WESTINGHOUSE CLASS 3

WCAP-9750

METHODOLOGY FOR THE SEISMIC QUALIFICATION OF WESTINGHOUSE WRD SUPPLIED EQUIPMENT

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ABSTRACT

This Topical Report describes the methodology used by Westinghouse Water Reactor Divisions (WRD) to seismically qualify seismic Category I equipment. In this report emphasis is placed on the seismic qualification of electrical equipment in accordance with IEEE 344-1975 and the Westinghouse Electrical Equipment Qualification Program described in WCAP 8587. However, the methods described herein are also applicable to mechanical equipment.

Westinghouse employs four methods for the seismic qualification of equipment; analysis, test, a combination of these two methods, and qualification based on previous tests. The static and dynamic analysis methods employed by Westinghouse utilize state of the art techniques. When equipment is qualified by test, Westinghouse utilizes both single frequency and multiple frequency test methods. This Topical Report describes both test methods in detail and includes a description of the test equipment, input motion, and test procedures used in the qualification testing.

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1.0 GENERAL

1.1 INTRODUCTION

This report describes the methods used by Westinghouse WRD to demonstrate the seismic qualification of seismic Category I equipment. Although the methods described herein primarily address the seismic qualification of electrical equipment in accordance with IEEE 344-1975, they are also applicable to the seismic qualification of mechanical equipment such as tanks, pumps, and heat exchangers.

The seismic qualification methods used by Westinghouse have evolved since the early 1960s in parallel with technological advances and new regulatory requirements. Section 2.0 briefly describes this evolution. Currently, four basic methods are used for seismic qualification; test, analysis, a combination of test and analysis, and previous test. Section 3.0 provides a general description of the different test and analysis methods currently used by Westinghouse as well as justification for the use of previously completed seismic qualification as meeting the requirements of IEEE 344-1975. The analysis procedures, both static and dynamic, utilized by Westinghouse are described in Section 4.0. Details of the test equipment, types of tests, test procedures, test inspections, required input motions, and functional operability are provided in Section 5.0.

Information relative to the seismic qualification of specific equipment is provided in stress reports, and design reports for mechanical equipment, and the Equipment Qualification Data Packages (Reference 1) for electrical equipment.

1.2 PURPOSE

The purpose of this Topical Report is to:

a. Describe the seismic methodology used by Westinghouse to qualify equipment.

b. Demonstrate that the seismic methodology used by Westinghouse for electrical equipment is consistent with the requirements of IEEE 344-1975.

c. Supplement the general program requirements for the qualification of electrical equipment that are described in WCAP 8587 (Reference 2).

1.3 SCOPE

The seismic qualification methodology described herein applies to seismic Category I electrical equipment that are qualified to the requirements of IEEE 344-1975 and can also be applied to selected seismic Category I mechanical equipment. The equipment qualified with these methods is identified in the Applicant's Safety Analysis Report.

1.4 LICENSING INTERFACE

The Westinghouse IEEE 323-1974 Equipment Qualification Program is defined in WCAP 8587. Supplement 1 to WCAP 8587 identifies the seismic qualification levels and spectra to be addressed by the qualification program. This Topical Report provides a detailed description of the seismic qualification methodology used by Westinghouse to demonstrate seismic qualification to the requirements and parameters defined in WCAP 8587. This Topical Report, along with WCAP 8587 and its supplement, constitute the Westinghouse licensing basis for the seismic qualification of electrical equipment. These Topical Reports are incorporated by reference in an Applicant's Safety Analysis Report and are submitted to the NRC as the generic basis for the Westinghouse IEEE 323-1974 Equipment Qualification Program.

This Topical Report may also be referenced in an Applicant's Safety Analysis Report when the methodology described herein is applied to the seismic qualification of mechanical equipment.

1.5 DEFINITIONS

a. natural frequency. The frequency or frequencies at which a body vibrates due to its own physical characteristics (mass, shape) and elastic restoring forces brought into play when the body is distorted in a specific direction and then released, while restrained or supported at specified points.

b. octave. The interval between two frequencies that have a frequency ratio of two.

c. operating basis earthquake (OBE). That earthquake which 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 power plant necessary for continued operation without undue risk to the health and safety of the public are designed to remain functional without sustaining damage.

d. required response spectrum (RRS). The response spectrum issued by the owner or his agent as part of his specifications for proof testing, or artificially created to cover future applications. The RRS constitutes a requirement to be met.

e. response spectrum. A plot of the maximum response of single-degree-of-freedom bodies, at a damping value expressed as a percent of critical damping of different natural frequencies, when these bodies are rigidly mounted on the surface of interest (that is, on the ground for the ground response spectrum or on the floor for the floor response spectrum) when that surface is subjected to a given earthquake's motion as modified by any intervening structures.

f. safe shutdown earthquake (SSE). That earthquake which 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 assure: (1) the integrity of the reactor coolant pressure boundary, (2) the capability to shutdown the reactor and maintain it in a safe shutdown condition, or (3) the capability to prevent or mitigate the consequences of accidents which could result in potential offsite exposures comparable to the guideline exposures of the Code of Federal Regulations. Title 10, Part 100 (December 5, 1973).

g. sine dwell. For test purposes, this refers to sinusoidal input with a constant frequency and amplitude.

h. sine sweep. For test purposes, this refers to sinusoidal input with continuously varied frequency.

i. sine beats. A continuous sinusoid of one frequency, with the amplitude modulated by a sinusoid of a lower frequency.

j. test response spectrum (TRS). The response spectrum that is constructed using analysis or derived using spectrum analysis equipment based on the actual motion of the shake table.

k. zero period acceleration (ZPA). The acceleration that appears as the constant portion of a response spectrum in the highest frequency range.

2.0 HISTORY

2.1 ANALYSIS METHODS

The nuclear industry has been involved with the seismic qualification of equipment since the mid 1960's. Originally, a large portion of the qualification of mechanical equipment was performed using static 'g' analysis methods. With this method, the inertial effects of the earthquake are represented by equivalent static loads applied to the component. The qualification level is specified as an acceleration value relative to gravity. The force on a given mass can then be expressed as the product of the mass, the acceleration of gravity and the ratio of the seismic load to the acceleration of gravity. As early as 1965 seismic loads were accounted for in this manner in analysis of the steam generator, reactor coolant pump and reactor pressure vessel.

By the early 1970's the disadvantages of static 'g' analysis methods were recognized for components or system that were not rigid i.e., contained natural frequencies below 33 Hz. As a result, static methods were abandoned for most non-rigid components and all piping systems supplied by Westinghouse.

Response spectrum analysis techniques were developed to provide additional analysis capability. Response spectrum analysis involves the computation of inertial forces dependent on the natural frequencies of the structure and the damping. To obtain the natural frequencies, a mathematical model is developed that consists of lumped masses and structural members to simulate the equipment being qualified. In 1971 the first response spectrum analysis of a Westinghouse steam generator was completed and, soon after, analyses for other components and systems were performed. These analyses used a seismic response spectrum in one horizontal and one vertical direction. By 1973 three dimensional analyses were performed with two horizontal and one vertical spectrum. In May, 1974 the NRC accepted WCAP-7921 (Reference 3) which presented and justified the damping values Westinghouse uses for three dimensional analysis.

During the mid 1970's time history seismic analysis techniques were developed and used for equipment qualification and analysis of several primary coolant systems. Time history structural analysis of a component or structural system is performed by applying an acceleration time history to a mathematical representation of the component or system being analyzed. The mathematical models used are similar to those described above for response spectrum analysis.

Seismic analysis now being performed by Westinghouse to satisfy IEEE 344-1975 requirements use state-of-the-art techniques as described in Section 4.0. These techniques are consistent with current regulatory requirements.

2.2 TEST METHODS

In 1969 Westinghouse began seismic qualification of electrical equipment by test for complex electrical equipment not amenable to seismic qualification by analysis. Components such as transmitters, process control equipment, solid state protection system, and static inverters were included in this program. The results of these tests were reported in WCAP-7817 (Reference 4) and WCAP 7821 (Reference 5) and submitted to the NRC for review in early 1972. The qualification methodology employed at that time was generally single axis single frequency tests, the same as specified in IEEE-344-1971. The NRC formally accepted these WCAP's in January 1973 as a basis for the licensing of Westinghouse plants.

WCAP-7817 (7821) was referenced for specific plant applications until December of 1974 when the NRC recinded its previous approval and issued questions concerned with the justification of the test methods that were used. Finally, in June of 1975, these WCAP's were declared unacceptable for further reference until more tests or analysis were performed to verify the conservatism of the original qualification methodology. The major concern identified by the NRC was the use of single axis sine beat testing. This concern surfaced with the issuance of IEEE-344-1975. That document limited single axis sine beat testing to situations where the equipment being qualified responded independently in three orthogonal axes. If independence could not be demonstrated, then the three dimensional character of an earthquake was required to be simulated.

In July of 1975, Westinghouse proposed a supplemental seismic qualification program. This program had three major objectives. The first and most important objective was to demonstrate that the previous single axis sine beat testing conservatively demonstrated the equipment's seismic capability. The accomplishment of this objective required some additional testing of certain equipment selected by the NRC using simulated multiple frequency inputs in more than one axis. The second and third objectives of this program were to demonstrate bistable operability during a seismic event and to address the potential for spurious operation resulting from high 'g' levels. Westinghouse completed the supplemental qualification program and submitted several qualification reports (e.g. References 6, 7, and 8) to the NRC.

To review the results of the supplemental seismic qualification program and to verify that adequate margin exists for equipment tested by Westinghouse prior to May 1974, the NRC performed a seismic audit of WRD supplied electrical equipment in 1975-76. The audit was led by the NRC's Mechanical Engineering Branch with the cooperation of the Electrical Instrumentation and Control Systems Branch. As part of the audit, tours of Westinghouse test facilities were held and specific pieces of equipment were inspected at plant sites. Determinations of the adequacy of test methods were made with reference to actual equipment configuration. Seismic test parameters such as equipment frequency, test amplitude, and test duration were reviewed. The Mechanical Engineering Branch reported (Reference 9) that, based on their review, adequate assurance existed that the electrical equipment studied could withstand an SSE. Although no generic NRC acceptance on the supplemental testing was received, it has been used to demonstrate the seismic qualification of electrical equipment for specific plants that have been licensed by the NRC.

With the issuance of Regulatory Guide 1.100, the methods of IEEE-344-1975 received NRC endorsement (with some modifications) as an adequate basis for seismic qualification of electrical equipment. Any seismic qualification testing that is performed by Westinghouse in the future will utilize the seismic methodology described in this document. As previously stated this methodology is consistent with the requirements of IEEE 344-1975.

3.0 QUALIFICATION METHODS

3.1 GENERAL

This section presents a general description of the seismic qualification methods used by Westinghouse. Four general approaches to seismic qualification are utilized; analysis, test, a combination of analysis and test, and qualification based on previous testing. Rationale for the selection of a particular test or analysis method is presented below and a description of the criteria associated with each of these two methods is presented in Sections 4.0 and 5.0. Section 3.4 describes how Westinghouse combines analysis and testing to qualify equipment. Qualification based on previous testing performed by Westinghouse is used when the criteria established in Section 3.5 are satisfied.

3.2 ANALYSIS METHODS

Analysis is utilized by Westinghouse for the seismic qualification of equipment when one of the following conditions is met:

a. The equipment is too large or the external loads, connecting elements, or appurtanances cannot be simulated with a shaker table test.

b. The only requirement that must be satisfied relative to the safety of the plant is the maintance of structural integrity (mechanical equipment only).

c. The component represents a simple linear system or nonlinearites can be conservatively accounted for in the analysis.

The seismic qualification of electrical equipment by analysis alone is not employed by Westinghouse WRD. However, analysis is employed to supplement tests or to provide verification that test results are applicable for a particular configuration.

There are two analytical approaches used by Westinghouse; static analysis and dynamic analysis. Details of these two methods are provided in Section 4.0. This section presents an overview of the methods and justification for their application.

3.2.1 STATIC ANALYSIS

Static seismic analysis methods are used in most cases for equipment evaluation if all of the natural frequencies of the component are above 33 hz. Typical types of equipment with natural frequencies above 33 hz include tanks and horizontal pumps. The equipment is evaluated by multiplying the design 'g' level by the equipment mass. It must be demonstrated that the actual zero period acceleration (ZPA) 'g' level at the equipments location in a particular plant is below the level used for the qualification. Since it is generally accepted that earthquake motion accelerations are not amplified above 33 hz, the static 'g' analysis method provides a realistic technique to analytically simulate seismic loads.

The static 'g' approach is also used for some equipment that has one natural frequency below 33 hz. In these instances, evaluations are performed to demonstrate that the design 'g' level is greater than the peak 'g' value of the actual response spectrum at the equipment natural frequency. The use of this technique for non rigid equipment is justified based on the following.

a. Components with only one natural frequency below 33 hz can be represented as rigid equipment with higher 'g' loads.

b. The design 'g' level is higher than the actual level at the equipment natural frequency.

c. The response of equipment is highest at the masses furthest from the supports and lowest at the masses closest to the supports. Static 'g' analysis assumes the largest 'g' value for the entire mass and, therefore, represents a conservative approximation of the total response.

3.2.2 DYNAMIC ANALYSIS

Dynamic analysis techniques are used when the component (e.g. steam generator, reactor coolant pump) being qualified has several natural frequencies below 33 Hz. Two methods of dynamic seismic analyses are employed by Westinghouse, response spectrum and time history.

The response spectrum method of dynamic analysis is the most common form for representing the seismic excitation of a component. Instead of applying a single acceleration to a structure, as is done for static analysis, the acceleration appropriate to a natural frequency of the structure is obtained from the response spectrum and used to calculate the inertial force.

In performing a time-history seismic analysis of a structure or component, the representation of the excitation is generally given as an acceleration time history. For a building or structure supported on the ground, this could be either an acceleration time history from an actual strong motion earthquake or a synthetic acceleration time history for the specified site motion. The acceleration time history response of the equipment support location is used for equipment or components installed in a building or structure.

For either dynamic analysis method, the structure or component is modeled similarly. The equipment is represented by a number of lumped masses that simulate its inertial characteristics. The masses are then connected by structural members. For response spectrum analysis, the normal mode approach that is used assumes that the dynamic response of the structure may be represented by the superposition of the response of the structure in its various modes.

3.3 TEST METHODS

Westinghouse utilizes testing for the seismic qualification of electrical equipment when the criteria defined in Section 3.2 for qualification by analysis do not apply. Both single frequency and multiple frequency test methods are employed. The guides used to determine which test method is employed are described below.

3.3.1 SINGLE FREQUENCY TESTING OF LINE MOUNTED EQUIPMENT

Single frequency testing is the method generally employed by Westinghouse for line mounted equipment. Line mounted equipment consists of devices such as valve actuators or accessories and resistance temperature detectors (RTDs) that are mounted on piping systems away from supports. For this equipment, sine beat or sine dwell tests are used to demonstrate seismic qualification. These tests are conducted using either single axis or multiple axis excitation depending upon the equipments symmetry and failure modes.

The response characteristics of piping systems to seismic excitation is the major reason single frequency methodology is chosen. Piping systems will amplify the excitation that is input at the supports if it corresponds with the system resonance frequencies. The response at frequencies other than resonance is small. Studies performed by Westinghouse show that the significant frequencies of piping systems containing line mounted equipment are in the [ ]^{b,e} Hz range. By performing sine beat or dwell tests at several frequencies within this range conservative loadings are applied to the equipment being tested. The magnitude of the acceleration input for the tests is based on the design seismic acceleration level for the component.

3.3.2 SINGLE FREQUENCY TESTING OF OTHER EQUIPMENT

For some non-line mounted equipment, Westinghouse may use single frequency sine beat testing. These tests are conducted along each of the three mutually perpendicular axes individually or in a manner that simulates multiple axis motion. Westinghouse has demonstrated the acceptability of this test method and its inherent conservatism as part of a supplemental test program described in Section 2.2.

As part of previous equipment qualification programs Westinghouse utilized single frequency testing. In some instances, Westinghouse has continued to use the same equipment qualified by this test method in current plants and continues to use the previous testing as the basis for seismic qualification. Equipment which uses previous seismic testing as a basis for qualification is defined in WCAP 8587 and justification for this position is provided in Section 3.5.

3.3.3 MULTIPLE FREQUENCY TESTING

For components that are attached directly to the building structure or located inside cabinets, multiple frequency testing is the method most often utilized for seismic qualification. This is the only type of testing used by Westinghouse since 1973 for non-line mounted electrical equipment such as reactor trip switchgear, transmitters, etc.

For a component that is attached to the building structure a test response spectrum (TRS) is developed which envelopes the required response spectrum (RRS). The RRS is generally an envelope of the response spectra at the equipment's location in several plants.

Two options are used for components that are located inside a structure, such as a device in a cabinet. The first method is to test the structure with the component in place. The second approach is to instrument the structure and perform the test without the component in place but with the device mass and stiffness represented. The results of the test without the component are then used to develop test levels that are used for a separate test of the component.

The two methods of multiple frequency testing outlined above provide conservative demonstrations of equipment capabilities for the specified seismic qualification level. Additional details of test sequences and qualification criteria are provided in Section 5.0.

3.4 QUALIFICATION BASED ON TEST AND ANALYSIS

A combination of test and analysis is used to qualify some equipment. This method of qualification is applied to equipment such as cabinets that may house several different configurations of devices or multiply joined cabinets and control boards. A test is perform to determine the response characteristics of the cabinet. An analytical model is then developed to perform a structural evaluation of the cabinet for the different configurations of devices. The test results are used to help in the development and refinement of the model and provide a check of the analytical results. The analytical model can also be used to develop response spectra for later tests of individual devices.

When a combination of test and analysis is used for equipment qualification the methods of Sections 3.2 and 3.3 apply. Details of the analysis and test procedures are presented in Sections 4.0 and 5.0 respectively.

3.5 QUALIFICATION BASED ON PREVIOUS TESTING

As discussed in Section 3.3.2 and in WCAP 8587 Westinghouse utilizes previous single frequency testing as a basis for the seismic qualification of selected electrical equipment such as the nuclear instrumentation system and the process protection sets. This previous testing is utilized when all of the following conditions are satisfied:

a. The thermal aging program for the equipment demonstrates that no deleterious aging mechanisms exist.

b. Any structural or design changes to the equipment have not affected the seismic characteristics of the equipment.

c. The conservatism of the single axis single frequency test can be demonstrated.

Westinghouse has demonstrated the acceptability of some of the original seismic tests of electrical equipment with a supplemental demonstration test program discussed in Section 2.2. This supplemental test program used multiple frequency testing of specific items to demonstrate the conservatism of the previous single frequency testing. The justification for the use of previous single frequency sine beat testing is based on inherent conservatisms that include:

a. The test amplification levels and frequencies used for the tests assume coincident occurrence of the building and equipment natural frequencies. In general, this condition will not exist and the equipment responses will be much smaller than those used for the tests.

b. The 10 cycle per beat input used by Westinghouse results in an equipment amplification that is sufficient to account for multi-mode and multi-directional effects.

c. The sine beat input is applied at the natural frequencies of the equipment; this results in a resonance build-up of component responses that is very conservative in terms of equipment malfunction compared to the smaller resonance build-up for a typical earthquake.

d. In the frequency range of significant response, sine beats will provide some multi-mode response. However, the sine beat individual response spectra will not envelope the entire frequency range of the typical floor response spectra.

e. The sine beat input subjects the equipment to a fatigue environment that exceeds the fatigue inputs of an actual earthquake.

As a result, Westinghouse has demonstrated that previous single frequency testing combined with the supplemental multiple frequency testing performed as part of the supplemental test program demonstrates qualification to the requirements of IEEE 344-1975.

4.0 PRECEDURES FOR QUALIFICATION BY ANALYSIS

This section presents the methods Westinghouse uses for the seismic analysis of equipment. Details such as modal combination, damping values, mathematical models, and computer codes are included.

4.1 GENERAL REQUIREMENTS

Westinghouse develops requirements for individual equipment based on its intended function in a nuclear power plant. These requirements, which include seismic qualification, are formally described in an equipment specification that is used as the basis for the design, manufacture, and analysis of the equipment. Equipment specifications generally include the following information related to seismic qualification:

a. Essential parameters required for demonstrating the functional operability of the equipment; (e.g., alignment, strains, deflections, and loads).

b. Limitations on the essential parameters and/or required manufacturer evaluation of limitations.

c. Interfaces as provided in Section 5.2.

d. Parameters required for seismic analysis such as response spectra, support stiffnesses and nozzle loads.

When analysis is used for seismic qualification the equipment specification forms the basis for defining acceptance criteria. As part of this acceptance criteria mechanical strength, alignment, and noninterruption of function are evaluated to assure that the functional requirements of the equipment during and after an SSE event are satisfied. Maximum displacement under all loadings are computed where required along with the evaluation of interference, and interaction effects.

The stresses and any additional parameters identified in the equipment specification that result from seismic exitation for OBE and SSE conditions are combined with other stresses according to the requirements of the equipment specification. The resultant combined stresses or stress intensities are limited to the allowables that are provided in the equipment specification.

4.2 ANALYTICAL MODELING AND VERIFICATION OF COMPUTER PROGRAM

4.2.1 DAMPING

For mechanical equipment and large piping systems values of 2 percent of critical damping for the OBE and 4 percent of critical damping for the SSE are used (Reference 3) for all of the modes considered in a response spectra analysis and time history dynamic seismic analysis. For small piping systems, damping values of 1 percent and 2 percent are used for OBE and SSE respectively. As specified in IEEE 344-1975, a damping value of 5 percent is used for both OBE and SSE analysis of electrical equipment. If damping values other than these are used in a seismic analysis justification will be provided.

4.2.2 MATHEMATICAL MODEL

Mathematical models that include the mass and stiffness properties of the equipment in three orthogonal component directions are developed. The models are used to determine the dynamic behavior of the equipment within the frequency range of interest. The model is refined to include sufficient dynamic degrees of freedom to ensure mathematical convergence of all significant modes of vibration.

Dynamic properties are chosen to represent the inservice operating conditions for the appropriate load combination. The effects of coupling between vibrations in different directions, dynamic effect of contained liquids, external structural restraints, attached piping and nonlinear responses are included in the analysis when found to be significant.

Modelling assumptions regarding mass distribution, the stiffness of joints, or buckling of plates in shear, are identified and if necessary verified. Verification is achieved by one or more of the following:

a. Static testing for deflection characteristics of an assembly to verify stiffness.

b. Dynamic testing of an assembly, either in-situ or by shaker table test, for frequencies and mode shapes.

c. From previous experience by comparing test data, such as a or b above, to analytical results obtained for assemblies of similar design and construction.

d. By comparison with the theoretical solution for similar problems.

4.2.3 COMPUTER PROGRAM VERIFICATION

The Westinghouse Quality Assurance Program (WCAP-8370 Rev. 9A) defines requirements for the control, verification, and documentation of computer programs. All computer programs used for seismic qualification are under this QA program. Computer programs are verified using the same computer that will be used to analyze the equipment model. The program version that was verified is used in the analysis.

Programs are verified by demonstration of the program capability to produce results closely matching benchmark solutions for a series of test problems encompassing the full range of permitted capabilities and usage of the program. Acceptable benchmark solutions include hand calculations, analysis by verified comparable public domain programs, empirical data, and information from the technical literature.

4.3 STATIC ANALYSIS

Equipment having all of its natural frequency greater than 33 Hz is categorized as rigid equipment. Since the frequency of this equipment does not coincide with amplification region frequencies, a static analysis is used to seismically qualify the equipment. Some equipment that has one natural frequency below 33 Hz is also qualified with static methods (see Section 3.2.1).

Static acceleration factors, defined in the equipment specification, are applied at the center of gravity of the equipment in each of three directions, two perpendicular horizontal and one vertical. The total response of the equipment is computed as the square-root-sum-of-squares of the uni-directional responses. In equation form, the expression is:

$$R_T = \left(\sum_{i=1}^{3} R_i^2 \right)^{1/2} \qquad (1)$$

where R_T represents the total combined response at a point and R_i is the response due to load application in direction i.

4.4 DYNAMIC ANALYSIS

Equipment having natural frequencies near the amplification region of the applicable floor response spectra are classified as flexible equipment. Generally, the natural frequency for flexible equipment is below 33 Hz. For flexible equipment, to properly evaluate the effects of possible resonance at the frequencies of the amplified excitation, a dynamic modal analysis or time-history analysis is performed.

4.4.1 MODAL RESPONSE SPECTRUM ANALYSIS

In computing the equipment displacements and stresses with response spectrum techniques, the analysis is performed using three earthquake components, two horizontal and one vertical. The horizontal spectra are applied in any two arbitrary perpendicular directions in the horizontal plane. The vertical spectrum is applied in the vertical direction. If a specific plant analysis is being performed, the three spectra components may be applied in the N-S, E-W, and vertical directions, as defined by the applicable response spectra for that plant. The three input spectra may be applied independently in the applicable direction with subsequent combination into a total response; or the three input spectra may be applied simultaneously to the mathematical model.

The total three directional response is calculated using the square-root-sum-of-squares (SRSS) of the modal contributions (with modifications, if necessary, for closely spaced modes as discussed below).

The mathematical expression for this technique is:

$$R_T = \left(\sum_{i=1}^{3} R_i^2 \right)^{1/2} \qquad (2)$$

$$R_i \left(\sum_{j=1}^{N} R_{ij}^2 \right)^{1/2} \qquad (3)$$

where

R_T = total combined response at a point

R_i = value of combined response of direction i

R_{ij} = absolute value of response for direction i, mode j

N = total number of modes considered

For systems having modes with closely spaced frequencies, this technique is modified to include the possible effect of these modes. The group of closely spaced modes is chosen such that the difference between the frequencies of the first mode and the last mode in the group does not exceed 10 percent of the lower frequency. No mode can appear in more than one group. The combined total response for systems which have closely spaced modal frequencies is obtained by adding to the square-root-sum-of-squares of all modes, the product of the responses of the modes in each group of closely spaced modes and a coupling factor ϵ. This can be represented mathematically by replacing R_i of equation (2) by the expression below:

$$R_i = \left[\sum_{j=1}^{N} R_{ij}^2 + 2 \sum_{j=1}^{S} \sum_{\ell=M_j}^{N_j-1} \sum_{n=\ell+1}^{N_j} R_{i\ell} R_{in} \epsilon_{\ell n} \right]^{1/2} \qquad (4)$$

where additional terms are defined as:

S = number of groups of closely spaced modes

M_j = lowest modal number associated with group j of closely spaced modes

N_j = highest modal number associated with group j of closely spaced modes

$\epsilon_{\ell n}$ = coupling factor with

$$\epsilon_{\ell n} = \{1 + \left[\frac{\omega_\ell' - \omega_n'}{\beta_\ell' \omega_\ell + \beta\,' \omega_n} \right]^2 \}^{-1} \qquad (5)$$

and

$$\omega_\ell' = \omega_\ell \left[1 - (\beta_\ell')^2 \right]^{1/2} \qquad (6)$$

$$\beta_\ell = \beta_\ell + \frac{2}{\omega_\ell \, t_d} \qquad (7)$$

ω_ℓ = frequency of closely spaced mode ℓ (rad/sec)

β_ℓ = fraction of critical damping in closely spaced mode ℓ

t_d = duration of the earthquake (sec.)

An example of the application of this equation to a system is shown below. In this example it is assumed that the predominant contributing modes have frequencies as given below:

Mode	1	2	3	4	5	6	7	8
Freq	5.0	8.0	8.3	8.6	11.0	15.5	16.0	20

and have responses in direction i of $R_1, R_2, \ldots, R_8$.

There are two groups of closely spaced modes, namely with modes 2, 3, 4 and 6, 7 . Therefore,

S = 2 number of groups of closely spaced modes
M_1 = 2 lowest modal number associated with group 1
N_1 = 4 highest modal number associated with group 1
M_2 = 6 lowest modal number associated with group 2
N_2 = 7 highest modal number associated with group 2
N = 8 total number of modes considered

The response in the ith direction for this system is, as derived from the expansion of equation (4):

$$R_i^2 = \left[R_1^2 + R_2^2 + R_3^2 + \ldots + R_8^2\right] + 2R_2R_3\epsilon_{23} + 2R_2R_4\epsilon_{24} + 2R_3R_4\epsilon_{34} + 2R_6R_7\epsilon_{67} \quad (8)$$

This response is combined with the responses of the two other mutually perpendicular directions by SRSS to obtain the total response (equation (1)).

4.4.2 TIME-HISTORY ANALYSIS

The system and equipment response can also be determined using time-history analyses. The methods used for generating artificial acceleration time histories for dynamic analysis are provided in Appendix A.

If the time-history analysis is performed by applying the two horizontal and one vertical time-history components sequentially, the total combined response is computed by; 1) adding algebraically the unidirectional responses at each time step, or 2) combining the maximum response in each direction by the square-root-sum-of-squares method.

If the time-history analysis is performed by applying the two horizontal and one vertical time-history components simultaneously, the combined response is obtained directly by integration of the equations of motion or by using modal superposition techniques.

5.0 PROCEDURES FOR QUALIFICATION BY TEST

This section presents the procedures followed by Westinghouse when tests are used to seismically qualify equipment. The procedures for both single frequency and multiple frequency tests are provided. Details of shaker table geometries that simulate multiple axis excitation, equipment interface requirements, test sequence, operability demonstration, and inspection requirements are furnished.

5.1 TEST EQUIPMENT

This section briefly describes the test table options and accelerometers locations for seismic testing. Because of the wide variety of test equipment available, it is not practical to provide additional details of all equipment that might be used for test. A list of the specific equipment utilized for a test is provided in the individual test report.

5.1.1 TEST TABLE CONFIGURATIONS

Three methods are used to simulate multiple axis seismic excitation (Alternatives A, B, and C) and one method is used to simulate single axis seismic excitation (Alternative D). All of these methods can be used for both single frequency and multiple frequency tests. Westinghouse selects the method that is compatible with the shaker table to be used for the test. The four alternatives are:

a. Alternative A - Rectilinear testing with the hydraulic actuator set at an angle of 35.26 degrees with the horizontal.

b. Alternative B - Rectilinear testing with the hydraulic actuator set at an angle of 45 degrees with the horizontal.

c. Alternative C - Testing with separate horizontal and vertical actuators.

d. Alternative D - The same as alternative C except that only horizontal or vertical actuation is used.

Figures 5.1 A, B and C provide a schematic representation of each alternative. The test inputs depend on which of these alternatives is selected. Westinghouse has used alternative A for most of the testing that has been performed since 1973.

5.1.2 ACCELEROMETER LOCATION FOR TESTS

Both strain gage and crystal type accelerometers are used by Westinghouse for test purposes.

As a minimum, two accelerometers are mounted to the test table along with the object to be tested. The purpose of these instruments is to provide information about the table motion; this information is used to verify the adequacy of the test input. When test table Alternative A, B, or C is used, one of the accelerometers is mounted along the horizontal projection of the actuator drive axis. For Alternative C, a second accelerometer is oriented to measure vertical motion. The control accelerometer for Alternative D is mounted to measure the horizontal or vertical excitation.

In addition to the control accelerometers which are mounted to the test table, other accelerometers are placed on the component being tested. The location of these instruments are chosen to obtain the maximum information concerning internal equipment response, equipment frequencies, and, when feasible, equipment mode shapes. The data gathered with these accelerometers are used to generate test requirements for the qualification of devices mounted to the equipment or to support analytical extrapolation of the test results.

5.2 <u>REQUIREMENTS FOR SIMILATION OF EXTERNAL EFFECTS</u>

External effects constitute most of the conditions that the test item is subjected to when installed in the plant. These external effects are simulated, when possible, during the test. As a result of the test, interface requirements may be specified relative to the way the equipment is installed in the plant and limitations may be required on the design of adjacent equipment or structures, and the placement of external attachments to the equipment. The following paragraphs discuss the significant interface requirements. These requirements can be eliminated if it can be demonstrated that their effects on the equipment being tested are insignificant or do not lead to non-conservative results.

5.2.1 MOUNTING OF THE EQUIPMENT

The equipment is mounted on the test table simulating installation in the plant. The equipment mounting details for a test are identified by sketches or other means in the test report. These details include:

a. Location of mounting bolts, welds, special hold-down hardware, or supports.

b. Size of bolts, size and length of welds or other special hold-down hardware or supports.

c. Type of material for the bolt or other special hold-down hardware.

d. Bolt torques used in the test simulation.

5.2.2 EXTERNAL WIRES, CONDUIT, BUS, BUS DUCT OR PIPES

External wires, conduits, busses, bus ducts, or pipes are simulated during the test to represent their installed conditions. As a minimum, unless they are demonstrated to be insignificant or do not lead to non-conservative results, the following parameters are simulated during the test.

a. Mass of attachments.

b. Stiffness of attachments.

c. Mass of external or internal field routed wires, cable trays, conduits, or bus ducts.

d. The support of external or internal field routed wire, pipe, or bus ducts.

Where such external connections cannot be specifically defined due to variability in installation methods and procedures, interface requirements may be identified to the installer to assure the applicability of the seismic qualification

5.2.3 PRESSURE, TEMPERATURES AND FLOW

The effects of normal pressures, temperatures and fluid flow relevant to the operability of the component during a seismic event are calculated. If significant, these effects are simulated or compensated for during the test.

5.2.4 NOZZLE LOADS

The magnitude of nozzle loads and the direction and the manner of their application during the seismic event are accounted for during the test or by subsequent analysis when the effect on operability and structural integrity may be significant.

5.3 CHECKOUT AND INSPECTION OF TEST ITEM

5.3.1 PRE-TEST EQUIPMENT CHECKOUT

After the test facility has received the equipment to be tested it is inspected for loose or broken parts and structural damage. Any significant damage and corrective action is recorded for inclusion in the test report.

At least one complete functional operability test is performed before the seismic test. The test is performed using the same procedure that is developed for functional operability monitoring during and after the seismic tests. The data obtained from this pre-test operability demonstration is used for evaluating any abnormalities that are observed during or after the seismic test.

5.3.2 POST TEST INSPECTION

After completion of the entire OBE test sequence and each individual SSE test, the test item is visually inspected for possible structural failure, local yielding, electrical and mechanical operability or malfunctions. All pertinent observations and deficiencies are logged. No tightening or corrective action is performed after the OBE test but corrective action is permitted after each SSE test. If corrective action is taken before all SSE tests are completed, justification for performing the remaining SSE tests without rerunning the OBE tests is provided. In cases where insufficient justification is available the OBE tests are rerun to provide for aging of the repaired component.

5.4 FUNCTIONAL OPERABILITY

The requirement that a component performs its intended safety function necessitates proving the equipment's functional operability. Functional operability is demonstrated before, during, and after seismic tests. The specific parameters needed to demonstrate functional operability are defined in the test specification for the equipment being tested. Examples of these parameters include:

a. Structural or pressure boundary integrity.

b. Continuity of electrical outputs (voltages, currents) that are used to initiate other safety equipment.

c. Misalignment of shafts, valve stems and similar mechanical linkages.

d. Start times for motors, generators etc.

e. Valve opening and closing times or relay operating time.

f. Minimum force outputs of actuators when tested separate from the valve or with the valve but without full flow conditions.

g. Accuracy of monitoring signals (temperatures, pressures, vibration) which result in the automatic starting or stopping of equipment or which are required by the control room operator.

h. Acceptability of minimum and maximum operating voltage range for electrical devices.

i. Relay or switch--opening, closing or chattering.

j. Continuity of wires, conduits and pipes.

k. The operational settings (minimum, maximum, or range of settings) for adjustable type devices.

The event sequence used to demonstrate functional operability during SSE tests is described in Sections 5.6.2.5 and 5.7.3.

5.5 RESONANCE SEARCH TEST

Prior to performing either single frequency or multiple frequency OBE and SSE testing, a resonance search test may be required by the test specification. The purpose of such a test is to identify the dynamic characteristics of the equipment being tested. This test is usually performed using a sine sweep input in the 1 to 50 Hz range with a sweep rate not exceeding 1 octave per minute. The amplitude of the input is 0.2 g along the axis of the horizontal control accelerometer. The output of all accelerometers is recorded. During the resonance search test, the equipment is in a non-operating mode and is in one of the four orientations described in Section 5.6.2.4..

In addit on to resonance search tests using the sine sweep method four other methods are employed, when necessary, to obtain the dynamic characteristics of a component.

a. Impulse testing (sometimes known as hammer tests), is a technique where a short duration force is applied to the equipment being tested. The input excitation and response of the equipment are measured and recorded. This data is then analyzed to determine the dynamic characteristics of the equipment.

b. Sinusoidal testing of equipment with a portable shaker is performed using the same methods as the sine sweep test on a shaker table.

c. Pluck tests involve the displacement of a portion of the equipment followed by a quick release that allows the component to respond freely. The equipment response is recorded and analyzed to determine the dynamic behavior.

d. Random excitation of the equipment on a shaker table is performed with the same data gathering techniques that are used for multifrequency tests.

5.6 SINGLE FREQUENCY TESTING

The methods used by Westinghouse to perform single frequency OBE and SSE testing are described below.

5.6.1 OBE TEST

The potential aging effects of low level seismic activity and some low level in-plant vibration is addressed by the OBE tests described below and is performed prior to SSE testing.

Five OBE tests are performed in one orientation on the test table. During this test the equipment is mounted on the table so that the equipments horizontal principle axes are located at a 45^{0} angle to the horizontal direction of table motion. During at least one of the OBE tests the equipment is on the operational mode.

The OBE test may be performed using either sine dwell or a sine sweep test. These two test alternatives are discussed below.

5.6.1.1 OBE Sine Dwell Test

A dwell test is performed at 0.5 times the required acceleration magnitude for the SSE. If the OBE for a particular plant is defined as being greater than one-half the SSE the actual ratio of OBE to SSE is used instead of 0.5. The number of dwell frequencies, and the type of waveform are the same as those used for the SSE tests but the time duration of the dwells is at least 5 times the minimum SSE duration to provide the equivalent excitation of 5 OBE's.

5.6.1.2 OBE Frequency Sine Sweep Test

A frequency sweep at 0.5 times the SSE required acceleration magnitude is performed. If the OBE for a particular plant is defined as being greater than one-half the SSE the actual ratio of OBE to SSE is used instead of 0.5. The sweep rate is no greater than 1 octave per minute and the sweep range is between 1 Hz and 40 Hz. One sweep is defined as going from 1 Hz to 40 Hz and then returning from 40 Hz to 1 Hz. A total of 3 complete sweeps is performed to similate the excitation effects of 5 OBE's.

5.6.2 SSE TEST

5.6.2.1 Input Motion

The acceleration waveform that is used for the SSE test is one of three described below. The use of a combination of the three types of testing for convenience of demonstrating functional operability is permitted. However, only one option is used during any single frequency dwell.

a. Continuous sine wave.

$$A(t) = B\ (\sin \omega t) \tag{9}$$

c. Continuous sine beats (10 cycles/beat).

The theoretical acceleration motions of the test table are defined by the mathematical equation:

a,b,c

(10a)

(10b)

The corresponding velocity and displacement waveforms are:

for velocity

a,b,c

(11)

(12)

c. Sinebeats (10 cycle/beat) with pauses.

The mathematical definition of the beat portion of a sine beat with pauses is the same as the definition for sine beats without pauses. The duration of the pauses between each beat is provided in Table 5.2.

5.6.2.2 Frequencies

The equipment is tested at the frequencies specified in Tables 5.1 and 5.2. Table 5.1 specifies the minimum number of frequencies for a continuous sine wave test and Table 5.2 specifies the minimum number of frequencies for a 10 cycle/beat sine beat test.

In addition to the frequencies specified in Tables 5.1 and 5.2 a test is performed at each resonance frequency below 33 Hz that is detected by resonance search tests (Section 5.5).

5.6.2.3 Duration

The equipment is tested for the minimum time duration as specified in Tables 5.1 and 5.2 for the different type of input waveforms. However, the total time at each dwell frequency is controlled to allow completion of all required functional operability tests. In the case of sine beat inputs, the time duration is extended by the following procedures applicable for the respective input waveform.

a. Continuous Sine Beat - By increasing the total number of sine beats so that the total test time exceeds the time required to demonstrate functional operability.

b. Sine Beats With Pauses - By increasing the number of beat-pause combinations such that the total time exceeds the time required to demonstrate functional operability. The pause duration is not increased.

5.6.2.4 Orientation

The SSE tests are performed using four equipment orientations. For all three test table alternatives, the vertical ard horizontal test table motions are rectilinear. The required orientations are:

a. Orientation Number 1 - The equipment is mounted on the table so that the horizontal principle equipment axes are located at a 45° angle to the horizontal direction of table motion.

b. Orientation Number 2 - Orientation Number 2 is a 90° clockwise rotation from Orientation 1.

c. Orientation Number 3 - For test machine Alternatives A and B, Orientation Number 3 is a clockwise rotation of 90° from Orientation 2.

   If test table Alternative C is used, an alternative procedure is used to simulate Orientation Number 3. Instead of rotating the equipment for Orientation Number 3, the acceler.tion phase relationship for this orientation is simulated by repeating the SSE testing in Orientation Number 1, but with vertical table motion 180° out of phase from the vertical table motion used for Orientation Number 1.

d. Orientation Number 4 - For test machine Alternative A and B, Orientation Number 4 is a clockwise rotation of 90° from Orientation 3.

   If test machine Alternative C is used, the alternative discussed under Orientation Number 3 may be used to simulate the Orientation Number 4 tests while in Orientation Number 2.

If geometric and dynamic symmetry exist about the two vertical planes that are parallel to the horizontal principle axes, SSE tests are required only for Orientation Number 1.

If geometric and dynamic symmetry exists about only one of the vertical planes which are parallel to a horizontal principle axis, SSE tests are required only for Orientations Number 1 and Number 3.

5.6.2.5 Functional Operability

During all of the SSE tests and at least one of the OBE tests it is necessary to demonstrate functional operability of the test item. The types of parameters used to demonstrate functional operability depend upon the test item and were discussed in Section 5.4. The specific time during the test when functional operability is demonstrated is defined below to ensure that functional operability is demonstrated during the most severe portion of the SSE or OBE test.

If continuous sine waves are used, the tests to demonstrate functional operability are initiated at any convenient time during the input, but no sooner than half way through the test time duration.

If sine beats are used, the tests to demonstrate functional operability are initiated after at least 3 beats are completed to allow for resonance buildup and during a time frame of two cycles after the center of a beat.

5.6.2.6 Compliance with Input Motions

Compliance with the input motion waveforms described in Section 5.6.2.1 for both sine dwell and sine test is determined by comparing the input motion with the actual table motion recorded on the control accelerometers.

5.7 MULTIPLE-FREQUENCY TEST SEQUENCE

The methods used by Westinghouse to perform multiple frequency OBE and SSE tests are described below.

5.7.1 INPUT MOTION

The inputs used to drive the test table actuators for OBE and SSE multiple frequency tests are synthetic acceleration time histories derived by combining several sine beat waveforms. The sine beat waveform has response characteristics which make it practicable for the generation of these time histories. The response of a sine beat is described by a predictable change to a response spectrum at the predominant frequency of the sine beat. By taking the sum of multiple sine beats of different frequencies, Westinghouse synthesizes an acceleration time history motion with a response spectrum that will envelope a specific design response spectrum. This method for developing the input motion allows Westinghouse to have greater control over the time during the test when maximum accelerations occur and, therefore, allows functional operability to be demonstrated during the most limiting portion of the earthquake. Further details of the methods used by Westinghouse to develop synthesized time histories is provided in Appendix B.

5.7.2 DURATION OF TEST

The minimum time duration for each multifrequency test is 20 seconds. Shorter test times can be used when the purpose of the test is to develop response spectra at various locations within the tested structure for later use in device tests or when the test is for demonstration purposes.

5.7.3 OBE TESTS

The potential aging effects of low level seismic activity and some low level in-plant vibration is simulated with OBE tests. These OBE tests are performed prior to the SSE tests.

Five repetitions of the synthesized input (see Section 5.7.1) at the OBE level are performed for the duration specified in Section 5.7.2. During the OBE test the equipment is mounted on the table so that the horizontal principle equipment axes are located at a 45^{0} angle to the horizontal direction of the table motion. During at least one of the OBE tests, the equipment is in the operational mode. After the first of the five repetitions, the test response spectrum (TRS) is compared to the required response spectrum (RRS). If the TRS does not envelope the RRS the inputs are adjusted as required until the TRS is attained and input motion requirements are satisfied.

5.7.4 SSE TEST

The input motion and duration of multiple frequency SSE tests are described in Sections 5.7.1 and 5.7.2.

5.7.4.1 Orientation

The SSE tests are performed using four orientations. These orientations are:

a. Orientation Number 1 - The equipment is mounted on the table so that the horizontal principle equipment axis are located at a 45^{0} angle to the horizontal direction of the table motion.

b. Orientation Number 2 - 90^{0} clockwise rotation from Orientation Number 1.

c. Orientation Number 3 - 180^{0} clockwise rotation from Orientation Number 1.

d. Orientation Number 4 - 270^{0} clockwise rotation from Orientation Number 1.

When test table Alternative A or B is used all four orientations are employed. For Alternative C only Orientation Number 1 and Number 3 are required.

If geometric and dynamic symmetry exist about the two vertical planes which are parallel to the horizontal principle axes, SSE tests are performed only for Orientation Number 1.

If geometric and dynamic symmetry exist about only one of the vertical planes which are parallel to a horizontal principle axis, SSE tests are performed only for Orientations Number 1 and Number 3.

5.7.4.2 Functional Operability

The types of parameters used to demonstrate functional operability depend on the test item and were discussed in Section 5.4. Functional operability is demonstrated before, during and after the multiple frequency seismic simulation test using the following requirements:

a. For equipment that operates without interruption, such as a device that produces a continuous electrical signal, the function is monitored before, during and after the shaking.

b. For equipment which may change state during an SSE (e.g. opening or closing of a switch or relay, or a change in output of an electronic circuit), the following are used to demonstrate functional operability:

    1. A time frame, corresponding to the strong motion portion of the synthetic earthquake, is identified for the test lab in the test specification. The performance of the function is demonstrated at least once during the time frame indicated for each orientation.

    2. If symmetry conditions have been demonstrated and tests are required in Orientation No. 1 only, two tests are performed for equipment in this category while in Orientation No. 1.

    3. When symmetry conditions have been demonstrated and tests are required in Orientations 1 and 3 one demonstration of functional operability shall be performed in each orientation.

c. Equipment which is required to cycle during the shaking is cycled as many times as practical. As a minimum, the times for cycling are selected to occur during the strong motion portion of the earthquake.

5.7.4.3 Compliance With Input Motion

The test table is shaken using a synthetic time history input motion as described in Section 5.7.1. The output of all accelerometers is continuously monitored and recorded. A plot of the TRS from the control accelerometer output is compared with the RRS. If the SSE level has not been achieved, the input is adjusted as required, and the test is repeated until the required TRS is attained.

TABLE 5-1

REQUIRED FREQUENCIES FOR SINE WAVE INPUTS

a,c

DWELL FREQUENCY(1) HZ	SSE MINIMUM TIME DURATION(2) SECONDS

4816A

TABLE 5.2

REQUIRED FREQUENCIES FOR 10 CYCLE/BEAT SINE BEATS

a,c

DWELL(1) FREQUENCY HZ	MINIMUM NUMBER OF BEATS	PAUSE TIME SECONDS	SSE MINIMUM TIME DURATION(2) (SECONDS) WITHOUT PAUSES	SSE MINIMUM TIME DURATION(2) (SECONDS) WITH PAUSES

16641-1

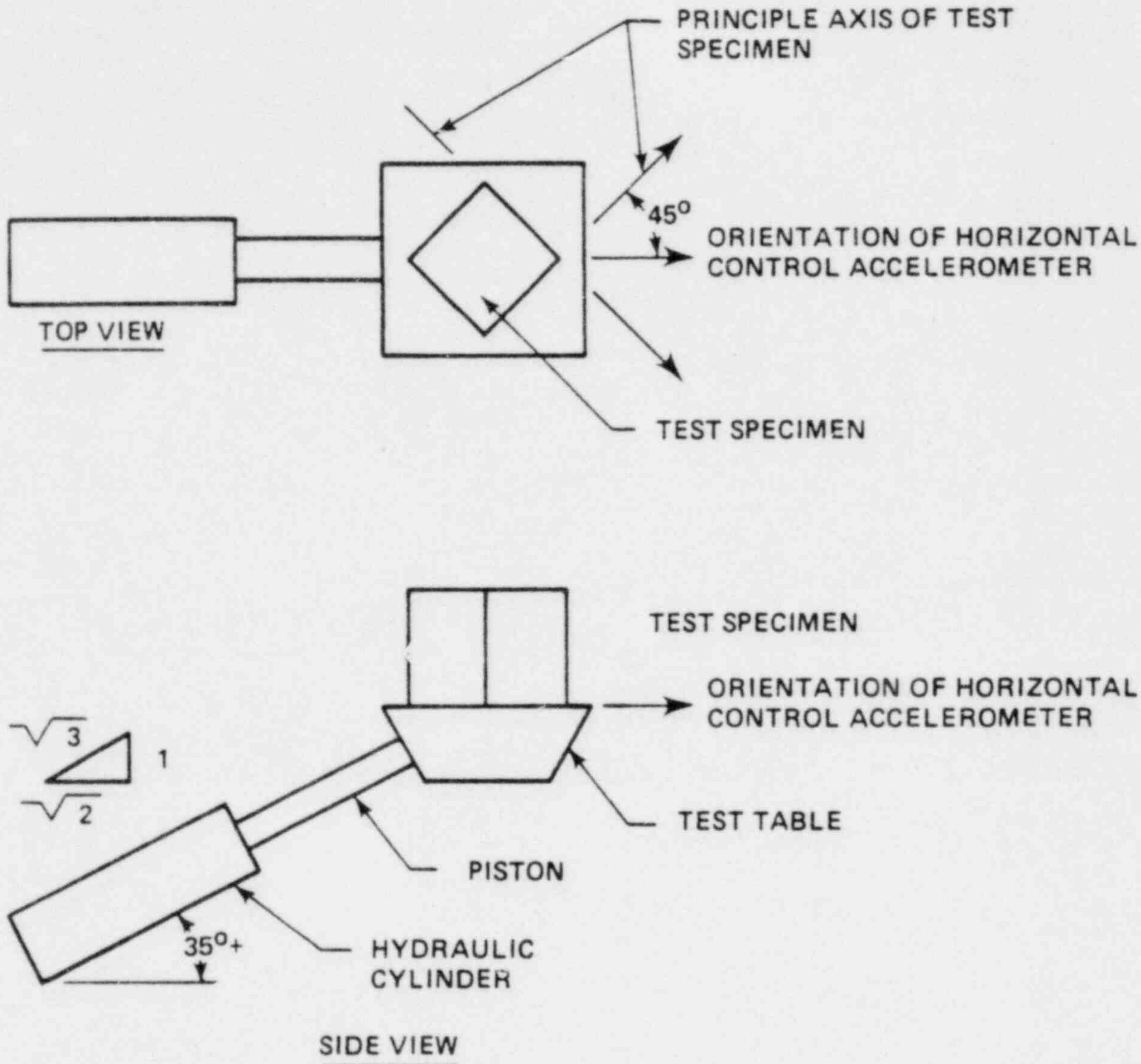
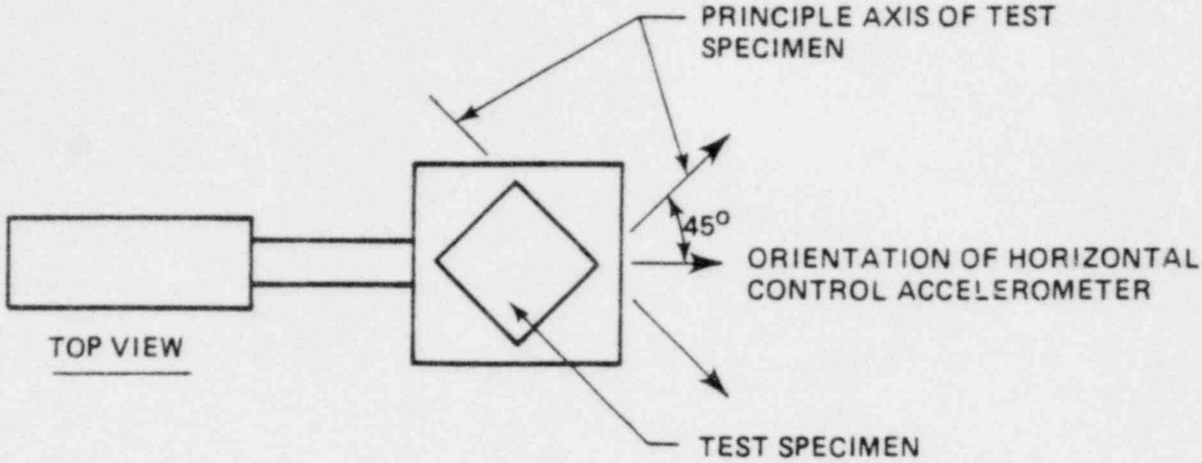


Figure 5.1A Schematic Diagram of Test Table Alternate A



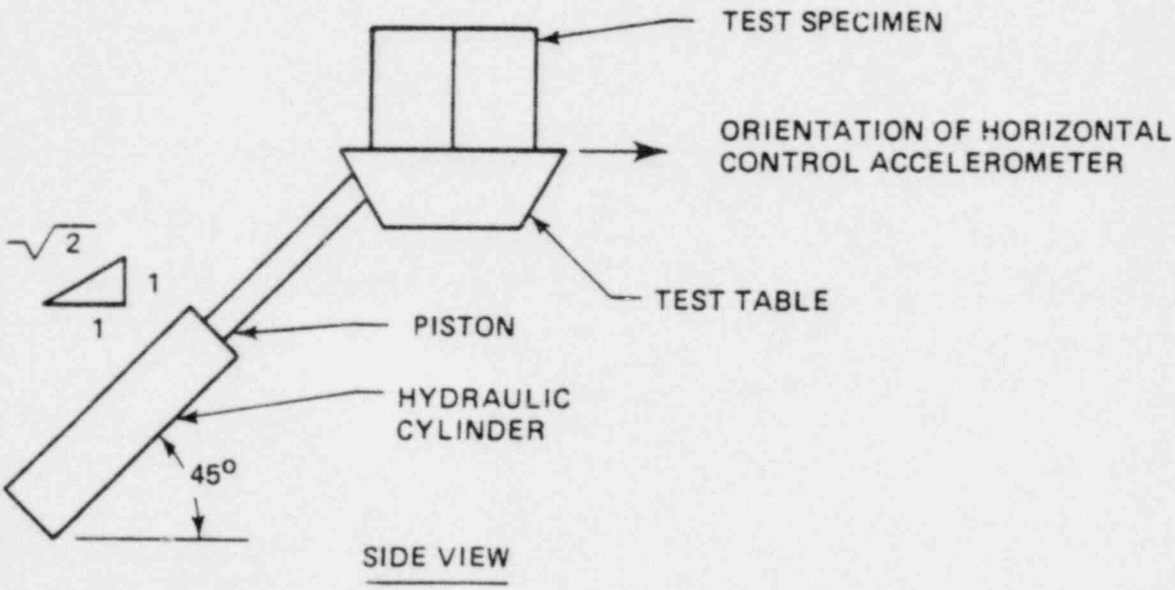


Figure 5.1B Schematic Diagram of Test Table Alternate B

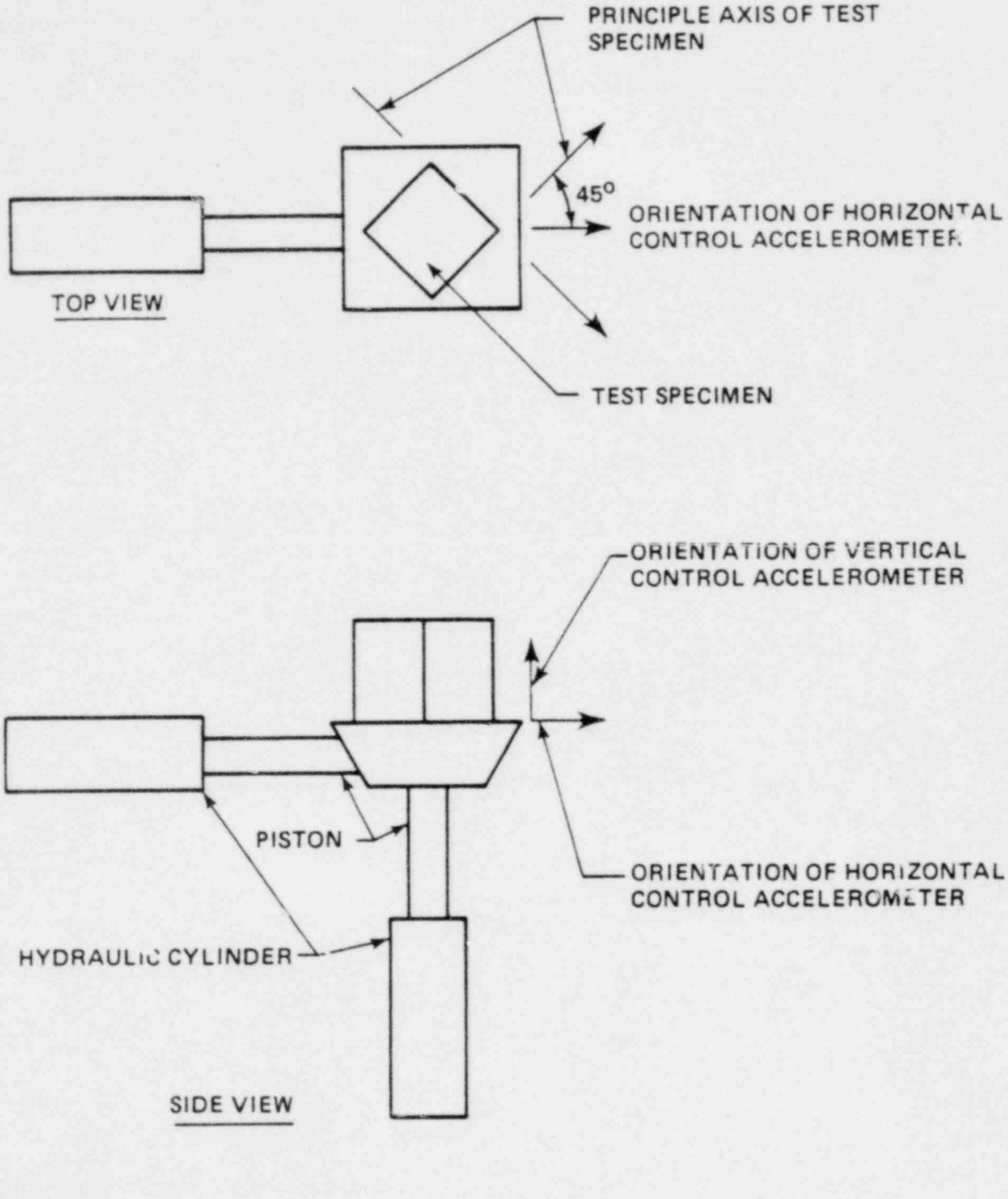


Figure 5.1C Schematic Diagram of Test Table Alternate C

6.0 SUMMARY

This Topical Report describes the methodology employed by Westinghouse for the seismic qualification of seismic Category I equipment. The methods used by Westinghouse include analysis (both static and dynamic), test (single and multiple frequency), a combination of analysis and test, and qualification based on previous testing. All of the methods used incorporate state-of-the-art techniques to demonstrate the acceptability of equipment. These seismic qualification methods are consistent with IEEE 344-1975 and satisfy all appropriate regulatory requirements. The program described herein supplements and satisfies the Westinghouse commitment in WCAP 8587 for a comprehensive electrical equipment qualification program.

7.0 REFERENCES

1. "Equipment Qualification Data Pacakages," WCAP-8587, Supplement 1.

2. Butterworth, C. and Miller, R. B., "Methodology for Qualifying Westinghouse WRD Supplied NSSS Safety-Related Electrical Equipment," WCAP-8587.

3. Clead, A. L., "Damping Values of Nuclear Power Plant Components, WCAP 7921, May, 1974.

4. Vogeding, E. L. "Seismic Testing of Electrical and Control Equipment," WCAP 7817, December, 1971.

5. Potochnik, L. M., "Seismic Testing of Electrical and Control Equipment (High Seismic Plants)," WCAP 7821, December, 1971.

6. Jarecki, S. J., Vogeding, E. L., "Multi-Frequency and Directional Seismic Testing of Relay," WCAP-8673, December, 1975.

7. Jarecki, S. J., Vogeding, E. L., "Seismic Qualification of Rotary Relay for use in the Solid State Protection System," WCAP-8694, January, 1976.

8. Jarecki, S. J., "General Method of Developing Multi-Frequency Biaxial Test Inputs for Bistables," WCAP-8624, December, 1975.

9. NRC Internal Memorandam from J. P. Knight, Acting Assistant Director for the Engineering Division of Systems Safety, to R. C. DeYoung, Assistant Directed for Light Water Reactors, dated August 26, 1976, subject: Report on Seismic Audit of Westinghouse Electrical Equipment.

a,c

APPENDIX A

GENERATION OF ACCELERATION TIME HISTORIES FOR ANALYSIS

This entire appendix is considered proprietary

a,c

[ ]

Figure A-1. A Two-Degree-of-Freedom Frequency-Suppressing Filter

a,c

APPENDIX B

MULTIPLE FREQUENCY TEST INPUTS

This entire appendix is considered proprietary