REVISION CONTROL SHEET
DOCUMENT TYPE: TECHNICAL SPECIFICATION

NO: PB-P-541

TITLE: TECHNICAL SPECIFICATION ON METHODS AND PROCEDURES FOR SEISMIC QUALIFICATION OF VALVES; PANELS, DEVICES; ROTATING AND RECIPROCATING EQUIPMENT; TANKS, VESSELS, PIPING AND SUPPORTS

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1.0 INTRODUCTION/SCOPE

A Nuclear Power Plant (NPP) has variety of structures, systems and equipment comprising of primary civil structures, secondary support structures supporting the systems and equipment viz., tanks, vessels, heat exchangers, piping, supports; valves; pumps, fans, blowers, motors; compressors, diesel generators, reciprocating pumps; instrumentation and electrical panels, instrumentation and electrical devices, reactor control and shutdown devices; etc. These NPP structures, systems and equipment are designed for various loads viz., loads during design, normal and upset conditions (pressure, temperature, mechanical, cycles, transients), loads during emergency and faulted conditions (pressure, mechanical), test load etc. as applicable, including natural phenomenon like earthquake. The seismic design considers two levels of earthquake i.e. Operating Basis Earthquake (OBE) alone or OBE and Safe Shutdown Earthquake (SSE) as specified. Design of structures, systems and equipment for dead weight, sustained loads, pressure and temperature and mechanical loads is a standard industrial design practice. However, seismic design is a special branch of engineering and has been specifically elaborated in this specification.

As specified in the NPCIL’s equipment specification, for the qualification of equipment the following requirements shall be met:

i) structural integrity and pressure boundary integrity of the equipment and

ii) intended functional operability of the equipment as applicable.

For passive equipment viz. tanks, vessels, heat exchangers, piping, supports qualification requirement are structural integrity and pressure boundary integrity. However, for active equipment viz., valves; pumps, fans, blowers, motors; compressors, diesel generators; electrical and instrumentation panels and devices involving mechanical motion, the qualification requirements shall also include functional operability.

This specification covers the procedure for qualification of secondary support structures, systems and equipment to meet the above qualification requirements.
2.0 CONTENTS

The specification has been presented under the following Sections and Annexures:

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Annexure-1 | Load Combinations For Design Condition and Service Levels for Equipment, Piping and Supports

Annexure-2 | Impact Hammer Test for Frequency Determination of Valves
3.0 **APPLICABLE CODES AND STANDARDS**

Applicable codes and standards for design and qualification of various structures, systems and equipment are given below.

1. ASME Boiler and Pressure Vessel code, Section-III, Division-1, Subsection NB, Class 1 components, 1992.

2. ASME Boiler and Pressure Vessel code, Section-III, Division-1, Subsection NC, Class 2 components, 1992.


5. ASME Boiler and Pressure Vessel code, Section-III, Division-1, Appendices, 1992.

6. ASME Boiler and Pressure Vessel code, Section-VIII, Pressure Vessels, Division 1, 1992.


11. ASCE-4-86, Seismic Analysis of safety related nuclear structures and commentary on standard for seismic analysis of safety related nuclear structures, 1986.


17. Combined modal response and spatial components in seismic response analysis USNRC RG 1.92.


24. ANSI B-16.41, Functional qualification requirements for power operated valve assemblies for nuclear power plants, 1983.


The Codes and Standards referred above or any of their latest revision can be used in concurrence with NPCIL.
4.0 QUALIFICATION METHODS AND PROCEDURES

The qualification of equipment in terms of

i) structural integrity and pressure boundary integrity

and

ii) functional operability

as applicable

can be performed by an analysis or by a combination of analysis and test. The qualification procedures are briefly described in this section.

4.1 Qualification for structural integrity and pressure boundary integrity

Qualification of structures, systems and equipment whether passive or active can be performed by analysis to assess their intended function in terms of structural integrity and pressure boundary integrity as per the requirements of governing code.

4.1.1 Qualification by Analysis

Qualification of structures, systems and equipment are required to be performed for various loads viz., loads during design, normal and upset conditions (pressure, temperature, mechanical, cycles, transients), including OBE; loads during emergency and faulted conditions (pressure, mechanical) including SSE; test loads; etc. as specified in NPCIL’s equipment specification and in the Vendor’s General Equipment Specification (VGES).

The general steps involved in qualification of structures, systems and equipment to meet the qualification requirements are:

i) Preparation of the finite element model which represents the equipment adequately.

ii) Identification of the applicable loads.

iii) Determination the structural response for these loads in terms of forces, moments, displacements and stresses. The seismic response shall be determined by using response spectrum analysis/time history analysis/equivalent static analysis method.

iv) Combination of the seismic responses with operating stresses and displacements for various load combinations as given in Annexure-1.

v) Comparison of the combined stresses and displacements with those that ensure compliance with design/codal requirements.
4.2. **Qualification for Functional Operability**

Qualification of system or equipment can be demonstrated by analysis and/or testing for assessing their intended functional operability.

4.2.1 **Functional Operability by Analysis**

The qualification of rotating equipment viz., pumps, fans, blowers, motors etc. and reciprocating equipment viz., compressors, diesel generators, reciprocating pumps etc. can be performed by analysis to assess their functional operability.

The general steps involved in qualification of these equipment to meet the qualification requirements of functional operability are the same as in para 4.1.1. In addition, the displacements of the moving components shall be demonstrated to be less than the clearances/gaps between the moving and stationary components/parts viz., shaft-bearing, impeller-casing, stator-rotor, piston-cylinder etc. The alignment of pump & motor shaft shall also be demonstrated to be within the specified value. The reactions at the bearing location shall be shown to be less than the specified bearing capacity.

4.2.2 **Functional Operability by Test**

Qualification of various types of electrical and instrumentation panels and devices, reactor control and shutdown devices, etc. can be performed by test to demonstrate their functional operability. In general, the seismic test should be conducted by mounting the equipment on a shake table. While a seismic motion is given to the shake table, the equipment should be checked for its intended functional operability. During the test, the operating loads/conditions of the equipment should also be simulated adequately. The test should conservatively simulate the seismic event at the equipment mounting location. The multidirectional nature of earthquake should be simulated. The list of the test facilities available in the country is included in NPCIL’s equipment specification.

4.2.3 **Functional Operability by a Combination of Analysis and Test.**

The electrical & instrumentation panels, devices and other active equipment can be qualified by a combination of analysis and test. The panel as a structure supporting the various active devices mounted at different locations in the panel can be analysed by time history analysis to calculate the seismic motion (i.e. time histories and response spectra) at the base of the active devices. The active devices then can be qualified on a shake table for the seismic motion determined at the base of these devices.
Moreover, it is not always practical to qualify all the equipment by testing. This may be because of the size of the equipment, its complexity, nature of equipment, etc. Large equipment, such as multibay equipment racks and consoles/panels etc., may be impractical to test at full scale due to limitations of the shake table. These type of equipment can also be qualified by using combination of analysis and testing.

4.3 Qualification by Past Test Data

Equipment which have been tested in the past for any other plant can be accepted if Test Response Spectrum (TRS) envelopes the Required Response Spectrum (RRS) at the base of the equipment for same values of damping.

4.4 Vendor’s General Equipment Specifications (VGES)

For demonstrating structural integrity and pressure boundary integrity by analysis, the various loadings on the equipment as specified in the NPCIL’s equipment specification shall also be specified in vendor’s general equipment specification (VGES). These loadings shall include loads during design, normal and upset conditions (pressure, temperature, mechanical), number of cycles of transients experienced by the equipment, including OBE; loads during emergency and faulted conditions (pressure, mechanical), including SSE; test loads, etc., as specified in NPCIL’s equipment specification. Above list is not complete, and as such, any additional loading coming on equipment due to specific design features shall also be specified in the VGES. The equipment is also required to be qualified for it’s intended functional operability for the earthquake loading in combination with other operating loads as specified in NPCIL’s technical specification and should form part of the VGES.

In order to meet the functional operability requirement of the equipment as brought out in this technical specification, various functions and functional parameters to be performed and measured by the various devices and subdevices in the equipment and which are to be monitored during the shake table test shall be brought out in the VGES. These functions and functional parameters shall include timings of opening and closing of valves, electrical contacts and relays; electrical contact and relay chattering; pressure, temperature, voltage, current settings etc.
5.0 SPECIFICATION FOR QUALIFICATION OF VALVES

This specification covers the procedure for qualification of a general valve assembly including actuator in terms of structural integrity, pressure boundary integrity and functional operability as brought out in NPCIL’s equipment specification and in the VGES. The procedure shall be applicable to various valves such as check valve, gate valve, ball valve, butterfly valve, relief or safety valve and diaphragm valve, etc. However, for a specific valve due to its specific design features if any additional specific technical requirements are to be met, same shall also be included in the VGES and shall also become part of the below mentioned qualification procedure.

In case of valves, general requirements of design are given in ASME Section-III, Division-1, Subsection-NB, NC and ND whichever is applicable. If any supports are used in the valve to support the valve component or the valve actuator from the valve body, those should be designed as per the general requirements given in ASME Section III, Division-1, Subsection NF. The material used for the equipment shall be as given in NPCIL’s specification or as given in VGES. Structural integrity and pressure boundary integrity of the valve assembly shall be demonstrated by carrying out analysis. The functional operability of valve assembly shall be demonstrated by a test. The tests covered in the specification pertain only to a seismic test. The list of test facilities available in the country is available in the NPCIL’s equipment specification. The detailed procedure for qualification of a general valve assembly is given below.

5.1 Qualification for Structural Integrity and Pressure Boundary Integrity

5.1.1 Qualification by Analysis

Structural integrity and pressure boundary integrity of the valve assembly shall be assessed by performing an analysis.

The valve assembly shall be analysed by finite element method. The various steps involved in finite element idealisation and the static and dynamic analyses of the valve assembly are brought out below.

5.1.1.1 Finite Element Modelling

Valve body, stem, bonnet, yoke, brackets for actuators, gear boxes and any other component may be modelled with appropriate material properties and section properties as calculated from the component detailed drawing using beam elements, with justification of assumptions.

Connection between valve body-stem, valve body-yoke, valve yoke-stem, gearbox housing-stem, actuator shaft-gear and any other connection may be appropriately modelled.
Concentrated masses of actuators, gearboxes, handwheel, disc of butterfly valve, limit switches or any other devices of the valve may be modelled as lumped mass at the C.G. location. The eccentricity of mass in the finite element model shall be taken into account.

Valve ends should be fixed and may be modelled using boundary elements, spring element or fixed boundary condition.

Any other peculiar construction details of valve assembly may also be modelled appropriately using spring or mass or spring-mass system.

Finite element model of the valve assembly using above considerations shall adequately represent the realistic static/dynamic characteristics of the valve assembly. While modeling the valve assembly apart from beam elements, shell, plate, 3D brick element or combination thereof may also be used with justification. The assumptions made in the finite element idealization with justification shall be brought out in the report. All the inputs used in the data preparation shall be from authenticated document and shall be referred/attached with the report.

5.1.1.2 Finite Element Analysis

Using validated software the valve assembly as modelled above shall be analysed to extract the first few natural frequencies of the valve. Two different sets of seismic qualification procedures exist depending upon whether the first natural frequency of the valve assembly is less than or greater than 33 Hz or rigid frequency. When the first natural frequency is less than 33 Hz or rigid frequency the valve assembly is called as flexible assembly, whereas when the first natural frequency is greater than or equal to 33 Hz or rigid frequency it is called as rigid assembly. All the valve assemblies shall be qualified for OBE alone or for OBE and SSE as applicable.

In case of rigid valve, the valve model shall be further analysed to evaluate seismic forces/stresses/displacements using equivalent static analysis method. In case of flexible valve assembly response spectrum analysis shall be performed.

In the equivalent static analysis method, force equivalent of 1.5 times the spectral peak acceleration shall be applied in 3 orthogonal direction at all mass points and the static analysis be carried out. The response spectra for OBE (2% damping) and SSE (3% damping) will be furnished by NPCIL as applicable. The accelerations on the valve in the three orthogonal directions, can also be obtained from the piping/equipment response spectrum analysis. In such case, equivalent static analysis shall be done for the force equivalent to 1.5 times the calculated accelerations of the valve.

For the response spectrum analysis to be performed on the flexible valve assembly, the applicable response spectra are the spectra at the valve mounting location on the piping system or equipment. These response spectra for OBE and SSE for 2% & 3% damping respectively will be furnished by NPCIL. The response spectrum
analysis shall include the addition of modal responses in each direction after accounting for closely spaced modes as per USNRC RG 1.92 and missing mass response as per NUREG 1061 vol. 4 (missing mass is the mass of the equipment which has not participated up to 33 Hz or cutoff frequency) and three orthogonal directional responses combination by SRSS method.

The valve assembly shall be analysed for various loads viz. loads during design, normal and upset conditions (pressure, temperature, mechanical, cycles, transients), including OBE; loads during emergency and faulted conditions (pressure, mechanical), including SSE; test loads; hydrodynamic, electromagnetic loads, etc. as specified in the NPCIL’s equipment specification and in the VGES.

For fatigue analysis, fifty stress cycles for five numbers of OBEs (ten stress cycles per OBE) shall be accounted in addition to the stress cycles due to other loads as specified in the NPCIL’s equipment specification and in the VGES.

5.1.1.3 ASME Codal Qualification

Load combinations to be adopted for ASME Class-1, 2 & 3 valves for design and service levels are given in Annexure –1.

The combined stresses calculated in the valve assembly shall meet the relevant codal requirements viz. ASME Section-III, Division-1, Subsection-NB-3000, NC-3000, ND-3000 whichever is applicable.

The combined stresses in the bracket, supporting structure of actuator etc shall meet the requirements of ASME-III, Division-1, Subsection-NF-3000.

The combined displacements between valve body-stem, stem-actuator shaft, etc. shall be checked for the specified clearances.

5.2. Qualification for Functional Operability

5.2.1 Qualification by Test

5.2.1.1 Choice of a Test Method

In case of the rigid valve, the seismic qualification test is a seismic loading test (equivalent static load test). In case of a flexible valve, the seismic qualification test is the shake table test.

Note: If the first natural frequency of the valve is less than 33 Hz or rigid frequency then necessary modifications in the design of the valve assembly may be done to increase the natural frequency of the valve assembly above 33 Hz or rigid frequency. It is desirable to perform modification at the design stage rather than back fitting improvements after manufacture and testing, which are difficult and costly. Seismic loading test is simpler and less expensive than the shake table test.
5.2.1.2 Determination of Natural Frequency

The first natural frequency or all modes below 33Hz or rigid frequency of valve assembly may be determined by exploratory vibration test. Exploratory vibration test on a valve assembly may be conducted on a shake table, as per the Annexure-E of ANSI B 16.41, with the modification that the vibration test shall be over a frequency range of 1 to 50 Hz. Natural frequency determination can also be done by Impact Hammer test, or any other justifiable method. The procedure for the Impact hammer test is given in Annexure-2.

The procedure covering the details of test method; mounting arrangements; test setup; test sequence; test equipment, instruments; measuring parameters; etc. shall be prepared as per the clauses given in this specification and shall be submitted to NPCIL for prior approval.

Exploratory vibration test shall then be conducted meeting the requirements of approved procedure.

5.2.1.3 Environmental Aging Test

Any environmental (temperature, pressure, humidity, plant operating vibration, irradiation) aging effects on the valve assembly, if specified in NPCIL’s valve specification, shall be simulated before the equivalent static loading test or before conducting the SSE shake table test. The guidelines for these tests viz., normal thermal aging test, normal pressurization cycle test, normal radiation test, vibration aging test, Design Basis Event (DBE) environment test are given in Part-III of IEEE 382 (1985). If the valve is determined not to have significant aging mechanisms by virtue of periodic inservice surveillance, maintenance etc. then periodic surveillance, maintenance interval becomes qualified life. In view of the above, omission or partial fulfillment of the environmental tests shall be done with justification as brought out in NPCIL’s valve specification.

5.2.1.4 Qualification of the Valve by Seismic Loading Test

The rigid valve assembly is required to be subjected to seismic loading test (equivalent static load test) as per Annexure-F of ANSI B 16.41. For seismic loading test, OBE response spectra alone or the envelope of OBE and SSE response spectra as applicable shall be used. The accelerations on the valve in the three orthogonal directions, can also be obtained from the piping/equipment response spectrum analysis. In such case, acceleration values equal to 1.5 times the calculated accelerations of the valve shall be used to calculate the equivalent static force. Cold cyclic tests are also required to be conducted as per Annexure-B of ANSI B 16.41. The valve assembly should be rigidly mounted in a fixture. The fixture shall be anchored to rigid concrete foundation. The calculated seismic load shall be applied on the valve assembly, at the C.G. location, in weakest direction in a horizontal plane of the valve using wire rope-pulley arrangement/tiebar-load
cell/turn buckle arrangement. In the deflected position of the valve assembly under equivalent static load, the intended functional operability of the valve shall be demonstrated.

The procedure for seismic loading (equivalent static load) test covering the loading calculation; mounting arrangement; loading procedure; test setup; test sequence; test equipment, instruments; cold cyclic test; measuring parameters (time, deflection); etc. shall be prepared and submitted to NPCIL for prior approval.

The seismic loading test (for RIGID valve assembly) shall then be performed and shall meet the functional operability requirements of ANSI B 16.41 Annexure-F and/or approved procedure.

5.2.1.5 Qualification of Actuator

The valve actuators shall be separately qualified seismically as per the requirements of IEEE 382. In case the actuator has already been seismically qualified by the actuator supplier, the qualification report shall be submitted to NPCIL for approval.

5.2.1.6 Qualification of Valve by Shake Table Test

The flexible valve assembly is required to be shake table tested as per the requirements IEEE 344.

The valve assembly shall be mounted on the shake table. While a seismic motion is given to the table the valve assembly should be checked for its intended functional operability. During the test the operating loads on the valve assembly should also be simulated adequately. The test should conservatively simulate the seismic event at the valve mounting location. The SSE and OBE required response spectra (RRS) at valve mounting location will be supplied by NPCIL. The multidirectional nature of earthquake should be accounted. In general the shake table motion should be such that it

i) produces a Test Response Spectra (TRS) that closely envelopes the Required Response Spectra (RRS).

ii) has a peak acceleration equal to or greater than RRS Zero Period Acceleration (ZPA).

iii) does not include frequency content above the RRS ZPA asymptote.

iv) has sufficient duration commensurate with strong motion part and fatigue inducing potential of the time history.

The procedure for seismic qualification test of flexible valve on shake table covering the details of mounting arrangements, loadings, shake table description, test sequence, RRS, etc. shall be prepared as per clauses given in this specification and as per IEEE 344 and shall be submitted to NPCIL for prior approval.
5.3 Documentation

The analysis report shall be prepared covering the description of the finite element model, assumptions made in the modelling and their justification, input data with supporting reference documents, software validation, natural frequencies calculated; equivalent static / response spectrum analysis results viz., stresses and displacements; compliance of stresses with codal requirements and displacements to be within the design clearances, etc. The reports shall be submitted to NPCIL for getting approval for subsequent seismic qualification test to be conducted on the valve assembly.

The test reports shall be prepared covering the test procedure, mounting arrangement, seismic load, equivalent seismic load test/shake table details, test setup, test sequence, results of the test, compliance with codal requirements viz. ANSI B 16.41/IEEE 344, etc.

Analysis reports and the test reports of valve assembly shall be documented in the form such that the reports are self explanatory and independently reviewable. Guidelines given in clause 10 of IEEE 344 may be followed for the same. Final qualification report based on the guidelines given above shall be prepared and submitted to NPCIL for approval.
6.0 **SPECIFICATION FOR SEISMIC QUALIFICATION OF PANELS AND DEVICES**

This specification covers the procedure for qualification of electrical and instrumentation panels and devices, reactor control and shutdown devices, etc. in terms of structural integrity, pressure boundary integrity and functional operability as brought out in the NPCIL’s equipment specification and in the VGES. This procedure shall be applicable to various panels such as instrumentation and electrical panels, standard electronic cabinet, control panels, panels used for A/c packages or switchgears, valve station racks, instrument racks, battery stands, instruments / devices / modules mounted on floor / walls / panels, etc. However, for specific panel/cabinet/rack or instrument/device/module due to its specific design features any specific functional requirement to be met shall also be included in the VGES and shall also become part of the below mentioned qualification procedure.

For the design of the panel as a structure, the general requirements of design are given in ASME Section III, Division-1, Subsection NF-3000. The material used for the equipment shall be as given in NPCIL’s specification or as given in VGES Structural integrity of the panel and pressure boundary integrity of any equipment mounted in the panel shall be demonstrated by carrying out an analysis. Functional operability of the panel can be demonstrated by testing or by combination of analysis and testing. The tests covered in this specification pertain only to seismic test. The list of test facilities available in the country is given in NPCIL’s equipment specification. The detailed procedure for qualification of a general panel assembly is given below.

6.1 **Qualification for Structural integrity and Pressure Boundary integrity**

6.1.1 **Qualification by Analysis**

The structural integrity of the panel as a structure shall be assessed by performing an analysis. The structural integrity and pressure boundary integrity of tanks, piping, heat exchangers etc. mounted on the panel can also be assessed by analysis.

The panel shall be analysed by finite element method. The various steps involved in finite element idealisation and the static and dynamic analyses of the panel are brought out below.

6.1.1.1 **Finite Element Modelling**

Major structural members of the panel may be modelled using beam elements with appropriate material and section properties calculated from detailed drawings of structural assembly. The plates used in the panel shall be modelled using plate / shell element unless otherwise justified.

Some of the panels may have heavy electrical components like blower, switch gear, transformers, coils, batteries, etc. and mechanical components like tanks, small heat
exchangers, valves etc. Such components may be decoupled from the panel after meeting the decoupling criteria as given in ASCE 4-86. The mass of the decoupled component shall be included as a lumped mass at appropriate nodes in the finite element model of the panel. The connection between heavy components and panel structure may be appropriately modelled with spring-mass system. In case the component does not meet the decoupling criteria, it shall be included in the model by its spring-mass system. It may not be possible to find out the parameters required to meet the decoupling criteria for the components mounted on thin sheet metal of the panel. In such cases following may be adopted.

Light devices and various instruments (viz. relays, contactors, PCB’s etc.) mounted on the plate (modules) may be modelled as lumped mass or combination of spring mass system with proper justification.

Cabling, tubing or any other connections connected with panel may be appropriately modelled by using spring/boundary elements. Similarly, the panel mounting/support arrangements may be appropriately modelled by using spring, boundary element or fixed boundary condition.

All the critical sections of panel, base plates, connections of instruments, mounting hardware of instruments, etc. shall be modelled adequately. The finite element model shall correctly represent the actual welding details viz. sport welds, line weld etc.

The finite element model using above considerations shall adequately represent the realistic dynamic/static characteristics of the panel assembly. While modelling the panel and the major mechanical and electrical components mounted on the panel like tanks, small heat exchangers, transformers, switchgears, etc., apart from beam, plate & shell elements, 3D brick element or combination thereof may also be used with proper justification. The assumptions made in the finite element idealization with proper justification shall be brought out in the report. All the inputs used in the data preparation shall be from authenticated document and shall be referred/attached with the report.

6.1.1.2 Finite Element Analysis

Using the validated software, the panel as modelled above shall be subjected to the response spectrum analysis. The response spectrum analysis shall include the addition of modal responses in each direction after accounting for closely spaced modes as per USNRC RG 1.92 and missing mass response as per NUREG 1061 Vol. 4 (missing mass is the mass of the equipment which has not participated upto 33 Hz or cutoff frequency) and three orthogonal directional response combination by a SRSS method. The panel should be qualified for OBE alone or OBE and SSE as applicable. The floor response spectra at the mounting locations of panel for OBE (2% damping) and SSE (3% damping) will be supplied by NPCIL as applicable.
Some of the panels may have components like tubing, tanks, piping, coolers, blower, small heat exchangers like radiator, etc. The panels and such components shall be analysed for various loads viz. loads during design, normal and upset conditions (pressure, temperature, mechanical, cycles, transients), including OBE; loads during emergency and faulted conditions (pressure, mechanical), including SSE; test loads; hydrodynamic, electromagnetic loads, etc. as applicable and as specified in the NPCIL’s equipment specification and in the VGES.

For fatigue analysis, fifty stress cycles for five numbers of OBEs (ten stress cycles per OBE) shall be accounted in addition to the stress cycles due to other loads as specified in the NPCIL’s equipment specification and in the VGES.

6.1.3 **Codal Qualification**

Load combinations to be adopted for ASME Class-1, 2 & 3 components (equipment, piping) and panel/component supports for design and service levels are given in Annexure-1.

The combined stresses in the components like tanks, piping, heat exchanger, etc. shall meet the requirements of ASME Section-III, division-1, Subsection-NB-3000, NC-3000, ND-3000 whichever is applicable.

The combined stresses in panel/component support structural members shall meet the requirements of ASME Section-III, division-1, Subsection-NF-3000.

The stresses in the base plate shall be checked. The stresses may be checked as per NUREG CR-6241, IS 800, IS 456 or any other applicable code. The foundation bolts design shall be checked as per ACI-349.

6.2 **Qualification for Functional Operability**

6.2.1 **Qualification by Test**

6.2.1.1 **Environmental Aging Test**

Before the shake table test of panel or the instrument/device/module on the panel, other environmental aging tests if specified viz. thermal, pressure, humidity, radiation, plant vibrations, OBE vibration shall be conducted in accordance with IEEE 323 and IEC 60780. The assessment of equipment aging effect is required to determine if aging has significant effect on intended functional operability of the devices in the panel. For example, electromechanical equipment shall be operated to simulate the expected mechanical wear and electrical contact degradation, contact pitting, etc. of the device to be tested. If the equipment is determined not to have significant aging mechanisms by virtue of periodic in-service surveillance, maintenance etc. then periodic surveillance, maintenance interval becomes qualified life. Omission or partial fulfillment of the environmental test shall be done with proper justification as brought out above.
6.2.1.2 Qualification by Shake Table Test

The panel or the devices can be shake table tested by one of the two methods given below.

a) Full scale testing of a panel:

The functional operability of the panel including the devices/instruments mounted on the panel can be demonstrated by full scale testing of the panel on a shake table in accordance with IEEE 344 and IEC 980.

The panel shall be mounted on the shake table. While a seismic motion is given to the table, the equipment should be checked for its intended functional operability. During the test, the operating loads on the equipment should also be simulated adequately.

The test should conservatively simulate the seismic event at the equipment mounting location. The multidirectional nature of earthquake should be accounted. In general the shake table motion should be such that it

i) produces a Test Response Spectra (TRS) that closely envelopes the Required Response Spectra (RRS).
ii) has a peak acceleration equal to or greater than RRS Zero Period Acceleration (ZPA).
iii) does not include frequency content above the RRS ZPA asymptote.
iv) has sufficient duration commensurate with strong motion part and fatigue inducing potential of time history.

In the panel testing, the RRS are the Floor Response Spectra (FRS) of the floor on which the panel is mounted.

b) Testing of devices mounted on the panel by combined analysis and test:

If panel/support/rack is found to be rigid (i.e. first natural frequency greater than or equal to 33 Hz or rigid frequency) then the functional operability of the instrument/device/module mounted in the panel/support/rack can be demonstrated by testing individual instrument/device/module on shake table. In this case the floor response spectra are the Required Response Spectra (RRS) for testing. The floor response spectra which is to be used for testing, for 5% damping for SSE and OBE will be supplied by NPCIL.

If the panel/support/rack is found to be flexible (i.e. first natural frequency less than 33 Hz or rigid frequency). The functional operability of the instruments/devices/modules mounted in the panel can also be demonstrated by testing individual instruments/devices/modules on the shake table. In this case, response spectra at the base of instruments/devices/modules mounted in the panel are used as Required Response Spectra (RRS) for
testing. These response spectra are obtained from time history analysis of the panel. The time history analysis of the panel shall be carried out using the same finite element model prepared as given in 6.1.1. Time history analysis shall be performed to calculate the time history and response spectra at the base of the instrument/device/module mounted in the panel. Any other method for generation of the RRS at the base of the device in the panel can also be used with proper justification. The intended functional operability of the instruments/devices/modules can be demonstrated by mounting them on a shake table and then perform the test in accordance with IEEE 344 and IEC 980. In the device testing, response spectra at the base of the device on the panel are used as Required Response Spectra (RRS).

The procedure for shake table test covering the mounting arrangement, pre-post intermediate inspection, monitoring parameters, input motion, shake table facility, environmental aging test, operational loads, acceptance criterion, etc. shall be prepared as per IEEE 344, IEC 980 and submitted to NPCIL for prior approval.

The shake table test shall then be conducted at a recognized institute and shall meet the requirements of IEEE 344, IEC 980 or the approved procedure.

6.2.4 Documentation

Analysis (Response spectrum analysis/time history analysis) reports covering the details of modelling, assumptions made while modelling and the justifications, input data with supporting reference documents, software validation, combination/calculation of stresses, stress compliance with code, etc. shall be prepared. The reports shall be submitted to NPCIL for getting approval for the subsequent seismic qualification test.

The test reports covering the test procedure, mounting arrangement, shake table details, test setup, test sequence, input motion and details of compliance with IEEE 344 and IEC 980 etc. shall be prepared.

The analysis/test reports shall be documented in the form such that the reports are self explanatory and independently reviewable. Guidelines given in clause-10 of IEEE 344 may be followed for the same. Final qualification report based on the above guidelines shall be prepared and submitted to NPCIL for approval.
7.0 SPECIFICATION FOR QUALIFICATION OF ROTATING AND RECIPROCATING EQUIPMENT

This specification covers the procedure for qualification of rotating and reciprocating equipment in terms of structural integrity, pressure boundary integrity and functional operability as brought out in the NPCIL’s equipment specification and in the VGES. The procedure shall be applicable to rotating equipment viz. pump-motor assembly, fan, blower etc. and reciprocating equipment viz. compressor, diesel generator, reciprocating pumps etc. However, for specific equipment, due to its specific design features any additional specific functional requirement to be met shall also be included in the VGES and shall also be included in the below mentioned procedure.

In case of pumps, general requirements of design are given in ASME Section-III, division-1, Subsection-NB, NC and ND whichever is applicable. If any supports are used in the equipment, those should be designed as per the general requirements given in ASME Section III, Division-1, Subsection NF. The material used for the equipment shall be as given in NPCIL’s specification or as given in VGES. Structural integrity, pressure boundary integrity and functional operability of the equipment shall be demonstrated by carrying out analysis. The functional operability of the equipment can also be demonstrated by a test. The tests covered in the specification pertain only to a seismic test. The list of test facilities available in the country is available in the NPCIL’s equipment specification.

As a representative of rotating equipment a procedure for qualification of pump-motor assembly has been covered below.

7.1 Qualification for structural integrity and pressure boundary integrity

7.1.1 Qualification by Analysis

The structural integrity and pressure boundary integrity of the equipment can be assessed by performing an analysis.

The pump-motor assembly shall be analysed by finite element method. The various steps involved in finite element idealisation and the static and dynamic analysis of the pump motor assembly are brought out below.

7.1.1.1 Finite Element Modelling

Pump casing, motor casing, stator, shaft and rotor, impeller, coupling, frame of motor and pump, bearings of motor, pump sealing arrangements, mounting base frame/structure and any other components may be modelled with appropriate section and material properties as calculated from/given in the component detailed drawings. These components may be modelled with beam/shell/plate/3 D brick elements or combination thereof so as to adequately represent the static/dynamic characteristics of the pump-motor assembly.
Motor casing, pump casing, shaft, supporting structure of motor and pump may be modelled with beam elements. Stator and rotor of motor, impeller of pump may be modelled as lumped mass/spring mass system at appropriate nodes. Bearings shall be modelled by spring elements if the shaft is decoupled from casing. However for integral shaft-casing model the bearing may be modelled by coaxial spring elements. Coupling may be modelled using spring elements/master-slave/rigid link element or with appropriate use of end release code. Sealing arrangement may also be modelled with appropriate spring mass system. The spring constants for bearings shall be used from authenticated document and shall be referred/attached with the report.

Extensions of a stationary component upto the rotating component may be modeled by appropriate rigid links.

Foundation bolts for base frame, bolts of motor casing with base frame, bolts of pump casing with base frame, coupling bolts if any and bolts of flanges may be appropriately modelled by using boundary elements.

Any other peculiar construction detail of pump-motor assembly may also be modelled appropriately by using mass and spring-mass system.

Finite element model constructed using above considerations shall adequately represent the realistic static/dynamic characteristics of the pump motor assembly. The assumptions made in the finite element idealization with proper justification shall be brought out in the report. All the inputs used in the data preparation shall be from authenticated document and shall be referred/attached with the report.

7.1.1.2 Finite Element Analysis

Using validated software, the equipment model shall be analysed to extract the natural frequencies of the equipment.

If the first natural frequency of support frame and pump casing and motor casing is above 33 Hz (or rigid frequency), then shaft, rotor and impeller model may be decoupled from support frame and pump-motor casings and analysed separately, using equivalent static analysis method or response spectrum analysis method.

The response spectrum analysis shall include the addition of modal responses in each direction after accounting for closely spaced modes as per USNRC RG 1.92 and missing mass response as per NUREG 1061 vol. 4 (missing mass is the mass of the equipment which has not participated upto 33 Hz or cutoff frequency) and three orthogonal directional response combination by SRSS method.

In the equivalent static analysis method, forces equivalent of 1.5 times spectral accelerations corresponding to the shaft-rotor-impeller assembly frequency may be applied simultaneously in the 3 orthogonal directions at all mass points and static analysis carried out.
If the first natural frequency of the assembly is less than 33 Hz (or rigid frequency), then integral model of support, stationary components, rotating parts and other devices may be analysed using response spectrum analysis.

The equipment shall be qualified for OBE alone or OBE and SSE. The applicable response spectra are the response spectra at equipment mounting location. OBE (2% damping) and SSE (3% damping) response spectra at the base of pump-motor assembly or floor will be supplied by NPCIL as applicable.

The pump shall be analysed for the loads experienced by it at the nozzle location from the connected piping. The pump shall be analysed for various loads viz. loads during design, normal and upset conditions (pressure, temperature, mechanical, cycles, transients), including OBE; loads during emergency and faulted conditions (pressure, mechanical), including SSE; test loads; hydrodynamic, electromagnetic loads, etc. as applicable and as specified in the NPCIL’s specification and in the VGES.

For fatigue analysis, fifty stress cycles for five numbers of OBEs (ten stress cycles per OBE) shall be accounted in addition to the stress cycles due to other loads as specified in the NPCIL’s equipment specification and in the VGES.

7.1.1.3 **Codal Qualification**

Load combinations to be adopted for ASME Class-1, 2 & 3 pumps and pump supports for design and service levels are given in Annexure-1.

The combined stresses in the individual components/elements shall meet the relevant codal requirements viz. ASME Section-III, division-1, Subsection NB-3000, NC-3000 and ND-3000 whichever is applicable.

The combined stresses in the base frame shall meet the requirements of ASME Section-III, division-1, Subsection-NF-3000.

The combined stresses in mounting bolts of pump casing to base frame between motor and base frame, coupling bolts, flanges connecting bolts shall meet the relevant codal requirement viz., ASME Section-III, division-1, Subsection NB-3000, NC-3000, ND-3000 & NF-3000.

The stresses in the base plate shall be checked. The stresses may be checked as per NUREG CR-6241, IS 800, IS 456 or any other applicable code. The foundation bolts shall be checked as per ACI-349.
7.2 Qualification for Functional Operability

7.2.1 Qualification by analysis

The seismic displacements as obtained by the analysis shall be combined with displacements/deflections due to other loads and shall be checked for operational/allowable clearances specified at various component sub-assemblies e.g. Shaft-bearing, impeller-casing, stator-rotor, coupling, alignment, etc. The reactions coming at the bearing locations shall be less than bearing load capacity.

7.2.2 Qualification by test

The functional operability of rotating and reciprocating equipment is generally demonstrated by analysis as brought out above. However, these equipment can as well be qualified for their functional operability by conducting a shake table test in accordance with IEEE 344 and IEC 980.

The equipment shall be mounted on the shake table. While a seismic motion is given to the table the equipment should be checked for its intended functional operability. During the test the operating loads on the equipment should also be simulated adequately.

The test should conservatively simulate the seismic event at the equipment mounting location. The multidirectional nature of earthquake should be accounted. In general the shake table motion should be such that it

i) produces a Test Response Spectra (TRS) that closely envelopes the Required Response Spectra (RRS).
ii) has a peak acceleration equal to or greater than RRS Zero Period Acceleration (ZPA).
iii) does not include frequency content above the RRS ZPA asymptote.
iv) has sufficient duration commensurate with strong motion part and fatigue inducing potential of time history.

In the equipment testing, the RRS are the floor response spectra (FRS) of the floor on which the equipment is mounted.

7.3 Documentation

The analysis report shall be prepared covering the description of the finite element model, assumptions made in the modelling and their justification, input data with supporting reference documents, software validation, natural frequencies calculated, equivalent static/response spectrum analysis results viz., stresses and displacements, calculation/combination of stresses and compliance of stresses with codal requirements and displacements to be within design clearances, etc.
The test reports covering the test procedure, mounting methods, shake table details, test setup, test sequence, input motion and details of compliance with IEEE 344 and IEC 980 etc. shall be prepared.

The analysis/test reports shall be documented in the form such that the reports are self-explanatory and independently reviewable. Guidelines given in clause-10 of IEEE 344 may be followed for the same. Final qualification report based on the guidelines given above shall be prepared and submitted to NPCIL for approval.
8.0 SPECIFICATION FOR QUALIFICATION OF TANKS, VESSELS, PIPING & SUPPORTS

This specification covers the procedure for qualification of passive equipment like tanks, vessels, heat exchangers, piping, supports, etc. in terms of structural integrity and pressure boundary integrity as brought in the NPCIL’s equipment specification and in the VGES.

In case of tanks, vessels, pressure vessel and tubes of heat exchangers, piping and supports general requirements of design are given in ASME Section-III, division-1, Subsection-NB, NC, ND for class-1, 2 and 3 respectively and Subsection NF whichever is applicable. For class-4 equipments, the general requirements of design are given in ASME section VIII, Division-1 and Division-2, whichever is applicable. For class-4 piping, the requirements of design are given in ASME/ANSI B-31.1. For heat exchanger, the general requirements of design are given in Mechanical standard TEMA class-C. The material used for the equipment shall be as given in NPCIL’s specification or as given in VGES. The special attention is also required while analysing nozzles on the tanks and vessels.

The procedure for seismic qualification of tanks, vessels, piping and supports is given below. However, any additional specific functional requirement to be met for specific equipment due to its specific design features shall also be included in VGES and also in the below mentioned procedure.

8.1 Qualification of Structural Integrity and Pressure Boundary Integrity

8.1.1 Qualification by Analysis

The structural integrity and pressure boundary integrity of tanks, vessels, piping, supports etc. can be assessed by performing analysis.

The tank, vessel, piping, support shall be analysed by finite element method. The various steps involved in finite element idealisation and the static and dynamic analysis of the tank, vessel, piping, support are brought out below.

8.1.1.1 Finite Element Modelling

The tank and vessel body may be modelled with beam, plate, shell, 3-D brick elements or combination thereof with proper justification.

The tank and vessel internals viz. baffle plate, tube bundles, adsorber, sparger, tubing, etc. may be modelled appropriately to represent their dynamic/static characteristics.

The support structure of the tank may be modeled with beam/plate elements with appropriate section properties as obtained from detail drawing of supports.
The foundation bolts may be modeled with boundary elements.

All the other components of tanks and vessels viz. piping, nozzle and support, manholes etc. shall be taken into consideration while preparing the finite element model. Tangent and bend elements shall be used for modelling the piping whereas beam and/or spring elements shall be used for modelling the supports in a piping layout. The effect of pressure on flexibility of bend element shall be accounted for Class-1 piping.

The finite element model of the tank, vessel, piping and support shall adequately represent the realistic dynamic and static characteristics of the tank, vessel, piping and support structure. The piping connected to the tank, vessel can be de-coupled after meeting the decoupling criteria as given in ASCE 4-86 and analysed separately. The assumptions made in the finite element idealization with proper justification shall be brought out in the report. All the inputs used in the data preparation shall be from authenticated document, and shall be attached/referred in the report.

8.1.1.2 Finite Element Analysis

The model prepared based on above guidelines shall be analysed by response spectrum analysis using validated software. The response spectrum analysis shall include the addition of modal responses in each direction after accounting for closely spaced modes as per USNRC RG 1.92 and missing mass response as per NUREG 1061 vol. 4 (missing mass is the mass of the equipment which has not participated upto 33 Hz or rigid frequency) and three orthogonal directional response combination by SRSS method.

The tank, vessel, piping, support shall be qualified for two levels of earthquake viz. OBE alone or OBE and SSE as specified in NPCIL’s specification and in the VGES.

The response spectra for SSE and OBE (as per applicable damping) at equipment foundation will be supplied by the NPCIL as applicable.

The applicable damping values as given in Appendix N, of ASME B &PV, Section III, Division 1, Appendices are given below:

<table>
<thead>
<tr>
<th>% critical damping</th>
<th>OBE</th>
<th>SSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Piping ≤ 300 mm dia.</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Piping &gt; 300 mm dia.</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

The loads coming at the nozzle locations on the tank, vessel shall be used for design and analysis of tank, vessel and their nozzles.
The equipment shall be analysed for the loads experienced by it at the nozzle location from the connected piping. The equipment shall be analysed for various loads viz. loads during design, normal and upset conditions (pressure, temperature, mechanical, cycles, transients), including OBE; loads during emergency and faulted conditions (pressure, mechanical), including SSE; test loads, etc. as specified in NPCIL’s equipment specification and in the VGES.

For fatigue analysis, fifty stress cycles for five numbers of OBEs (ten stress cycles per OBE) shall be accounted in addition to the stress cycles due to other loads as specified in the NPCIL’s equipment specification and in the VGES.

8.1.1.3 **Codal Qualification**

Load combinations to be adopted for ASME Class-1, 2 & 3 vessels, component and piping and supports for design and service levels are given in Annexure-1.

The combined stresses in pressure vessel and piping shall meet the relevant codal requirements viz. ASME Section-III, division-1, Subsection-NB-3000, NC-3000 or ND-3000 whichever is applicable.

The combined stresses in support structure etc. shall meet the requirements of ASME Section-III, division-1, Subsection-NF-3000.

The combined stresses in the nozzle, as calculated using WRC-297/WRC-107 or any other justifiable method shall meet the requirements of ASME Section-III, division-1, Subsection NB, NC and ND.

The stresses in the base plate shall be checked. The stresses may be checked as per NUREG CR-6241, IS 800, IS 456 or any other applicable code. The foundation bolts shall be designed as per ACI 349.

8.2 **Documentation**

The analysis report shall be prepared covering the description of the finite element model, assumption made while modelling and their justification, input data with supporting reference documents, software validation, natural frequencies calculated, equivalent static/response spectrum analysis results viz., stresses and displacements, combination/calculation of stresses and compliance of stresses with codal requirements and displacements to be within the design clearances, etc.

Results of the analysis of the tank, pressure vessel, piping, nozzle and support structure should be documented in the form of analysis reports, which are self-explanatory and independently reviewable. Guidelines given in ASME Section-III, Division 1, Appendices, Appendix-C may be followed for the same. Final qualification report based on the guidelines given above shall be prepared and submitted to NPCIL for approval.
ANNEXURE-1

Load combinations for Design condition and service levels for equipment, piping & supports

<table>
<thead>
<tr>
<th>Plant Classification</th>
<th>Design/Service level</th>
<th>Load combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>Design condition</td>
<td>Pressure dead weight, sustained loads, temperature$^{(1)}$</td>
</tr>
<tr>
<td>Normal</td>
<td>Service level A</td>
<td>Normal operating transients (pressure, temperature, mechanical)</td>
</tr>
<tr>
<td>Upset</td>
<td>Service level B</td>
<td>Pressure, dead weight, sustained loads, upset condition transients (pressure, temperature$^{(2)}$, mechanical), including OBE$^{(3)}$</td>
</tr>
<tr>
<td>Emergency</td>
<td>Service level C</td>
<td>Pressure, dead weight, sustained loads, temperature$^{(1)}$, emergency condition transients (pressure, mechanical)</td>
</tr>
<tr>
<td>Faulted</td>
<td>Service level D</td>
<td>Pressure, dead weight, sustained loads, temperature$^{(1)}$, faulted condition transients (pressure, mechanical), pipe rupture loads, SSE$^{(3)}$</td>
</tr>
</tbody>
</table>

Note No: 1) Temperature is used to determine allowable stress only

2) Thermal transients under Level C shall also be considered in Level B

3) OBE and SSE include both inertial and seismic anchor movement (SAM)
ANNEXURE-2

Impact Hammer Test for Frequency Determination of Valves

Impact hammer test shall be used for estimation of modal frequencies of the valves. The test will require impact hammers instrumented with a force transducer to measure the impact force, response measuring transducers (accelerometers) to measure the response caused by the known impact force, signal conditioners to condition the signal for the required frequency band and amplification, two channel signal analyser for signal analysis; and for computing frequency response function and coherence function. The model frequencies shall be estimated by appropriate analytical curve fitting method.

The particular characteristics of each element of the test are described below:

1. Impact Hammer: The impact hammer shall have a built in force transducer. Two important characteristics of impact hammer are its weight and tip hardness. Appropriate range hammer with selectable tip (soft, medium and hard) shall be used. The force transducer shall be integrally fixed on the hammer for impact force measurement.

2. Response Transducer (accelerometers): Transducer shall be used for measurement of response at atleast two locations on the valve body. Sensor sensitivity shall be high enough to get repeatable signal above background noise.

3. Signal Conditioning Units: The units shall be suitable for low signal-to-noise ratio (40dB) and must be able to detect over load in the response signal.

4. Analysis System: Two-channel dynamic signal analyser shall be used. The analyser shall have zoom transform capability, appropriate window functions for impulse input signal and decaying response signals, and analytical curve fitting capability to extract modal properties.

Measurement Procedure

1. The valve assembly should be mounted in the rigid flange fixture. This fixture should be anchored to the anchor bolts embedded in rigid heavy mass concrete platform. The machinery noise in the shop should be minimal.

2. Frequency Response Measurement (FRF) shall be made at many locations on the valve body to identify major resonances. Use impact hammer of appropriate weight and tip hardness. Determine two best locations along each axis for mounting response accelerometer either by a strong magnet or by adhesive.

3. Check the repeatability of FRF Test. Preload the valve body (if required) to minimise non-linearities caused by gaps and clearances. Confirm low non-linearity effect on the response signal by coherence measurement.
4. Ensure that input signal is not zero in the frequency band of interest.


7. Determine FRF from the ratio of Cross Spectrum to Power Spectrum of input signal. Average (at least 24) and process the signal to minimise bias error in the estimation of the Cross-Spectrum. Estimate the coherence function to monitor the quality of FRF measurement.

8. Display FRF as magnitude versus frequency in logarithmic scale. Display phase versus frequency in linear scale.

9. Estimate modal parameter (if specified) by fitting an analytical curve on the FRF function. Ensure reasonable fit for good estimation of modal properties.

10. Perform zoom analysis around closely spaced modal frequency (Resolution 10:1).

11. Determine the phase between two measurement locations (along the axis) at the identified natural frequencies.

12. Include one set of prints of input autospectrum, FRF and coherence function, phase angle etc. for each direction of test in the report.