**ANSI/IEEE C37.98-1987**
(Revision of ANSI/IEEE C37.98-1978)

## *An American National Standard*

# IEEE Standard Seismic Testing of Relays

Sponsor
**Power System Relaying Committee**
**of the**
**IEEE Power Engineering Society**

Secretariat

**Institute of Electrical and Electronics Engineers**
**National Electrical Manufacturers Association**

Approved June 13, 1985
Reaffirmed December 6, 1990
**IEEE Standards Board**

Approved January 15, 1988
Reaffirmed May 20, 1991
**American National Standards Institute**

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# Foreword

(This Foreword is not a part of IEEE C37.98-1987, IEEE Standard Seismic Testing of Relays.)

This standard is for developing data related to the seismic capabilities of relays. This standard complements IEEE Std 344-1987, IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations, which provides general guidelines for developing data related to seismic qualification of equipment used in nuclear generating plants.

Data must be developed by testing rather than analytical means since protective relays fall into the category of complex devices as described in Section 5 of IEEE Std 344-1987; however, analysis may be used in data reduction, reconciling response spectra, justifying methods of evaluating changes, and justifying seismic qualifications of relays of similar construction.

It should be emphasized that while a primary purpose in preparing this standard was to cover the application of relays to nuclear generating plants, the standard is not restricted to this application. This standard may be applied to any area in which the seismic response of relays is a design consideration.

This standard was prepared by Working Group K1, Seismic Relay Performance, of Subcommittee K, Relaying Practices of the Power System Relaying Committee.

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# IEEE Standard Seismic Testing of Relays

## 1. Scope and References

### 1.1 Scope

#### 1.1.1 Introduction

This standard specifies the procedures to be used in the seismic testing of relays used in power system facilities. The standard is concerned with the determination of the seismic fragility level of relays and also gives recommendations for proof testing.

#### 1.1.2 Purpose

The purpose of this standard is to establish procedures for determining the seismic capabilities of protective and auxiliary relays. These procedures employ what has been called fragility testing in IEEE Std 344-1987 [3].[1] To define the conditions for fragility testing of relays, parameters in three separate areas must be specified. In general, they are

1) The electrical settings and inputs to the relay, and other information to define its conditions during the test.
2) The change in state, deviation in operating characteristics or tolerances, or other change of performance of the relay that constitutes failure.
3) The seismic vibration environment to be imposed during the test.

Since it is not possible to define the conditions for every conceivable application for all relays, those parameters, which in practice encompass the majority of applications, have been specified in this standard. When the application of the relay is other than as specified under any of (1), (2), and (3), or if it is not practical to apply existing results of fragility tests to that new application, then proof testing must be performed for that new case. The use of these capability data will assist in the selection of relays. One number will be used to catalog the seismic capability of a relay. This number is the zero period acceleration level, and is understood to refer to the standard response spectrum shape as defined in this standard. The capability data will help designers of generating stations, substations, and various other power system installations to incorporate the seismic capabilities of the relays into the overall design of these facilities.

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[1] The numbers in brackets correspond to those of the references in 1.2.

### 1.1.3 Limitation of Test Results

This standard applies only to the testing of protective and auxiliary relays and does not apply to switchboards, panels, or any structure upon which the relay may be mounted. It is the responsibility of the power system facility designer to combine data on the seismic performance of the relay mounting structure and the relay to arrive at an acceptable equipment design.

## 1.2 References

This standard shall be used in conjunction with the following publications:

[1] ANSI/IEEE Std 323-1983, IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations.[2]

[2] IEEE Std 344-1987, IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations.[3]

[3] 10 FR, Energy. Chapter I, Nuclear Regulatory Commission.[4]

# 2. Definitions

**auxiliary relay:** A relay whose function is to assist another relay or control device in performing a general function by supplying supplementary actions.

NOTES:

1 — Some of the specific functions of an auxiliary relay are
  a) Reinforcing contact current-carrying capacity of another relay or device
  b) Providing circuit seal-in functions
  c) Increasing available number of independent contacts
  d) Providing circuit-opening instead of circuit-closing contacts or *vice versa*
  e) Providing time delay in the completion of a function
  f) Providing simple functions for interlocking or programming

2 — The operating coil or the contacts of an auxiliary relay may be used in the control circuit of another relay or other control device. For example, an auxiliary relay may be applied to the auxiliary contact circuits of a circuit breaker to coordinate closing and tripping control sequences.

3 — A relay may be auxiliary in its functions even though it may derive its driving energy from the power system current or voltage; for example, a timing relay operating from current or potential transformers.

4 — Relays which, by direct response to power system input quantities, assist other relays to respond to such quantities with greater discrimination, are not auxiliary relays; for example, fault-detector relays.

5 — Relays that are limited in function by a control circuit but are actuated primarily by system input quantities are not auxiliary relays; for example, torque-controlled relays.

**biaxial test:** The relay under test is subjected to acceleration in one principal horizontal axis and the vertical axis simultaneously.

**dependent biaxial test:** The horizontal and the vertical acceleration components are derived from a single-input signal.

**fragility:** Susceptibility of equipment to malfunction as the result of structural or operational limitations, or both.

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[2] ANSI/IEEE publications are available from IEEE Service Center, 445 Hoes Lane, PO Box 1331, Piscataway, NJ 088551331, or from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

[3] IEEE publications are available from IEEE Service Center, 445 Hoes Lane, PO Box 1331, Piscataway, NJ 08855-1331.

[4] This publication is available from Superintendent of Documents, US Government Printing Office, Washington, DC 20402.

**fragility level:** The highest level of input excitation, expressed as a function of input frequency, which an equip ent can withstand and still perform the required Class 1E functions.

**fragility response spectrum (FRS):** A test response spectrum obtained from tests to determine the fragility level of equipment.

**independent biaxial test:** The horizontal and vertical acceleration components are derived from two different input signals, which are phase incoherent.

**octave:** The interval between two frequencies that have a frequency ratio of two. For example, 1 Hz to 2 Hz, 2 Hz to 4 Hz, and 4 Hz to 8 Hz.

**one-third octave:** The interval between two frequencies that have a frequency ratio of 2 1/3. For example, 1 Hz to 1.26 Hz, 1.26 Hz to 1.59 Hz, and 1.59 Hz to 2.0 Hz.

**operating basis earthquake (OBE):** That earthquake that could reasonably be expected to affect the plant site during the operating life of the plant; it is that earthquake which produces the vibratory ground motion for which those features of the nuclear plant necessary for continued operation without undue risk to the health and safety of the public are designed to remain functional.

**operating time:** The time interval from occurrence of specified input conditions to a specified operation.

**protective relay:** A relay whose function is to detect defective lines or apparatus or other power system conditions of an abnormal or dangerous nature and to initiate appropriate control circuit action.

NOTE — A protective relay may be classified according to its operating principle, or performance characteristics.

**required response spectrum (RRS):** The response spectrum issued by the user or agent as part of the specifications for proof testing, or artificially created to cover future applications. The RRS constitutes a mandatory requirement.

**response spectrum (as applied to relays):** A plot of the peak acceleration response of damped, single-degree-of-freedom bodies, at a damping value expressed as a percentage of critical damping of different natural frequencies, when these bodies are rigidly mounted on the surface of interest.

**safe shutdown earthquake (SSE):** An earthquake that produces the maximum vibratory ground motion for which certain structures, systems, and components are designed to remain functional. These structures, systems, and components are those necessary to ensure

a) The integrity of the reactor coolant pressure boundary
b) The capability to prevent or mitigate the consequences of accidents that could result in potential offsite exposures comparable to the guideline exposures of 10 FR, Ch l, Section 100 [3].

**standard response spectrum (SRS):** An RRS that is artificially created to cover the standard testing of relays and whose shape is defined. For example, Figs 1 and 3. The SRS may be terminated at any convenient frequency above 35 Hz.

**test response spectrum (TRS, as applied to relays):** The acceleration response spectrum that is constructed using analysis or derived using spectrum analysis equipment based on the actual motion of the shake table.

**transitional mode:** The change from the nonoperating to the operating mode, caused by switching the input to the relay from the nonoperating to the operating input, or *vice versa*.

**zero period acceleration (ZPA):** The peak acceleration of motion time-history that corresponds to the high-frequency asymptote on the response spectrum.

## 3. Test Preparation

### 3.1 Environmental Conditions

All relay seismic tests shall be conducted under the prevailing ambient conditions of the test laboratory.

### 3.2 Method of Mounting

The test specimen shall be mounted on the test fixture as it normally is while in service, using recommended mounting hardware. The effect of normal electrical connections shall be considered. The test fixture must be a rigid structure to minimize amplification and spurious motion within the frequency range of the test.

### 3.3 Instrumentation

#### 3.3.1 Instrumentation Required

Sufficient instrumentation shall provide

1) Acceleration at mounting surface of relay and table
2) Electrical inputs to relay under test
3) Relay output change of state
4) Operating time of relay under test, if applicable
5) Test response spectrum

#### 3.3.2 Test Tolerances

All test equipment used to monitor the tests in 3.3.1 shall be checked and calibrated periodically in accordance with an established quality control program. The accuracy of the measurements made to monitor the parameters listed in 3.3.1 shall be as follows:

1) The measured acceleration values shall be within ±5% of true value
2) The measured electrical input values shall be within ±5% of true value
3) The measured relay output change of state detector time shall be within ±10% of the true value
4) The measured relay operating time shall be within ±10% of the true value or ± 1 ms, whichever is greater
5) The test response spectrum generation equipment shall produce a plot within ±10%, of the true plot

## 4. Test Conditions

### 4.1 Selection and Preparation of Samples

For seismic testing, a minimum of three specimens is required for the test. These specimens shall be randomly selected from production and shall conform to manufacturer's applicable standards of quality assurance and control. They shall have all calibrated quantities recorded along with manufacturer's tolerances. Reference should be made to ANSI/IEEE 323-1983 [1], 6.3.2 through 6.3.5 for other previbration preparations when the relays are being considered for Class 1E functions.

### 4.2 State of the Relay Under Test

All relays shall be tested in the nonoperating, transition and operating modes. For each of these tests, Table 1 lists (by relay characteristic) the required relay settings and inputs. All relays shall be tested in the transition from the nonoperating to operating mode as specified in Table 1. This test shall be performed by applying an input equal to the nonoperating input followed in time by an acceleration equal to the fragility level established for the device in the nonoperating condition. During the seismic simulation, the relay input shall be changed to the value specified under operating input in Table 1 and the operating time measured. The percentage deviation from zero acceleration test of the same operating input shall be included in the documentation.

## 4.3 Relay Output

### 4.3.1 Contact Monitoring

All multicontact relays that can have a variation of contact formations shall be tested with the following arrangement:

1) All contacts open
2) Half normally open and haft normally closed contacts
3) A contact arrangement that can be proven more severe

**Table 1—Relay Settings and Inputs (Nonoperating and Operating Modes)**

| | |
|---|---|
| | 1. Nondirectional Current Relays |
| a. Instantaneous | |
| Relay setting: | Minimum setting |
| Relay input: | Nonoperating—25% of pickup setting |
| | Operating—200% of pickup setting |
| b. Time delay | |
| Relay Setting: | Minimum setting, time dial |
| Relay input: | Nonoperating—60% of pickup setting |
| | Operating—200% of pickup setting |
| c. Over/undercurrent | |
| Relay setting: | Minimum overcurrent/undercurrent ratio and minimum overcurrent setting |
| Relay input: | Nonoperating—Midway electrically between overcurrent and undercurrent settings |
| | Operating—50% of undercurrent and 200% of overcurrent settings |
| | 2. Directional Current Relays |
| a. Phase overcurrent unit | |
| Relay setting: | Same as single function current relays |
| Relay input: | Same as single function current relays |
| b. Phase directional unit | |
| Relay setting: | Maximum sensitivity |
| Relay input: | Nonoperating—100% voltage and current as in overcurrent unit, with the current voltage phase relationship of unity power factor in the tripping direction. |
| | Operating—50% voltage and current as in overcurrent unit, with the current voltage phase relationship at maximum sensitivity angle in the tripping direction |
| c. Ground overcurrent unit | |
| Relay setting: | Same as single function current relays |
| Relay input: | Nonoperating—0% of current |
| | Operating—200% of pickup setting |
| d. Ground directional unit | |
| Relay setting: | Maximum sensitivity |
| Relay input: | Nonoperating—0% polarizing quantity |
| | Operating—200% of overcurrent unit pickup in the residual current circuit at maximum sensitivity angle in the tripping direction; polarizing voltage to be 10% of continuous rating. |
| | 3. Power or Angle Directional Relays |
| a. Instantaneous | |
| Relay setting: | Maximum sensitivity |
| Relay input: | Nonoperating—100% voltage, 25% rated current at maximum sensitivity angle in the nontripping direction |
| | Operating—50%, voltage, 200% of pickup current at maximum sensitivity angle in the tripping direction |

## Table 1—Relay Settings and Inputs (Nonoperating and Operating Modes) *(Continued)*

| | |
|---|---|
| b. Time delay<br>Realy setting:<br>Relay input: | Maximum sensitivity, time dial<br>Nonoperating—same as for instantaneous power or angle directional relays<br>Operating—same as for instantaneous power or angle directional relays |
| 4. Voltage Relays | |
| a. Undervoltage (Time delay or instantaneous) | |
| Relay setting: | Maximum setting or approximately 90% of rating, whichever is lower |
| Relay input: | Nonoperating—rated voltage |
| | Operating—80% of setting |
| b. Overvoltage (Time delay or instantaneous) | |
| Relay setting: | Minimum setting or approximately 100% of rating, whichever is higher |
| Relay input: | Nonoperating—80% of setting |
| | Operating—120% of setting |
| c. Over/undervoltage (Time delay or instantaneous) | |
| Relay setting: | Minimum overvoltage setting or approximately 110% of rating, whichever is higher |
| Relay input: | Maximum undervoltage setting or approximately 90% of rating, whichever is lower |
| | Nonoperating—rated voltage |
| | Operating—120% of rated for overvoltage setting followed by 80% of undervoltage setting |
| 5. Differential Relays | |
| a. Low impedance | |
| Relay setting: | Maximum sensitivity, minimum slope, and time dial if induction disk |
| Relay input: | Nonoperating—25% of pickup current in the differential circuit and tap current in one restraint circuit |
| | Operating—200% of pickup setting through the differential circuit |
| b. High impedance | |
| Relay setting: | Maximum sensitivity and time dial if induction disk |
| Relay input: | Nonoperating—0% of pickup voltage |
| | Operating—200% of pickup voltage (auxiliary current relay to be tested in accordance with 1.a. of this table |
| c. Linear coupler types | |
| Relay setting: | Maximum sensitivity acceptance test condition as defined in manufacturer's instructions |
| Relay input: | Nonoperating—25% of pickup current or voltage |
| | Operating—200% of pickup current or voltage |
| 6. Temperature Relays | |
| Relay setting: | Minimum setting |
| Relay input: | Thermal indication such as actual temperature or RTD resistance value to be: |
| | Nonoperating—80% of pickup |
| | Operating—120% of pickup |
| | Replica relays to be energized at: |
| | Nonoperating—full load current |
| | Operating—150% of full load current |
| 7. Reclosing Relays | |
| Relay setting: | Instantaneous or minimum time delay |
| Relay input: | Nonoperating—energized in a reset condition |
| | Operating—energized for a reclosure mode |
| 8. Synchronizing and Synchrocheck Relays | |
| Relay setting: | Minimum angular setting and time dial delay where applicable |
| Relay input: | Nonoperating—completely de-energized except see 4.3.3 |
| | Operating—rated voltage on both sides at 0° |
| 9. Timing Relays | |

**Table 1—Relay Settings and Inputs (Nonoperating and Operating Modes)** ***(Continued)***

| | | | |
|---|---|---|---|
| Relay setting: | Minimum time delay | | |
| Relay input: | Nonoperating—completely de-energized | | |
| | Operating—energized normally | | |
| 10. Underfrequency Relays | | | |
| Relay setting: | 1 Hz below normal system frequency with a minimum delay | | |
| Relay input: | Nonoperating—100% rated voltage at normal system frequency | | |
| | Operating—85% rated voltage at 2 Hz below setting | | |
| 11. Distance Measuring Relays | | | |
| Relay setting: | Maximum sensitivity with the reach set at 25% of maximum ohmic setting | | |
| Relay input: | Nonoperating—rated voltage and current at unity power factor in the tripping direction | | |
| | Operating—200% of rated current at maximum sensitivity angle and voltage produced by an impedance of 50% of the relay setting | | |
| 12. Auxiliary Relays | | | |
| a. Latching relays | | | |
| Relay setting: | Normal calibration with relay latched and unlatched | | |
| Relay input: | Completely deenergized | | |
| b. Contact multipliers and contactors | | | |
| Relay setting: | Normal calibration | Case 1 | Case 2 |
| Relay input: | Nonoperating | 0% of rating | 100% of rating |
| | Operating | 80% of rating (ac)<br>100% of rating (dc) | 0% of rating |
| 13. Current or Voltage Balance Relays | | | |
| Relay setting: | Maximum sensitivity and minimum time delay | | |
| Relay input: | Nonoperating—Three phase, balanced current or voltage at rated magnitude | | |
| | Operating—An imbalanced condition representing 120% of the sensitivity setting | | |

All relays that have single contacts, or groups of contacts, or both, between external terminals shall be tested so that each set of external terminals shall be monitored separately. As an alternative, all normally open contacts can be connected in parallel and all normally closed contacts can be connected in series when the relays are in the nonoperate condition. When using the alternative connection for relays in the operating mode, the reverse configuration shall be used (that is, all normally open in series, and all normally closed in parallel).

### 4.3.2 Output Loading

The source voltage for all contact loadings shall be 125 V dc or rated, whichever is less.

If a contact circuit between a pair of external terminals has a seal-in or holding coil function, the contact load circuit shall be such that it draws twice rated seal-in or holding current from the source voltage. The load shall have a series $L/R$ ratio of 0.04 s. This load shall be applied for nonoperating and operating mode tests. For all contacts without a seal-in or holding coil function, the contact load shall be as shown in Table 2. The output load of all relays with a solid-state output shall be 1 A resistive from a 125 V dc source or as rated, whichever is less.

### 4.3.3 Control Power

If the relay uses external control power, it shall be applied during test at rated voltage.

### 4.3.4 Relay Operate Time

Relay operate time shall be the time measured from initiation of electric input to completion of 2 ms sustained output minus 2 ms.

## 4.4 Maintenance and Adjustment of the Relay During Test

At the completion of any given fragility test level, it is permissible to inspect the relay and make any adjustments to ensure the relay's integrity for the next series of tests. Any adjustments made shall be recorded as per Section 6

# 5. Test Methods

## 5.1 Introduction

The principal aim of this standard, as stated in 1.2, is to establish standard methods to generate data that define the seismic capability of protective and auxiliary relays. These methods employ what has been called Fragility Testing in IEEE Std 344-1987 [2], and they have also been referred to as generic testing in the industry. These data will aid the designer of a nuclear power plant in the selection of relays for his/her application since their seismic capability will be catalogued and can be compared based on performance under standardized tests.

The use of a relay for a given function in any one application requires that it be qualified for that specific nuclear power plant. The qualification of relays for such specific applications is only a secondary aim of this standard because it is not practical to perform fragility testing for every conceivable set of operating conditions and seismic environments. It may be possible to use the fragility data described above in the qualification of a relay when the electrical settings, the failure criteria, and the seismic conditions employed in fragility testing satisfy the requirements of the specific application. When the fragility data cannot be extended or otherwise justified to be applicable, it shall be necessary to qualify the relay using proof testing for that specific application. For these reasons this standard

1) Gives specific direction in establishing standards for fragility testing
2) It also provides guidance for proof testing

## 5.2 Fragility Testing

To define the seismic environment for standardized fragility tests, a number of practical considerations should be taken into account.

1) The seismic environment, both in terms of the levels and frequencies of vibration, vary from one situation to another and from one relay mounting location to another.
2) It is desirable that the capability data of relays that are generated in fragility testing be applicable to as many different locations as is practical.
3) One approach is to construct an SRS shape that is sufficiently broadband in its frequency content it envelopes, within practical limitations, the individual requirements for all locations. Using this SRS it is possible with a minimum of testing to meet most seismic requirements. In this standard this is the preferred approach. This method of fragility testing is described in 5.2.1.1. In some cases, this approach has practical disadvantages that required an alternative method of fragility testing be made available to the relay manufacturer or user. The reasons for this are briefly described as follows:

4) The width in terms of frequency of the region of maximum amplification of acceleration of the broadband SRS of (3) is much greater than the typically narrowband region of the RRS for each specific location. In practice it has been found that the zero-period acceleration (ZPA) during such a broadband test is much higher relative to the level of the amplified region of the response spectrum, compared to that of the actual narrowband requirement in any specific application. In other words, the broadband SRS shape of (3) produces a severe overtest. Therefore, in the interests of producing a relatively simple test, a severe seismic requirement is imposed that differs significantly from that which applies for any one location. It is practical, therefore, to consider a second method of fragility testing as an alternative, which imposes a more realistic seismic environment.
5) The second approach is to divide the broadband SRS shape into a series of narrower spectrum shapes which more closely represent the requirements of specific locations. This alternative is described in 5.2.1.2. By testing separately for each of the component peaks, capability data is developed that meet the intent of the broadband SRS shape while imposing a seismic environment that more realistically fits the actual requirements. The shaker-table input motion to generate each component peak may be put on a tape and thus by testing for each peak in sequence essentially only one test is required.

**Table 2—Contact Loading During Tests**

| Contact Status During Test | | Load |
|---|---|---|
| Nontransition mode | Open | 2A or more $L/R = 0.04$ s |
| | Closed | 25 mA or less |
| Transition mode | Open to closed | 25 mA or less |
| | Closed to open | 25 mA or less |

### 5.2.1 Fragility Test Options

#### 5.2.1.1 Broadband Multifrequency Fragility Testing

Repeatable multifrequency input motions shall be used in the fragility testing. It is the test's objective to produce an FRS that envelopes the SRS shape using a biaxial input motion. The method of achieving an acceptable biaxial test is described in 5.2.2.

Figure 1, the SRS shape (at 5% damping), is defined by four points:

Point A = 1.0 Hz and an acceleration equal to 25% of the ZPA

Point D = 4.0 Hz ard 250% of the ZPA

Point E = 16.0 Hz and 250% of the ZPA

Point G = 33.0 Hz and a level equal to the ZPA

The range of maximum amplification of acceleration, 4.0 Hz to 16.0 Hz, has been designed to most realistically match the range of peak acceleration input to the relays by the equipments and panels on which they are mounted. Below 4.0 Hz, it is possible to encounter building frequencies to as low as 1.5 Hz. The resulting panel motions would probably be enveloped by the line AD since the amplification of panels at these low frequencies is small. Above 16 Hz, there are equipment and panel resonances; however, the seismic energy input in this range is generally reduced and, therefore, the motions would probably be enveloped by the line EG.

The horizontal and vertical shaker-table input components for the test should be equal within the capability of the test equipment. For the equalization of the input motion, the multifrequency input signals should be shaped at one-third octave frequency intervals or less. The duration of the test should at least meet the requirements of 5.2.3.

The FRS will in all probability not have a shape that exactly matches the SRS of Fig 1. A relay will be given an acceleration g rating based on the lower value of the horizontal or vertical ZPA, or point G of Fig 1, when the FRS has completely enveloped the shape of Fig 1. Figure 2 illustrates the use of this method of seismically rating a relay. In this example, note that the point G on the SRS defines the g rating of the relay as 2.68: see 5.2.5.

### 5.2.1.2 Narrowband Multifrequency Fragility Testing

Repeatable multifrequency input motions shall be used in the fragility testing. It is the test's objective to produce a series of narrow band FRS that envelope the series of narrowband standard response spectrum shapes using biaxial input motions. The method of achieving an acceptable biaxial test is described in 5.2.2.

In dividing the broadband curve of Fig 1 to produce a number of component narrowband curves, a practical compromise must be made. On the one hand, as the width of the peak is reduced the test approaches the realism of an actual real-world requirement, and on the other, as the number of curves increases, the sophistication of the test method escalates. It is recommended that as a maximum the amplified region 4.0 to 16.0 Hz be divided into six component peaks, each one-third octave in width, as shown by the standard response spectrum shapes in Fig 3 (at 5% damping). Where a more conservative simulation is selected, the test may be performed by lumping pairs of narrow peaks to produce three separate motions, or lumping peaks in two groups of three to produce two separate input motions. The breakpoint frequencies that define the component peaks are as follows:

4.0 Hz, 5.0 Hz, 6.3 Hz, 8.0 Hz, 10.0 Hz, 12.5 Hz and 16.0 Hz. The SRS shape is defined by the following points.

Point A = 1.0 Hz and an acceleration equal to 50% of the ZPA

Point B = 2.5 Hz and 250% of the ZPA

Point C = 3.2 Hz and 250% of the ZPA

Point D = 4.0 Hz and 500% of the ZPA

Point E = 16.0 Hz and 500% of the ZPA

Point F = 20.0 Hz and 250% of the ZPA

Point G = 33.0 Hz and a level equal to the ZPA

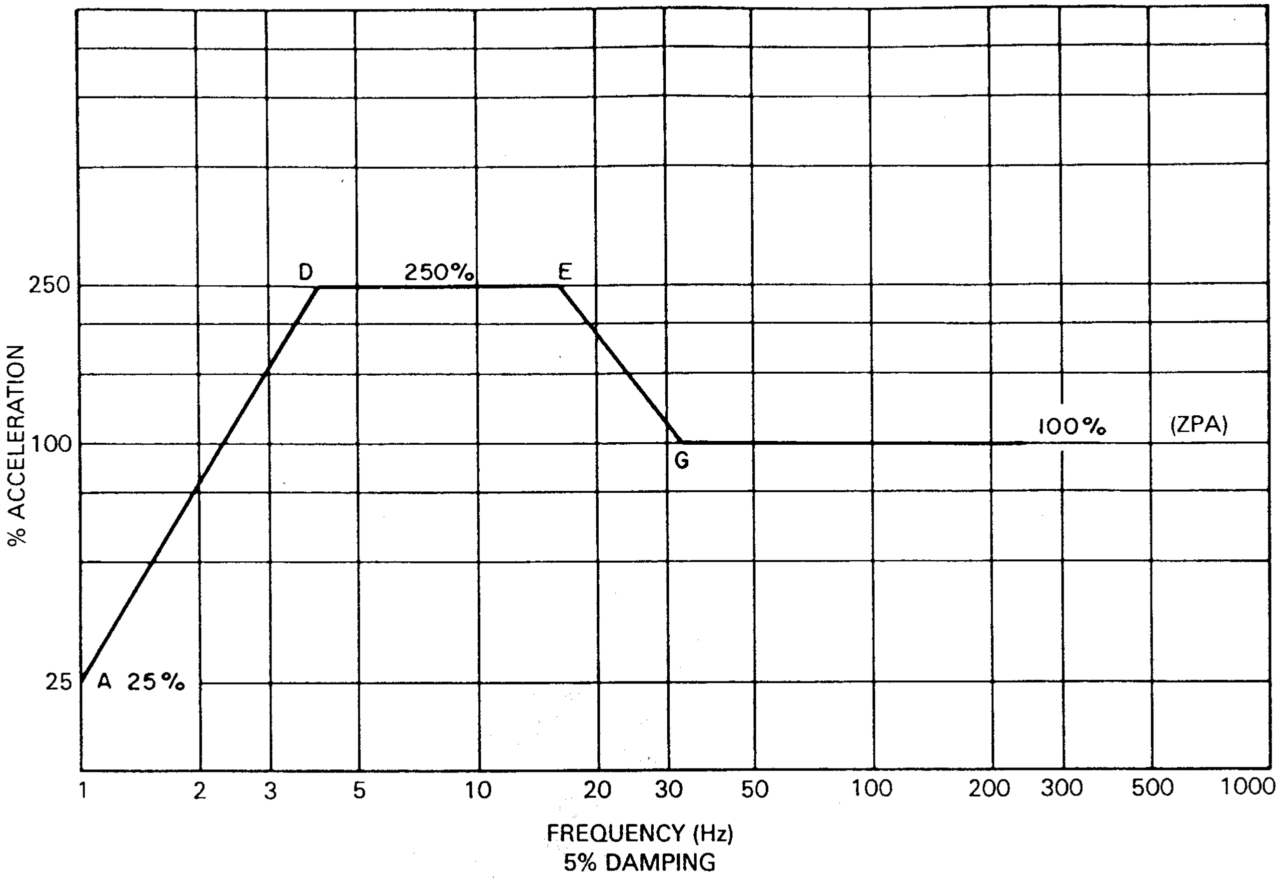


**Figure 1—Multifrequency Broadband Standard Response Spectrum Shape**

The narrow spectrum shape of Fig 3 has a broadband shoulder under the narrow peaks that is half the level of the peaks and ranges from 2.5 Hz to 20 Hz. This shoulder is maintained for each peak. Its purpose is to envelope secondary peaks due to other lesser modes of vibration that occur in many applications. The side slopes of the narrow peaks are such that they meet the broadened shoulder at the next one-third octave interval frequency point.

The horizontal and vertical shaker-table input components for the test should be equal within the capability of the test equipment. For the equalization of the input motion the multifrequency input signals should be spaced at one-third octave frequency intervals or less. The duration of each narrowband test should at least meet the requirements of 5.2.3.

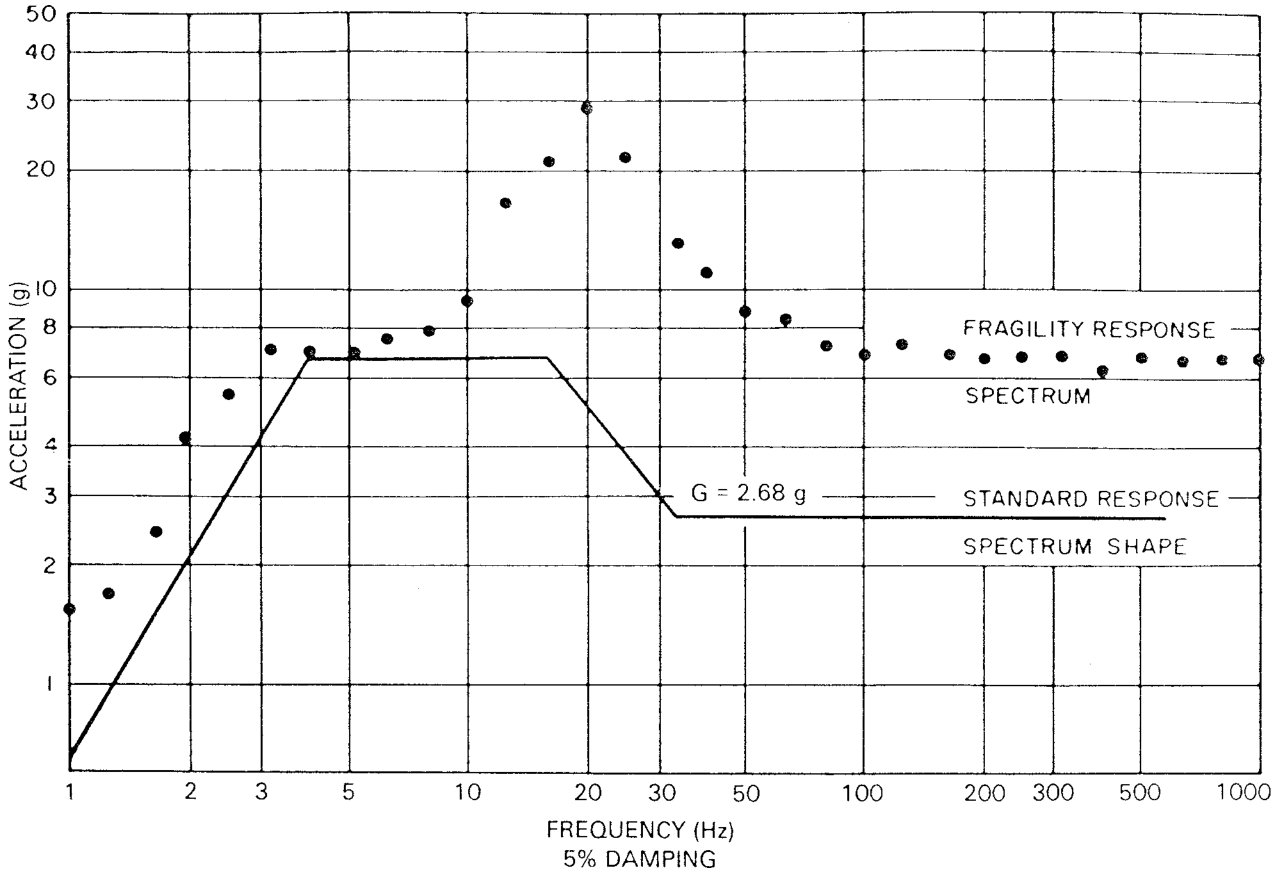


Figure 2—Fitting the Standard Response Spectrum Shape to a Fragility Response Spectrum

The FRS for each component peak will in all probability not have a shape that exactly matches Fig 3. A relay will be given an acceleration g rating based on the lower value of the horizontal or vertical ZPA, or point G of Fig 3, when the FRS has completely enveloped that component peak SRS shape of Fig 3. The actual g rating for the relay will be the smallest of the values obtained from the test samples for each given narrowband SRS. Figure 4 illustrates the use of this method of seismically rating a relay, by establishing the g level of point G for a test designed to envelope the 8 Hz to 10 Hz component peak. In this example note that the point G on the SRS defines the g rating of the relay at 2.68; see 5.2.5.

### 5.2.2 Multiaxis Testing

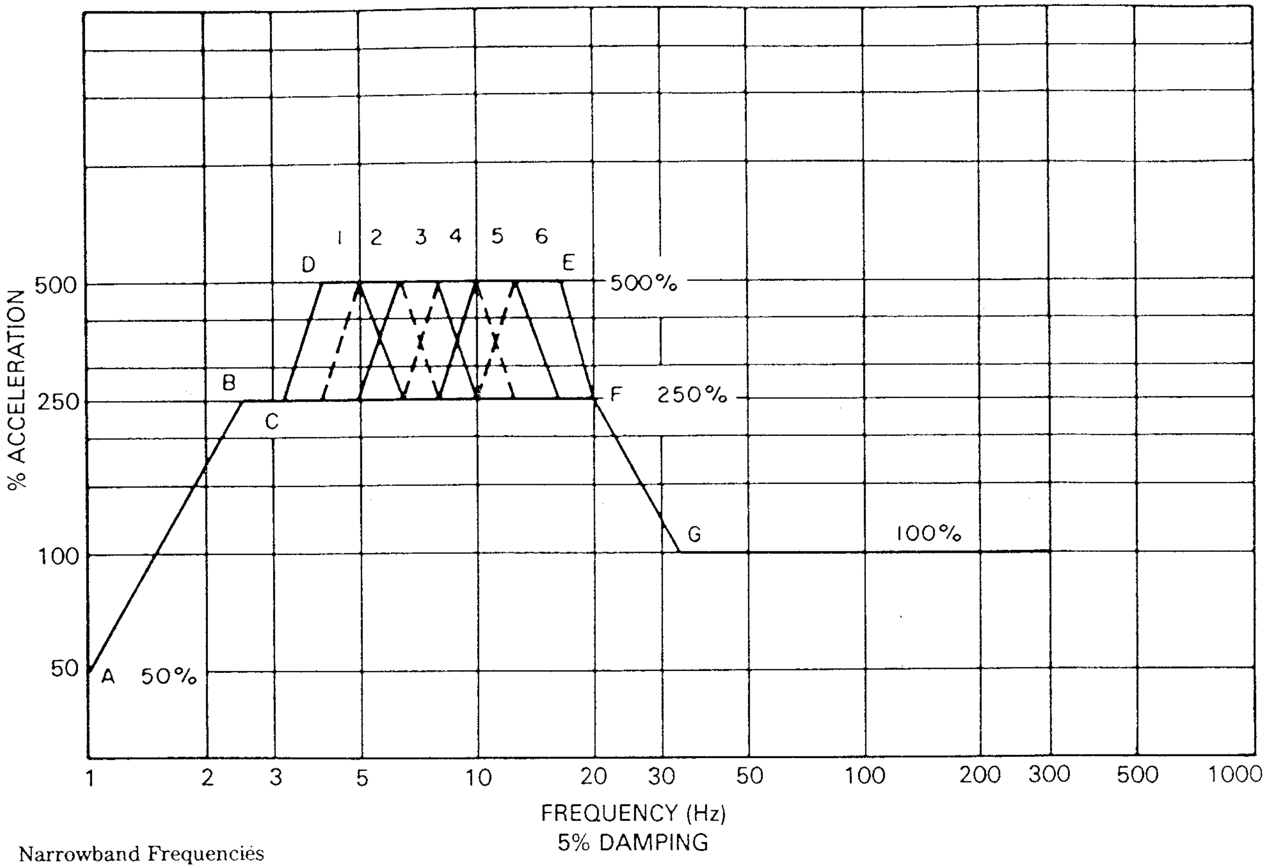
Seismic ground motion occurs simultaneously in all directions in a random fashion. The direction of test input motion should, therefore, be in all three principal axes simultaneously. At the present time, however, two-axis test facilities are limited and three-axis facilities are nonexistent; therefore, two satisfactory biaxial alternatives are allowed.

It is the test's objective to develop a FRS that reproduces the standard response spectrum shapes of Fig 1 or Fig 3 using a biaxial multifrequency input motion. The horizontal and vertical levels of the components of the motion shall be equal within the capability of the test equipment.

When identical biaxial inputs are used in the two axes, which is always the case with a single thruster inclined at 45° to the horizontal plane, four tests shall be made.

1) With the inputs in phase
2) With one input 180° out of phase
3) With relays rotated 90° about the vertical axis and the inputs in phase
4) With the relay orientation as in (3) but with one input 180° out of phase

When a single inclined thruster is used, the 180 out-of-phase input is achieved by rotating relays 180 about the vertical axis for tests (2) and (4).



Narrowband Frequencies

| SRS No | Hz |
|---|---|
| 1 | 4.0-5.0 |
| 2 | 5.0-6.3 |
| 3 | 6.3-8.0 |
| 4 | 8.0-10.0 |
| 5 | 10.0-12.5 |
| 6 | 12.5-16.0 |

**Figure 3—Multifrequency Narrowband Standard Response Spectrum Shape**

### 5.2.3 SSE and OBE, and the Duration of Testing

The duration of each test designed to reproduce the SRS shape shall be at least 15 s in duration.

Prior to conducting tests at the rated g level (the SSE level), devices shall be subjected to five times or more to at least half of the rated level (the OBE level). These tests are to be performed in any orientation. Tests at the OBE level are for fatiguing exposure only. The devices under test need not be energized or any failure criteria exercised.

The duration of each OBE test shall at least equal the 15 s duration of the SSE test. Credit may be taken for any test preceding the SSE test, if shown to be greater than or equal in severity to the required OBE. Fragility test duration, by their nature, will normally far exceed the preceding 15 s duration requirement.

### 5.2.4 Determination of Failure

#### 5.2.4.1 Output Change of State

Failure is an unauthorized electrical output change of state in the output circuit lasting 2 ms or more.

The time measuring circuit should have a reset time of less than 200 µs to avoid integration of a number of short pulses, and an operating point of 50% of applied voltage. In addition, the unauthorized operation of a defined external auxiliary device operated by the relay under test will also be considered as a failure.

#### 5.2.4.2 Operability

The inability of the relay to perform during transitional testing shall be classified as a failure.

#### 5.2.4.3 Structural Damage

Structural members of the relay exhibiting any fracture damage or plastic yielding that might cause misalignment or failure of the relay shall be classified as test failure.

#### 5.2.4.4 Post Test

Failure of the relay to perform within twice accepted tolerances as referenced in 4.1 after the fragility testing is completed without readjustment shall be classified as a test failure.

### 5.2.5 Application of g Rating Data

Seismic data produced by testing a series of relays can be presented in catalog data by referring to the g level at the ZPA and the method of test, that is broadband or narrowband.

NOTES:

1 — The g rating is based on the lower value of the horizontal or vertical components and not on the resultant of the two.

2 — The minimum fragility level of the test samples described in 4.1 shall be used.

Thus for industry use, the SRS of Fig 1 or Fig 3 becomes the TRS for the application engineer. The application engineer can select seismically qualified relays by obtaining from the catalog data sheets the g values at the ZPA that can be used to construct a TRS similar to Fig 1. Based on his/her unique relay requirement, he/she can compare the needed seismic environment as described in a specific RRS to the prequalified seismic environment (derived from Fig 1 or Fig 3) and select qualified relays accordingly. The additional requirement in the qualification of relays is that the standardized failure criteria employed in the fragility testing matches those, or can be extended to or otherwise justified to apply, in his/her specific application, and that electric inputs to the relay during fragility testing are compatible with his/her application.

An additional note of explanation is necessary in comparing the SRS shapes of Figs 1 and 3. In the examples that illustrate the use of SRS shapes, Figs 2 and 4, both relays have a g rating of 2.68. Because the narrowband SRS shape has a much higher ratio of the peak response (points D to E in Fig 3) to the ZPA (point G) compared to that in Fig 1, the two 2.68 g relays are not equivalent. It can be seen that the relay that was tested using the narrowband approach has been subjected to a much higher seismic environment and, consequently it is the superior relay; see Fig 5. In summary, when two relays have been tested to the two methods their capability cannot be compared based on the ZPA alone, rather the entire SRS shape must be considered.

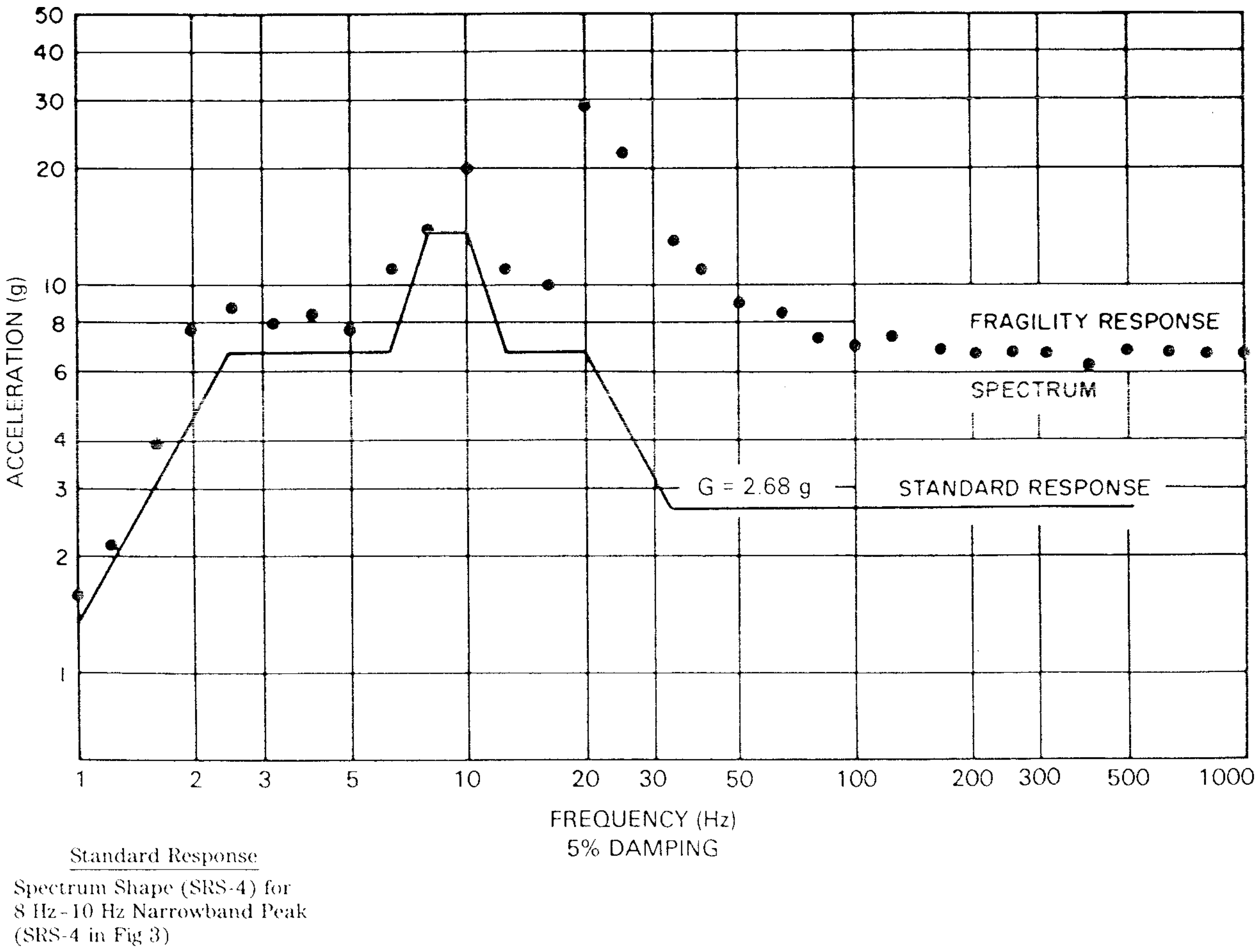


**Figure 4—Fitting the Narrowband Standard Response Spectrum Shape (SRS-4) to a Fragility Response Spectrum**

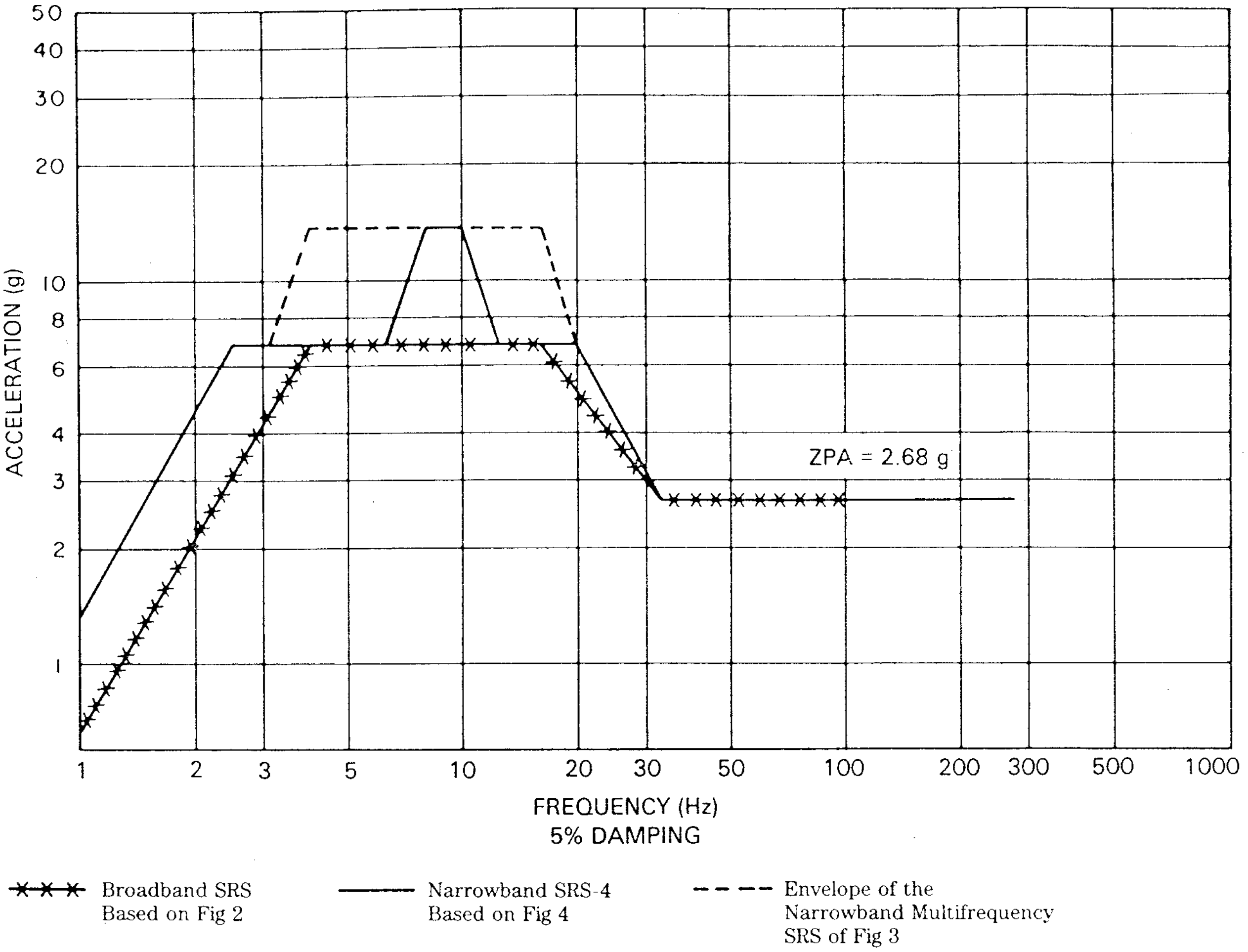


Figure 5—Comparison of the Two Multifrequency Testing Methods

## 5.3 Proof Testing

A proof test shall be used to qualify relays for a particular application or to a particular requirement using the acceptable methods described in IEEE Std 344-1987 [2]. As such, a detailed testing specification must be provided. Items to be considered in this specification are as follows:

### 5.3.1 Seismic Input

The selection of the seismic input should achieve the following.

1) A TRS that envelopes the RRS using single-or multiple-frequency input as required to provide a conservative test table motion
2) A peak input acceleration equal to or greater than the ZPA of the RRS. The TRS shall be plotted to that frequency that gives a clear indication of the ZPA
3) No frequencies need be input above the ZPA frequency of the RRS
4) A duration equal to a minimum of 15 s in each test
5) At least 5 OBE level tests should precede the SSE level test

### 5.3.2 Rigid Mounting

When relay equipment to be tested is rigidly mounted to the test table, the seismic input to the shaker table shall be such that the TRS envelopes the RRS applicable at the mounting position of the relay in its normal service location. The mounting location RRS shall be obtained either from test data or calculation of accelerations imposed on the relay in its normal service location.

### 5.3.3 Determination of Failure

For proof testing, the detailed specification shall define what constitutes failure. This will not necessarily be the same as the standardized failure criteria described in 5.2.4 which is used in fragility testing.

# 6. Documentation

## 6.1 General

The documentation for each device shall show its performance when subjected to seismic accelerations.

## 6.2 Test Report

The test report shall contain the following information.

1) Dates of test
2) Reference to QA procedures followed
3) Test specimen description (identification and specification)
4) Test facility name and location
5) Test facility and equipment hookup description
6) Test equipment certification
7) The general test description shall be given to clearly demonstrate that all requirements of Section 5 have been met
8) Test data in the form of acceleration versus frequency curves, tables and photographs, and records of any adjustments made to the relay during the test
9) Test facility temperature, humidity, and pressure ranges during tests
10) Results, conclusions and analysis of failures, and specific device limitations
11) Approved signatures and date

# 7. Generalization of Test Results

It is desirable to minimize the testing requirements of qualifying relays for seismic conditions, however, generalization of test results must be made with good engineering judgement and periodically reviewed for significant design changes that could affect the qualification of an entire line of relays, and shall be documented by analysis. There are obvious situations where the test results on a particular model of relay may be valid information for many relays of the same type, provided the mechanism directly associated with the device's output, its electrical rating, and its packaging are justified to be equivalent. A particular relay may consist of several subassemblies. A test on the complete package is directly applicable to the relay using only one or more of the identical subassemblies; however, the tests on a relay incorporating only one of these subassemblies is not valid for the complete relay.

These considerations should be made before the specimens are selected for testing.