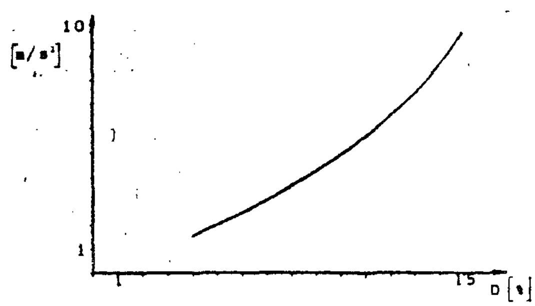


Figure 4. Damping vs. Acceleration[9]

Bechtel/ANCO Test Program

The San Fernando earthquake of 1971 caused a great deal of property and structural damage in California. Examination of the raceway equipment at Sylmar Converter Station and other power stations showed that the simple, unbraced, raceway hanger systems withstood the earthquake vibrations with very little structural damage. Even in cases where some damage occurred, the cables themselves continued to function properly. Engineers began to wonder if the same flexible systems might work in nuclear power plants as well, replacing the stiff, cumbersome systems found in most plants.

Bechtel Power Company therefore began an electrical raceway test program to determine more accurately the properties of cable tray system components. The work was done by ANCO Engineers, in their test laboratory. The program was also supported financially by several electrical utilities. These companies are listed in Appendix A. Much of the experimental data has not been released to the public. Bechtel is working on a final report containing summary results of the project. After approval by the contracting utilities, the report should be available to the public.

ANCO designed and built a large shaker table specifically for this test program. The table is designed so that its dynamics don't interfere with the dynamic properties of the test equipment. The table is capable of maximum input motions of ± 3 in., ± 30 in./sec, and ±2g.[11] It can test tray configurations up to 40 ft long and weighing 12,000 pounds. It can support a four bay, five support system, and can test two side-by-side runs. Over 500 different electrical raceway configurations were tested for the program. Several actual earthquake time histories and some synthetic inputs were used to test the specimens.

Linderman and Hadjian list the following objectives for the electrical raceway testing program.[12]

- Determine dynamic properties of various raceway systems, such as damping, fatigue life, and failure modes.
- Determine differences, if any, in dynamic properties of different cable trays, conduits, hangers and connection hardware.
- Determine behavior of different raceway construction details.
- Assess the importance of nonlinear dynamic behavior.
- Demonstrate that electrical circuits remain functional even under plastic deformation of support systems.
- Validate computer models of raceway systems.
- Assure electric functional behavior during seismic loading.
- Provide data for development of a comprehensive design guide.

The results related to all these goals will not be dealt with here, since we are concerned mainly with damping values. It is important to remember, however, that for any design or analysis of cable tray systems, factors such as fatigue life, failure modes and overall fragility must be considered in order to use the damping values properly.

Figures 5 and 6 show example results from some of the tests. It was found that the fundamental mode resonant frequency did not differ much between the various types of trays (different styles and manufacturers), but the fundamental mode damping ratios were quite varied at inputs above 0.1g, as shown in Figure 5. Figure 6 shows the results of increasing the number of transverse braces from 2 to 5. Damping increases a great deal with increasing accelerations.[11]

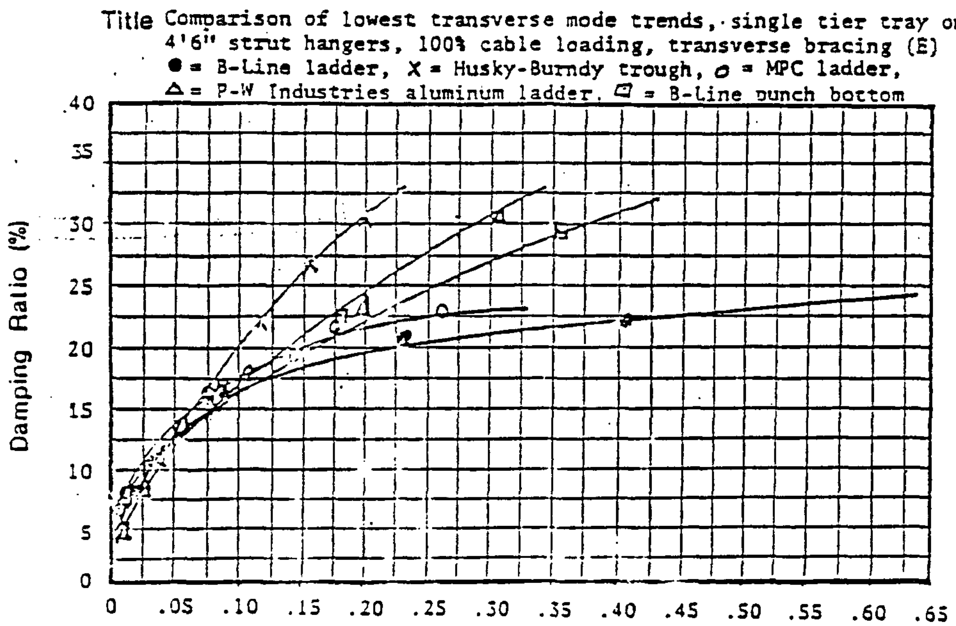


Figure 5. Comparison of Various Trays' Damping Ratios[11]

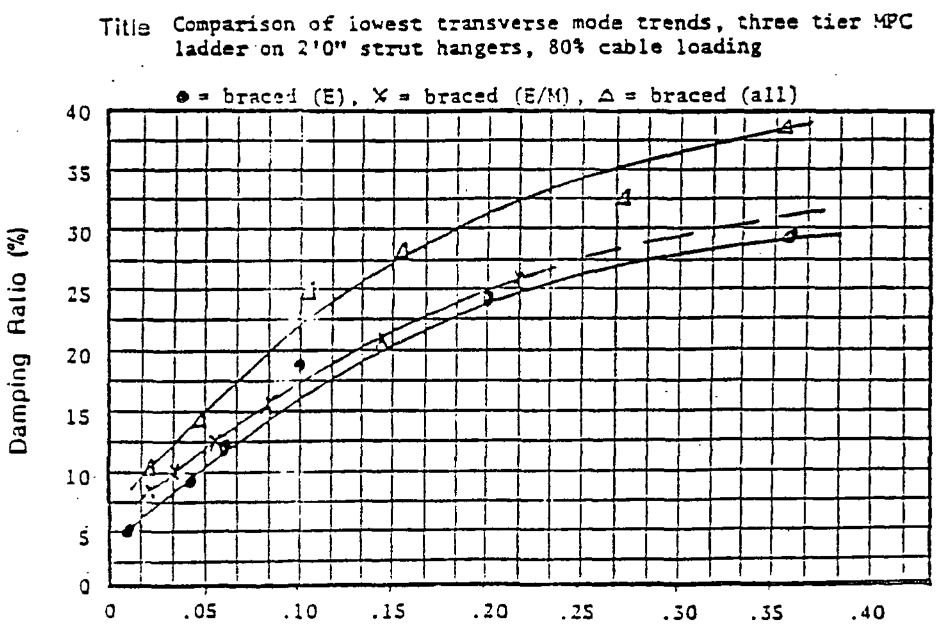


Figure 6. Damping Ratios for Several Bracing Configurations[11]

Figures 7, 8, and 9 show more results from the testing. They are reproduced from Seismic Testing of Electric Cable Support Systems, by Paul Koss.[4] The ANCO program included tests on cable tray systems alone, conduit systems alone, and systems combining the two. Figure 7 shows typical test results for a cable tray system alone and a conduit system alone.

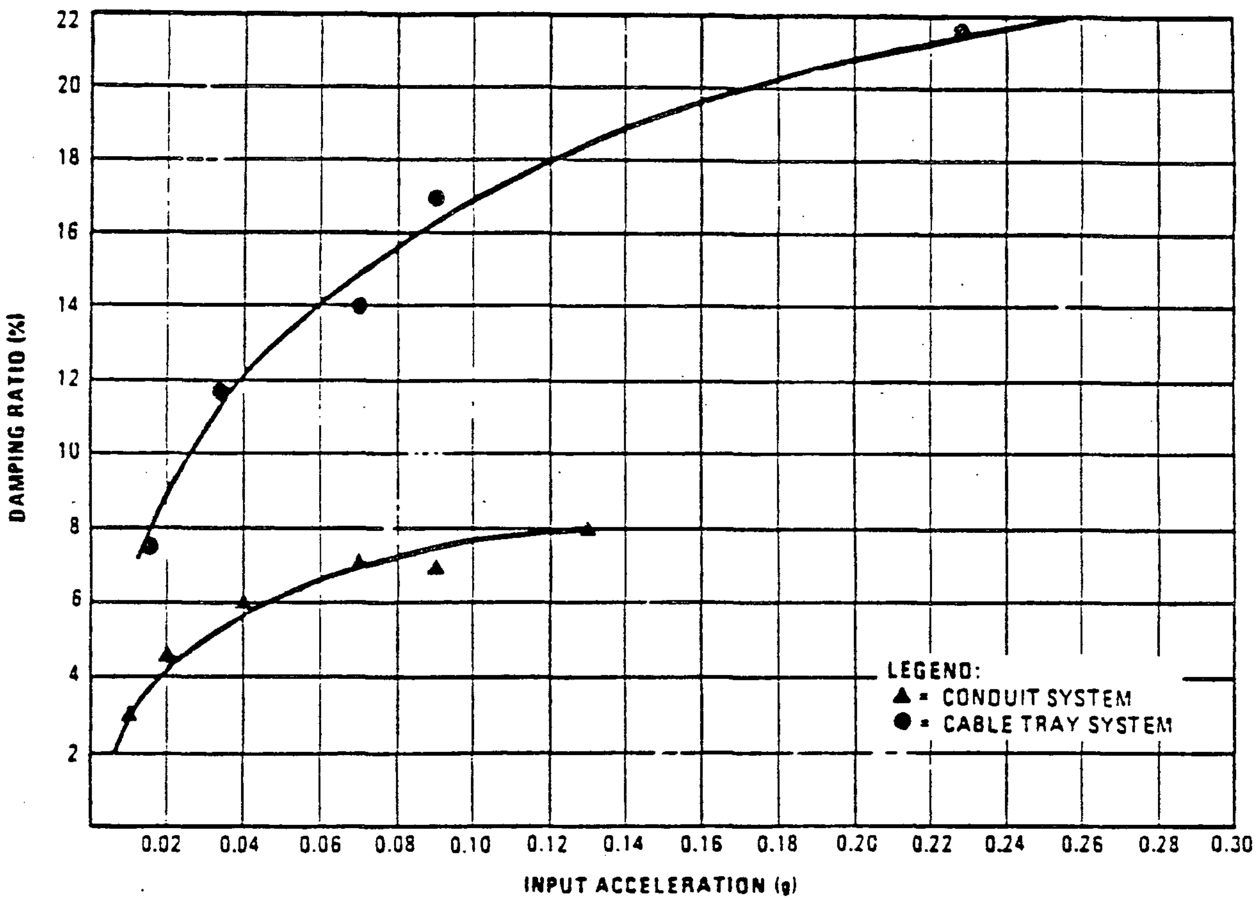


Figure 7. Typical Conduit and Tray Test Results[4]

Figure 8 shows data points for a test of braced hanger systems. It shows that while a system damping curve can be found, there is wide scatter associated with the data. Figure 9 is the final recommendation curve obtained from the damping tests. Damping values as high as 20% of critical are recommended, considerably higher than the values in RG 1.61. Figure 8 represents fairly conservative average values. Higher values might be used for a specific electrical raceway system on which ANCO has data.

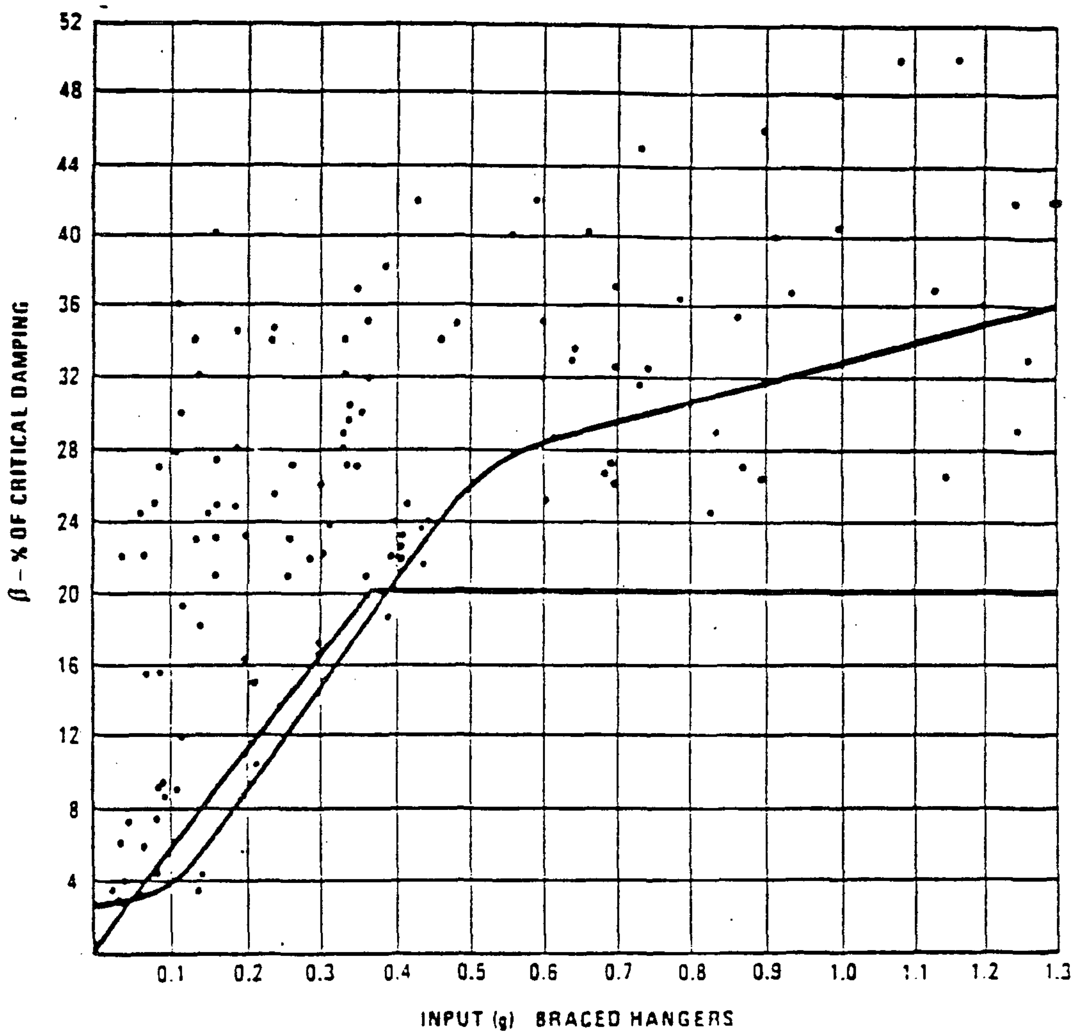


Figure 8. Damping vs. Input Level for Braced Hanger Systems[4]

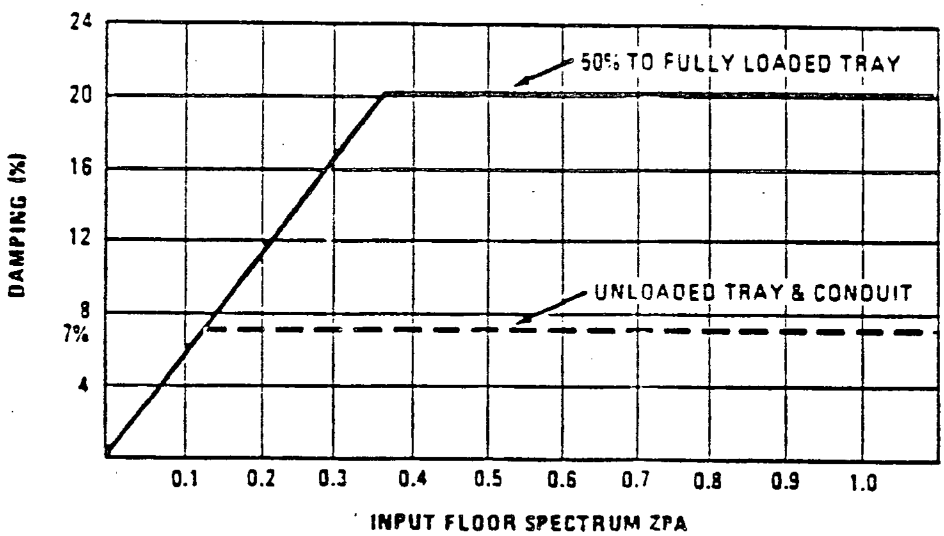


Figure 9. Recommended Damping for the Design of Raceway Systems[4]

Further results of the ANCO/Bechtel test program are summarized below.[4,11,12,13] More detailed results may be found in the listed references, or obtained from the electrical utilities list in Appendix A.

- In general, damping values of 15% to 20% of critical may be used when cable loading is 20 to 50 lbs. per ft of tray. For a tray with light or no loading, 7% should be used.
- Damping increases greatly with increasing input accelerations.
- Electrical conduits average about one third to one half the damping of cable trays. Systems with both conduits and trays have about the same damping as cable tray systems alone.
- A small amount of bracing increases the resonant frequency, decreases deflections and increases the system damping. This is partly because the braces induce flexural bending in the tray system.
- Cables don't influence system response other than changing the damping and mass.
- Cantilever side loading hanger systems have higher damping than trapeze hanger systems.

-Splice plates and their location, a mix of cable sizes, the presence of cable ties, and the type of tray do not have much influence on the dynamics of cable tray systems.

-All strut supported cable trays survived the tests with little damage.

-Moderate structural damage to the system did not damage the cables, and they continued to function.

-The type of conduit clamp did not affect the resonant frequency or damping ratio of the system.

Although the values in RG 1.61 are still the standard, the ANCO results are in use. According to Don Moore of Southern Company Services, the company currently uses damping values of up to 15%, based on the Anco/Bechtel tests.[13] They are waiting for further data and analyses that may justify the use of even higher values. The ANCO/Bechtel test program was quoted by several other authors, and was the best known among professionals contacted.

URS/John Blume Test Program

Requirements to seismically qualify nuclear power plants have changed a great deal in recent years. Some of the older plants do not specifically meet each of the new requirements. Therefore, the USNRC started the SEP. The purpose of the program was not to determine if plants met the letter of the new requirements. Rather, it was to determine if the older plants would perform properly and reach a safe shutdown in the event of an earthquake. Another objective of the program was to develop mathematical models and techniques applicable to plants not yet built. URS/John A. Blume & Associates, Engineers (URS/Blume) was hired to perform an analytic and testing program on existing electrical raceway systems for the SEP owners group. Appendix B lists the nuclear power plants participating in the test program. Information about this test program was obtained from Analytical Techniques, Models, and Seismic Evaluation of Electrical Raceway Systems, and Shaking-Table Testing for Seismic Evaluation of Electrical Raceway Systems, prepared by URS/Blume.[1,15]

The electrical raceway systems in participating plants were surveyed to determine the percentages of various kinds of trays, supports, and hangers used. Test specimens were then constructed based on these results. Shake table tests, followed by analytical studies were then conducted on the test specimens. Three parameters were considered significant in evaluating the systems; the number of tiers, the distance from the hanger anchorage to the topmost tier, and the hanger spacing. After surveying 2,276 tray hangers and 584 conduit hangers, an "average" system was established. The average tray hanger system is one or two tiers, has 1.5 to 5 ft clearance from overhead anchorage, and 5 to 6 ft between hangers. The average conduit hanger system consists of one tier, 1.5 to 2.5 ft from the overhead anchorage, and has hangers spaced from 4 to 7 ft apart.

The trays tested ranged from a simple, one tier model, to a four tiered model including perpendicular intersecting tray runs, wall bracket supports, tray risers, and conduit connections to tray side rails. Trays were tested with rod supports and three types of strut supports; trapeze, laterally braced cantilever, and unbraced cantilever. Trays were also tested with a sprayed on fire retardant material used in nuclear power plants.

URS/Blume found that as the cable fill in a tray increases, the damping increases with additional cable load, then decreases. This is because the damping is highly influenced by the cable movement in the tray. As the number of cables initially rises, they are free to move and dissipate energy. If the number of cables gets too high, however, they restrain each other and the damping decreases. Figure 10 illustrates this phenomenon. Damping curve number 1 summarizes damping values which may be used for a restrained, rod-supported cable tray system, with cable fill of more than 10 lb/ft.

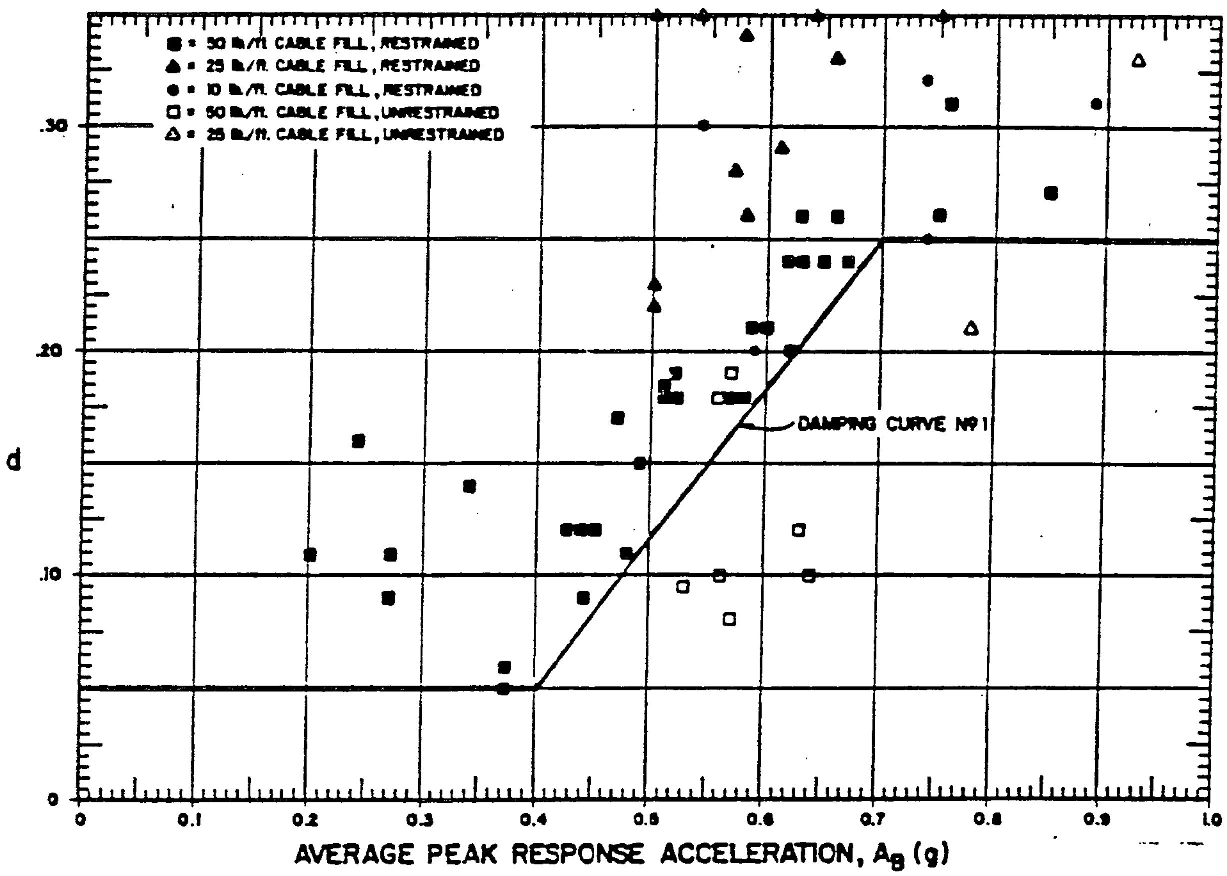


Figure 10. Damping values for Rod-Supported Cable Tray Systems[15]

One unique aspect of the URS/Blume test program was its work with fire retardant material used in nuclear power plants. The fire retardant is sprayed on the cables and upon drying hardens, forming the cables into a solid mass. This decreases the damping, since the cables are not free to slide and move within the tray. Figure 11 shows values obtained from tests on a rod-supported cable tray system with the fire retardant. Damping curve number 2 may be used for trays with cable load of 10 lb/ft or more.

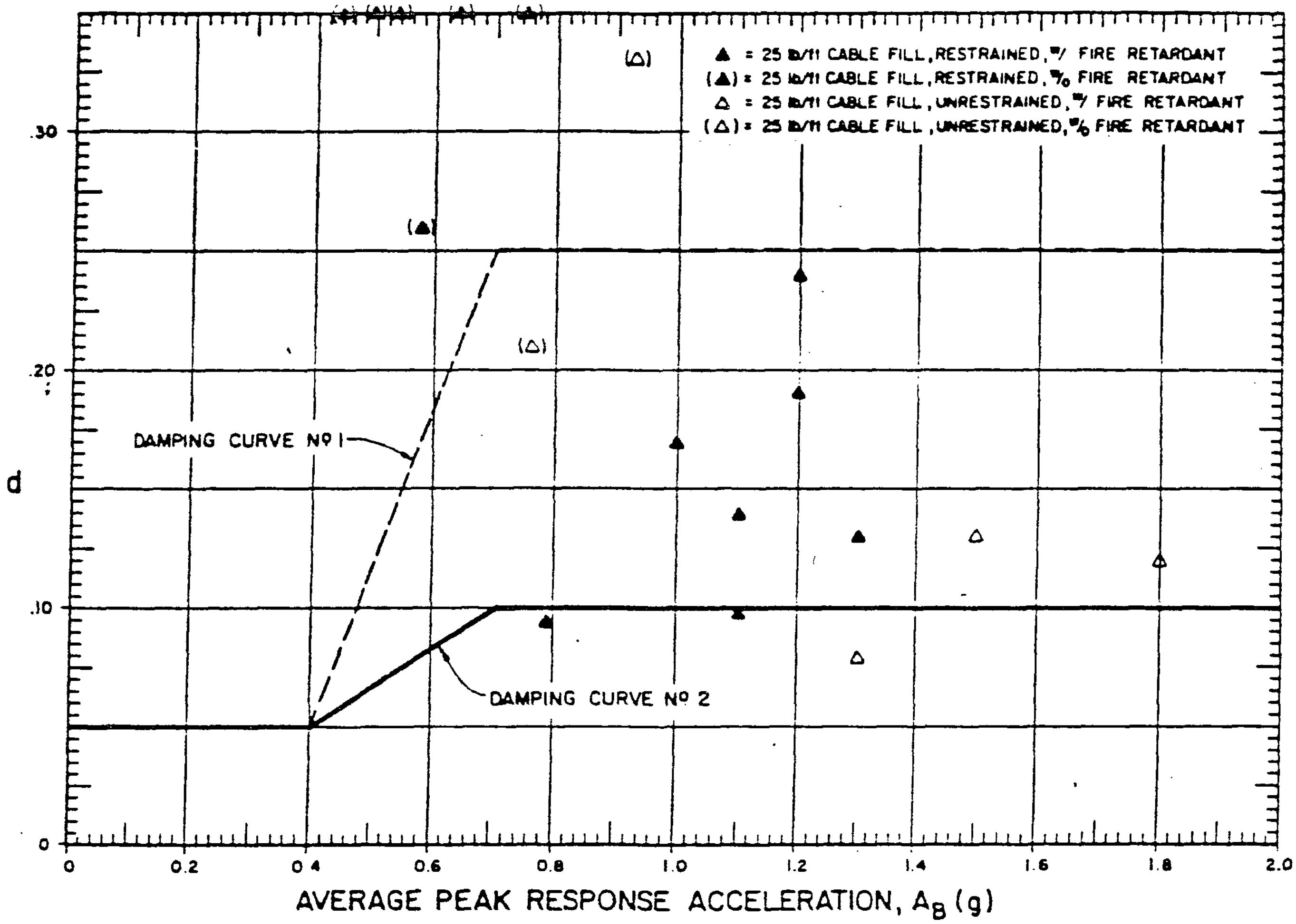


Figure 11. Damping with Fire Retardant[15]

Figure 12 show damping values obtained from tests on strut-supported cable tray systems. Figure 13 shows the final damping curves for various systems. A damping value of 5% of critical is recommended for all conduits and all cable trays loaded with < 10 lb/ft.

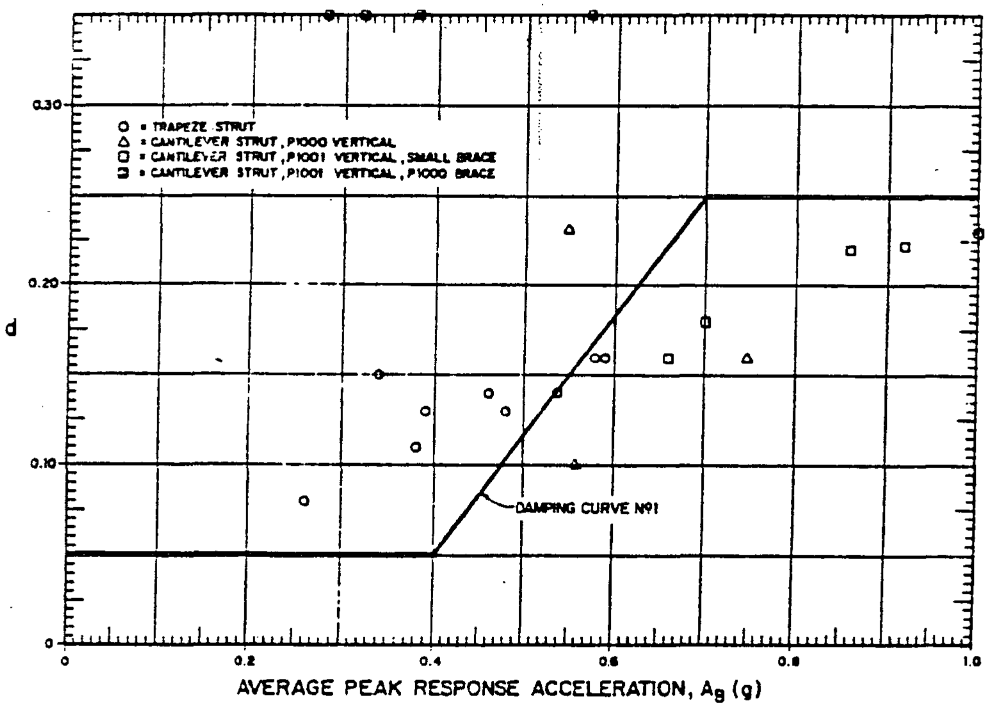


Figure 12. Damping Values for Strut-Supported Systems.[15]

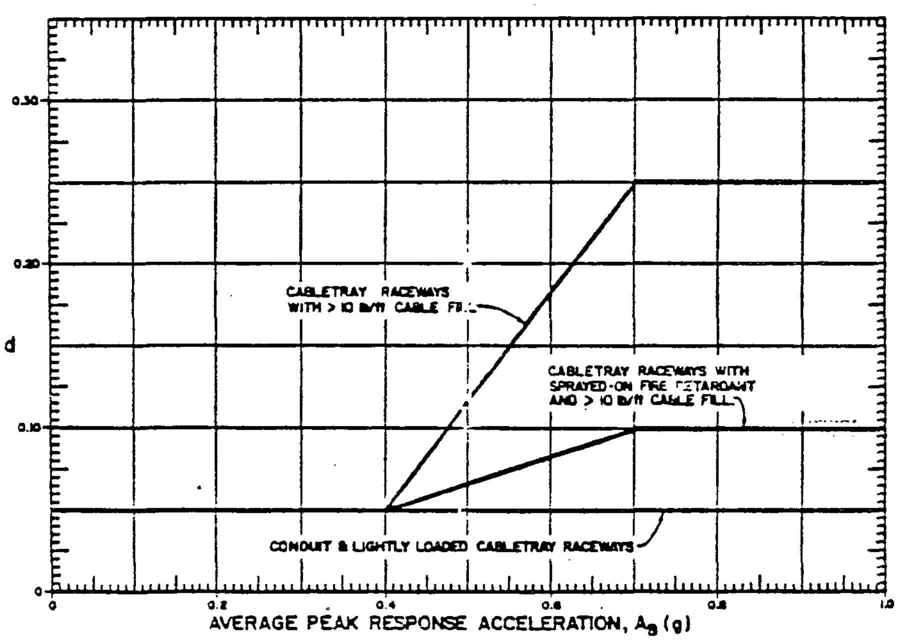


Figure 13. Damping Curves from URS/Blume Program.[15]

The overall conclusion of the URS/Blume program is that the electrical raceway systems in older nuclear power plants would perform safely in the event of an earthquake. Also, damping values used in previous designs are very conservative, and may be replaced in the future with the higher values found as the result of URS/Blume test program.

TVA Test Program

The Tennessee Valley Authority (TVA) is conducting vibration tests on electrical conduit to determine the damping inherent in these type systems. Conduits differ from the cable trays shown in Figures 1 through 3 in that they are small, thin-walled pipes through which the electrical cables are routed. Thus they represent some features of piping in the geometric sense, and some of the features of cable trays in that damping is influenced by the electrical wires that are being routed.

The first series of tests[16] was conducted on 1.5- and 3-in. steel conduits under a variety of conditions, including wire loading, initial amplitude, and the presence or absence of a fire barrier mat. The fire barrier mat is analogous to thermal insulation on nuclear power plant piping. Installation details and subsequent dynamic history of the electrical conduit were found to influence both natural frequency and damping. The fire barrier mat, 3M Corporation M20A, was installed in five layers on the 1.5-in. conduit and in four layers on the 3-in. conduit. It increased damping more significantly for horizontal oscillations than for vertical oscillations. Damping was observed to increase at higher amplitudes of excitation for the 3-in. conduit, but was not clearly related to amplitude for the 1.5-in. conduit. Damping ranged from 20 to 38% of critical for the 1.5-in. conduit with fire barrier mat at higher amplitudes, and from 5 to 21% for the 3-in. conduit with fire barrier mat. Examples of the test results are shown in Figures 14 and 15.

The second set of TVA tests used 0.75-, 1.5-, 3- and 5- in. aluminum conduits.[17] The smaller two sizes were tested using both 1- and 2-hole clamps, while the 3- and 5-in. conduits were tested with 2-hole clamps.

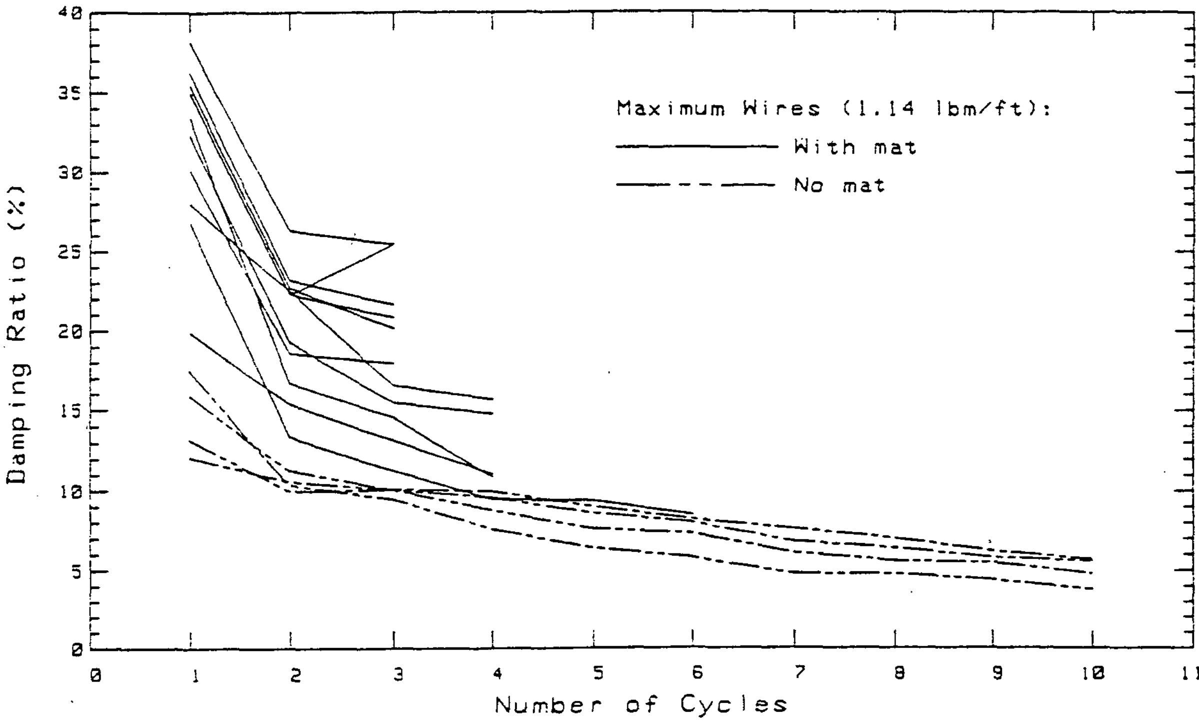


Figure 14. TVA 1.5-in. steel conduit results.[16]

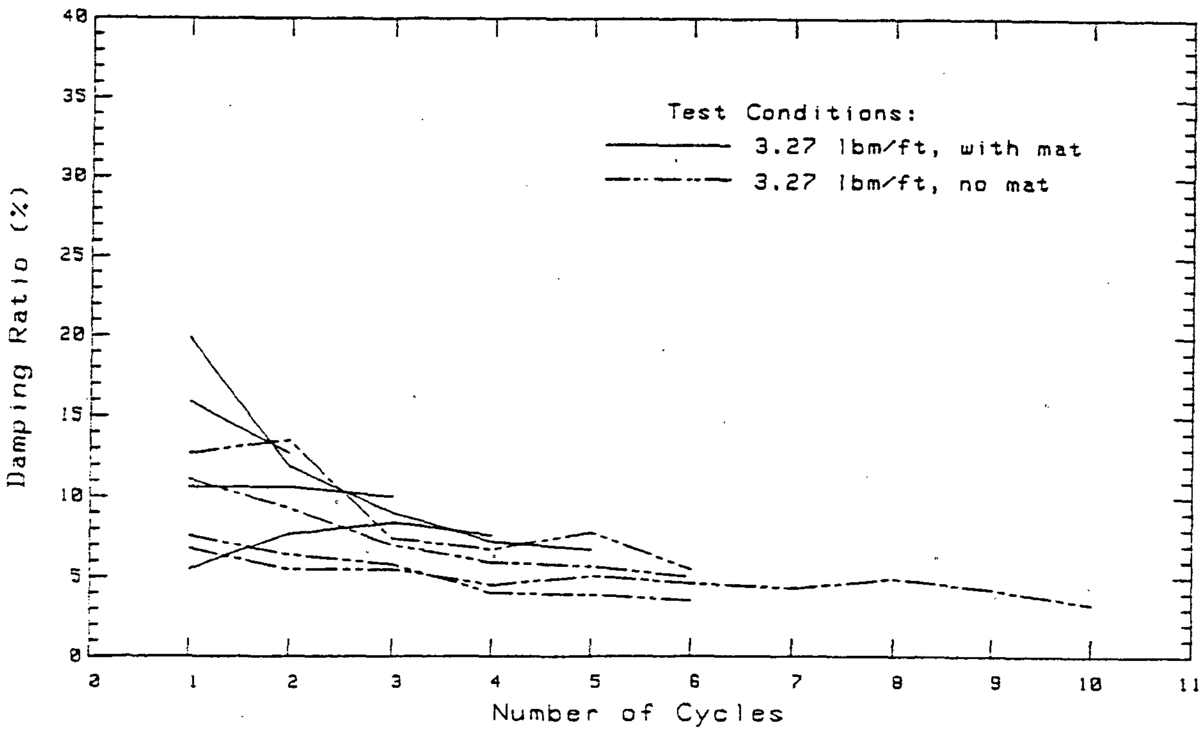


Figure 15. TVA 3-in. steel conduit results.[16]

Summaries of the damping results are listed in Table 3 and are shown graphically in Figure 16.

Table 3. TVA ALUMINUM CONDUIT DAMPING VALUES[17]
(Percent of Critical Damping)

Diameter	# bolts	Max amplitude	Min amplitude
0.75	1,2	27.5 to 31.8	6.5 to 11.8
1.5	2	20.0 to 21.2	11.9 to 14.3
1.5	1	32.3 to 38.6	16.8 to 23.2
3	2	17.4 to 22.6	4.9 to 6.0
5	2	--------- 8.1 to 10.4	--------

Other features noted in these tests were that damping generally increased with increased amplitude of excitation. This was not observed for the 5-in. conduit where damping was relatively constant with amplitude. The presence of wiring significantly increased damping. Damping decreased with larger conduit diameters. The installation details can produce considerable variations in damping.

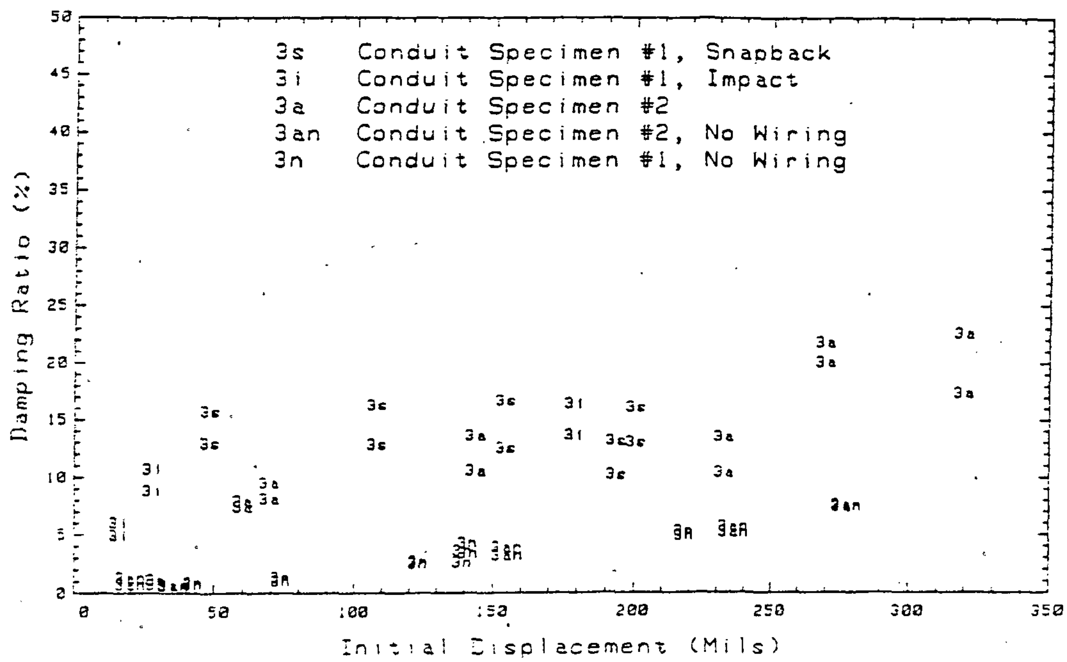


Figure 16. TVA aluminum conduit test results.[17]

The third set of tests was conducted on 3-, 4-, and 5-in. steel conduits.[18] The 3-in. tests were conducted on 10-ft spans with the conduit coupling at the center of the span in some cases normally tightened and in others loosely tightened. Tests were also conducted on a triple span with normal center coupling tightening. The 4-in. tests used 10 ft single spans with end coupling, center coupling, and threadless coupling at the center of the span. The 5-in. tests involved a single span with end coupling. Damping values are listed in Table 4 and are shown graphically in Figure 17.

Table 4. TVA STEEL CONDUIT DAMPING VALUES[18]
(Percent of Critical Damping)

Diameter	Spans	Coupling	Damping
3	1		4.6 to 14.7
3	3		5.1 to 16.5
3		loose	10.4
3		normal	5.8
4	1	center	6.0 to 21.2
4	1	end	4.7 to 9.8
5	1	end	3.4 to 15.5

According to Bill Naely[19], these preliminary tests indicate the following damping values may be acceptable:

-for steel conduits, a damping values of 5% of critical
-for aluminum conduits, 15% for $\leq$1.5-in. diameter, 10% for diameters of 2 to 3 in., and 7% for diameters of 4 to 5 in.

3	Single Span, Center Coupling, Snapback
3t	Triple Span, Center Coupling, Snapback
3l	Single Span, Loose Center Coupling, Snapback
3i	Single Span, Center Coupling, Impact
4e	Single Span, End Coupling, Snapback
4c	Single Span, Center Coupling, Snapback
4ei	Single Span, End Coupling, Impact
4ci	Single Span, Center Coupling, Impact
4gi	Single Span, Gedney Center Coupling, Impact
5	Single Span, End Coupling, Snapback
5i	Single Span, End Coupling, Impact

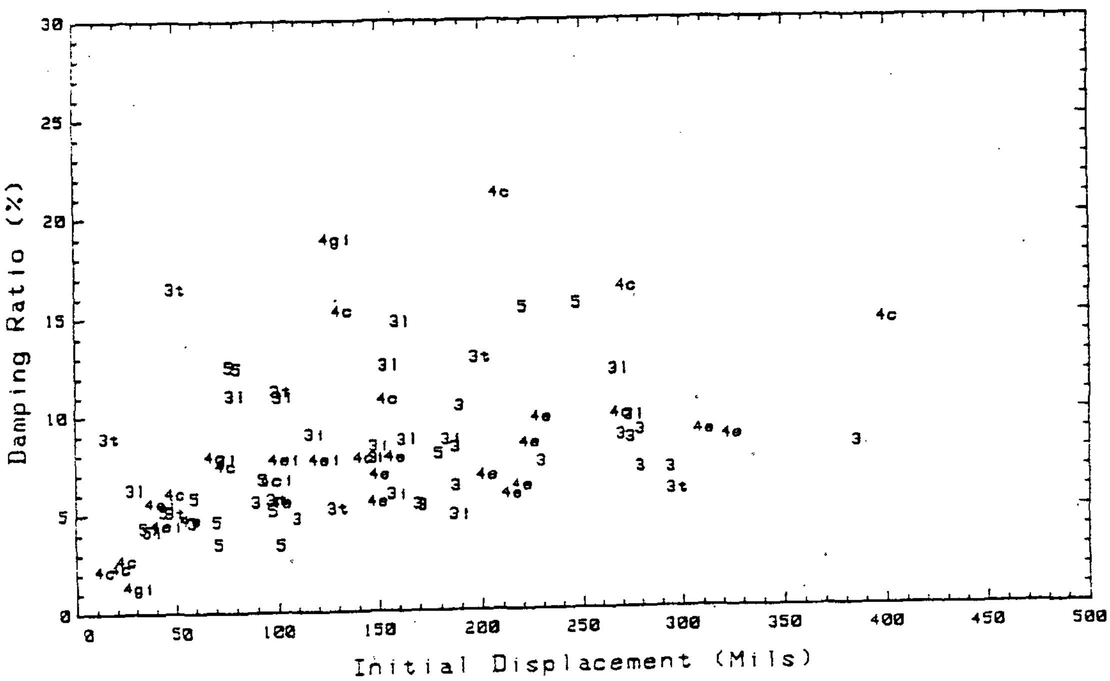


Figure 17. TVA steel conduit test results.[18]

CONCLUSIONS

Cable trays and conduits are necessary for the safe operation and shutdown of nuclear power plants. Therefore, there should be specific guidelines for damping values used in their design. There is a great deal of experimental evidence to support higher damping values for cable trays than those recommended in RG 1.61.

Figure 9, the result of the Bechtel/ANCO tests, and Figure 13, the result of the URS/Blume tests, give proposals based on two different sets of experiments. The Bechtel recommendation ramps upward from 0 gs acceleration to 20% of critical damping for loaded trays and 7% for unloaded trays at 0.35 gs. Further unpublished Bechtel research[20] indicates that damping can also be related to tray geometry, such as the number of trays stacked together (see Figure 3). In comparison, the URS Blume proposal recommends 5% of critical damping to 0.4 gs, then ramps upward to 25% of critical damping for loaded trays and 10% for lightly loaded trays with sprayed-on fire retardant at 0.7 gs. For conduits and lightly loaded cable trays a constant 5% of critical damping is recommended for all acceleration levels. The difference in the 5 versus 7% values and the 20 versus 25% values at higher acceleration levels are considered inconsequential. The primary difference is whether the ramp should begin at 0 or 0.4 gs. Since there would probably be little friction or impacting at very low acceleration levels, the Bechtel approach of 0% of critical damping at 0 gs seems reasonable. In addition, some of the Bechtel/ANCO data is at low acceleration levels, while the URS/Blume results are all >0.2gs. This point is relatively inconsequential, however, since at low g levels cable trays would not be expected to fail. Based on a review of the data, the Bechtel recommendation for heavily loaded trays would envelope most of the test data, the URS/Blume recommendation of 10% of critical damping at high g levels for raceways with sprayed-on fire retardant seems appropriate, and a 7% of critical value for unloaded trays as recommended by Bechtel is reasonable. Since a final report by Bechtel has not been released, the data should be reassessed when this information becomes available.

Both URS Blume and TVA (for steel) recommend 5% of critical damping for conduits, while Bechtel recommends 7%. Preliminary TVA results show that 7% of critical damping may be appropriate for 4- to 5-in. diameter aluminum conduits, and even higher damping may be suitable to represent 1- to 3-in. diameter aluminum conduits. A suitable representation of the test data that combines these recommendations would be 5% of critical damping for steel conduits and 7% for aluminum conduits. With the conclusion of the TVA test program, this conclusion should be reassessed.

Further information on cable tray and conduit damping can be found in References 21 through 23.

REFERENCES

1. URS/John A. Blume & Associates, Engineers, Shaking-Table Testing for Seismic Evaluation of Electrical Raceway Systems, URS/JAB 8050, April 1983.

2. Riad M. Shahin, Ruben Manuelyan, and Chung-Mong Jan, "Seismic Analysis and Design of Electrical Cable Trays and Support Systems," Nuclear Engineering and Design, Volume 45, 1978.

3. M.W. Dixon et al., "New Cable-Tray Hanger Design Concept for Nuclear Power Plants," Civil Engineering and Nuclear Power Volume 1, paper 11-7, September 1980.

4. Paul Koss, "Seismic Testing of Electric Cable Support Systems," Bechtel Power Corporation, Los Angeles Power Division, Paper presented at the 48th Annual Convention of the Structural Engineers Association of California, Coronado, California, October 4-6 1979.

5. Arthur G. Ware, "A Survey of Experimentally Determined Damping Values in Nuclear Power Plant Piping Systems," NUREG/CR-2406, November 1981.

6. U.S. Atomic Energy Commission, Regulatory Guide 1.61, "Damping Values for Seismic Design of Nuclear Power Plants", 1973.

7. F.A. Thulin, Jr., "Constructing Mathematical Models of Cable Tray and Support Systems to Determine Seismic Response in Nuclear Plants," Transactions of the 4th International Conference on Structural Mechanics in Reactor Technology, San Francisco, California, 1977.

8. M.F. Samara and D.J. Drag, "Analysis and Design Procedure for Cable Tray Support Systems Subjected to Dynamic Loading," Transactions of the 8th International Conference on Structural Mechanics in Reactor Technology, Brussels, Belgium, 1985.

9. G. Krause and S. Kremer, "Seismic Design and Qualification of Cable Trays in Nuclear Power Plants," Transactions of the 6th International Conference on Structural Mechanics in Reactor Technology, Paris, France, 1981.

10. F.C. Nelson, "Techniques for the Design of Highly Damped Structures," Transactions of the 3rd Conference on Structural Mechanics in Reactor Technology, London, United Kingdom, 1975.

11. P. Ibâñez, W.E. Gundy, and R.S. Keowen, "A Seismic Shake Table for Testing Overhead Equipment," ANCO Engineers, Inc., Santa Monica, California, presented at the 25th Instrument Society of America Simposium, May 7-10, 1979.

12. R.B. Linderman and A.H. Hadjian, "Development of Bechtel's Electrical Raceway System Test Program," Proceedings of the American Power Conference Volume 43, 1981.

13. Paul Y. Hatago and Gregory S. Reimer, "Dynamic Testing of Electrical Raceway Support System for Economical Nuclear Power Plant Installations," Bechtel Power Corporation, F 79 166-0.

14. Don Moore, private communication, Southern Company Services, June 2, 1986.

15. URS/John A. Blume & Associates, Engineers, Analytical Techniques, Models, and Seismic Evaluation of Electrical Raceway Systems, URS/JAB 8050, August 1983, .

16. P.A. March, "A Preliminary Study of Vibration Damping in Electrical Conduit", TVA EL Report No. WR28-4-900-140, October 1984, revised March 1986.

17. P.A. March, "An Experimental Investigation of Vibration Damping in Aluminum Electrical Conduit", TVA EL Report No. WR28-4-900-176, March 1986.

18. P.A. March, "An Experimental Investigation of Vibration Damping in Steel Electrical Conduit", TVA EL Report No. WR28-4-900-179, March 1986.

19. Bill Naely, private communication, Tennessee Valley Authority, June 3, 1986.

20. A.H. Hadjian, presentation to USNRC staff, Bethesda, Md., July 9, 1986.

21. Anil K. Kar, "Cable Trays and Their Supports," Civil Engineering and Nuclear Power, Volume 1, paper 11-8, September 15-17, 1980.

22. A.H. Hadjian, "State of Knowledge of Seismic Response of Nuclear Facilities," Bechtel Power Corporation, Civil Engineering and Nuclear Power, Volume VI, September 15-17, 1980.

23. N.M. Newmark, "Inelastic Design of Nuclear Reactor Structures and its Implications on Design of Critical Equipment," Transactions of the 4th International Conference on Structural Mechanics in Reactor Technology, San Francisco, California, 1977.

APPENDIX A

UTILITIES PROVIDING SUPPORT FOR ANCO TESTS

ANCO Engineers, Incorporated
Arizona Nuclear Power Project participants
Bechtel Power Corporation
Boston Edison Company
Georgia Power Company
Mississippi Power and Light Company
Pennsylvania Power and Light Company
Philadelphia Electric Company
Public Service Electric and Gas Company
Puget Sound Power and Light Company
Standardized Nuclear Unit Power Plant System participants (SNUPPS)
Southern California Edison Company

APPENDIX B

PARTICIPANTS IN URS/BLUME TEST PROGRAM

Plant	Utility
Big Rock Point Nuclear Power Plant	Consumers Power Company
Connecticut Yankee Atomic Power Plant	Northeast Utilities
Dresden Nuclear Power Station, Unit 2	Commonwealth Edison Company
Millstone Nuclear Power Station, Unit 1	Northeast Utilities
Nine Mile Point, Unit 1	Niagara Mohawk Power Corporation
Oyster Creek Station, Unit 1	GPU Nuclear Utilities
Palisades Nuclear Power Plant	Consumers Power Company
Robert E. Ginna Nuclear Power Plant	Rochester Gas & Electric Company
Yankee Nuclear Power Station (Yankee Rowe)	Yankee Atomic Electric Company

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This paper examines current knowledge on cable tray system and conduit damping values. Current design conventions with regard to damping values are discussed, and recent experimental results are presented. Representative damping values for heavily loaded and unloaded cable trays and for conduits are included.

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