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STUDIES TO DEMONSTRATE THE ADEQUACY OF TESTING RESULTS OF THE QUALIFICATION TESTS FOR THE ACTUATOR OF MAIN STEAM SAFETY RELIEF VALVES (MSSRV) IN AN ADVANCED BOILING WATER REACTOR (ABWR)

P.F. Gou, R. Patel, G. Curran, D. Henrie, E.R. Solorzano
GE Energy, Nuclear
General Electric Company
Phone: 408 925-4115, FAX: 408 925-1193
bob.gou@gene.ge.com

ABSTRACT

This paper presents several studies performed to demonstrate that the testing results from the qualification tests for the actuator of the Main Steam Safety Relief Valves (MSSRV; also called SRV in this paper) in GE's Advanced Boiling Water Reactor (ABWR) are in compliance with the qualification guidelines stipulated in the applicable IEEE standards.

The safety-related function of the MSSRV is to relieve pressure in order to protect the reactor pressure vessel from over-pressurization condition during normal operation and design basis events. In order to perform this function, the SRV must actuate at a given set pressure while maintaining the pressure and structural integrity of the SRV. The valves are provided with an electro-pneumatic actuator assembly that opens the valve upon receipt of an automatic or manually initiated electric signal to allow depressurization of the reactor pressure vessel (RPV). To assure the SRV can perform its intended safety related functions properly, qualification tests are needed in addition to analysis, to demonstrate that the SRV can withstand the specified environmental, dynamic and seismic design basis conditions without impairing its safety related function throughout their installed life under the design conditions including postulated design basis events such as OBE loads and Faulted (SSE) events. The guidelines used for the test methods, procedures and acceptance criteria for the qualification tests are established in IEEE std 344-1987 and IEEE std 382-1985.

In the qualification tests, the specimen consists of the actuator, control valve assembly, limit switches, and limit switch support structure. During the functional, dynamic and seismic tests, the test specimen was mounted on a SRV. Qualification of safety related equipment to meet the guidelines of the IEEE standards is typically a two-step process: 1) environmental aging and 2) design basis events qualification. The purpose of the first step is to put the equipment in an end of qualified life condition that represents the worst state of deterioration. The second step demonstrates that adequate integrity remains in the equipment such that it will withstand the loadings of the specified design basis event conditions and still perform its intended safety related function.

Keywords: valves, testing, seismic loads, qualification

1. INTRODUCTION

General Electric (GE) has received design certification for the Advanced Boiling Water Reactor (ABWR) from the United States Nuclear Regulatory Commission (USNRC). It is envisioned that the certified design can be constructed, without further licensing effort, at locations suitable for nuclear power plant sites anywhere in the U.S. when the site-specific conditions are encompassed by the design envelope parameters. One of the parameters is the peak ground acceleration (PGA) for the Safe Shutdown Earthquake (SSE) equal to 0.3g. The ABWR plant is designed for a rated thermal output of 3926MWt, which provides for an electric output in excess of 1350Mwe. Many salient features of an ABWR plant can be found in Reference 1 (Wilkins, 1986). A cutaway view that shows reactor pressure vessel (RPV), reinforced concrete containment vessel (RCCV) and reactor building (RB) is presented in Figure 1. The ABWR is the first of a new generation of nuclear power plants equipped with advanced technologies and features that raise plant safety to new levels that significantly improve the economic competitiveness with other forms of generation. GE's ABWR was optimized with many enhancements and designed to reduce calculated core damage frequency by an order of magnitude relative to currently operating plants. The most important design feature contributing to this goal is the adoption of reactor internal, vessel-mounted pumps. These eliminate large, recirculation piping on the vessel, particularly involving penetrations below the top of the core elevation, and make possible a smaller Emergency Core Cooling System network to maintain core coverage during postulated loss-of-coolant events. Through nitrogen inerting, containment integrity threats from hydrogen generation were eliminated. Control and Instrumentation were enhanced through incorporation of digital technologies with automated self-diagnostic features.

In this paper, a summary is presented of the results of several studies that were performed to demonstrate that the testing results from the qualification tests for the actuator of the Main Steam Safety Relief Valves (MSSRV; also called SRV in this paper) are in compliance with the qualification requirements and guidance stipulated in the applicable IEEE standards.

The safety-related function of the MSSRV is to relieve pressure in order to protect the reactor pressure vessel from over-pressurization condition during normal operation and design basis events. In order to perform this function, the SRV must actuate at a given set pressure while maintaining the pressure and structural integrity. A typical SRV is shown in Figure 2. The valves are provided with an electro-pneumatic actuator assembly to enable opening the valve upon receipt of an automatic or manually initiated electric signal to allow depressurization of the reactor pressure vessel (RPV). To assure the SRV can perform its intended function properly, qualification tests are needed in addition to analysis, to demonstrate that SRV can withstand the specified environmental, dynamic and seismic design basis conditions without impairing its intended safety related functions throughout their installed life under the design conditions including postulated design basis events The guidelines for the test methods, procedures and acceptance criteria for the qualification tests are established in IEEE std 344-1987 and IEEE std 382-1985.

In the dynamic qualification tests, the specimen consists of the actuator, control valve assembly, limit switches, and limit switch support structure. During the functional, dynamic and seismic tests, the test specimen was mounted on a SRV. Qualification of safety related equipment to meet the requirements of the IEEE standards is typically a two-step process: 1) environmental aging and 2) design basis events qualification. The purpose of the first step is to put the equipment in an end of qualified life condition that represents the worst state of deterioration. The second step demonstrates that adequate integrity remains in the equipment such that it will withstand the loadings of the specified design basis event conditions and still perform its intended safety related function.

The following three topics are addressed in this paper:

(a). Margin evaluation of Seismic Testing of MSSRV.
(b). Demonstration of how the acceptance criteria defined in IEEE Std 344-1987 are satisfied.
(c). Demonstration of how seismic/dynamic aging test guidelines given in IEEE Std 382-1985 are met.

2. GENERAL DESCRIPTION OF QUALIFICATION TEST

A typical qualification test program consists of the following sequence:

1) Environmental Ageing
- Mechanical Aging Test (36 years)
- Replacement of Non-metallic
- Normal Radiation Aging
- Thermal Aging
- Mechanical Aging Test (4 years)

2) Seismic/Dynamic test
- Resonance Frequency and Vibration Characteristics Test
- Vibration Aging Test
- SRV Cycle Test
- Upset Dynamic Load Test
- Faulted Dynamic Load Test

- Chugging Cycle Test
- 3) LOCA Simulation test
- DBE Radiation Aging
- DBE Environmental Simulation Test (LOCA)
- Post Test Inspection

Functional test are performed before and throughout the test sequence to monitor any variation in SRV performance.

3. SEISMIC AND DYNAMIC Tests

In the qualification tests, the specimen consists of the actuator, control valve assembly, limit switches, and limit switch support structure. Figure 2 shows the test specimen mounted on a typical SRV, which is anchored on the testing table for the functional, dynamic and seismic tests.

The specimen is in the valve-closed position with the solenoid valve control voltage adjusted to nominal voltage and average pneumatic supply at the start of the test. Both horizontal axes and the vertical axis are excited independently, but simultaneously. The inputs for the three axes are phase incoherent during the Random Multi-frequency Tests. The specimen is subjected to tri-axial multi-frequency random motion which is amplitude-controlled in one-third octave bandwidths spaced one-third octave apart over the frequency range of 5 to 100 Hz for a duration defined according to various test conditions. Three simultaneous, but independent, random signals are used as excitation to produce phase incoherent motions in the vertical and two horizontal axes. The amplitude of each one-third-octave bandwidth was independently adjusted in each of the three axes until the Test Response Spectra (TRS) enveloped the Required Response Spectra (RRS) within the limitations of the test machine. The Zero Period Acceleration (ZPA), as well as other areas of the RRS, may be exceeded during the test in order to meet the peaks of the curves. A response spectrum analyzer analyzed the resulting motion at 2% damping and plotted at one-sixth octave intervals over the frequency range of 1 to 200 Hz. A typical RRS is shown in Figure 4.

4. MARGIN EVALUATION OF SEISMIC TESTING OF MSSRV AND GENERATION OF NEW (OR REVISED) RESPONSE SPECTRA

Ideally, the TRS of the selected location and direction for the specimen should envelope the RRS to satisfy the qualification test. Frequently, in the comparison of TRS with RRS, for certain locations and some directions, it was found that the TRS did not envelope the RRS for certain range of frequencies. At this point, it is not correct to conclude that the specimen has failed the qualification test. One of the important steps is to examine whether there are significant inherent margins that were introduced into the RRS in the early stage of design to cover unknown information or uncertainties because of unavailability of numerous design parameters (e.g., piping and building design details, etc.) at the beginning of a project. The original RRS were generated using multiple, independent, response spectra applied at individual support attachments. When the final main steam piping system design is completed and final design information is available, a refined and more accurate analyses using multiple, independent, time history analysis methodology to obtain more realistic RS for the "as-designed" condition was performed. The Main Steam Line (MSL) "B" model contains the main steam piping from RPV nozzle through and including the outboard MSIV, associated SRV's including actuator and SRV discharge lines up to the diaphragm floor anchor to form a complete analytical piping model. Figure 5 shows the MSL "B" piping system model used in the as-designed analysis. The SRV model of the five valves that were coupled to the MSL is also shown in the same figure. This model is then analyzed by applying individual and independent TH at each support attachment.

Table 1 summarizes the Operation Base Earthquake (OBE) THs and the SRV discharge (an upset transient) THs applied to the dynamic model together with the corresponding output spectra for the Upset condition to be used to generate the new RS. Acceleration TH’s due to the OBE at each of the pipe support attachments were obtained from the global TH analyses of the reactor building (RB) dynamic analysis model based on the ABWR design. There are three sets of TH’s: North-South (NS) direction, East-West (EW) direction and vertical direction. They are individually and independently applied to the analytical piping model by program called PISYS to generate the acceleration TH’s at the pipe-to-SRV inlet flange connection (Node 31 in Figure 5). For each set of the global TH’s as input to the PISYS piping model, there are three (longitudinal, lateral and vertical) components of acceleration TH’s. Each response spectrum (RS) is generated from one of these three components of acceleration TH’s. The relations between the TH’s and the generated RS with their corresponding direction are illustrated in Table 1 for which the referenced building coordinate system is shown in Figure 3. The building vibrations due to the SRV actuation are represented by H1, H2, V1 and V2 in Table 1. They were also obtained from the global dynamic analyses of the RB model. Same as TH's of OBE, the TH's of SRV defined by H1, H2, V1 and V2 are individually and independently applied to the analytical piping model by PISYS to generate the acceleration TH's at the pipe-to-SRV inlet flange connection. For Upset condition, OBE is combined with the SRV loads based on the corresponding direction as shown in Table 1 to obtain the controlling new RS. The load combination for this condition consists of loads due to OBE and SRV. Since these are all dynamic loads and the peak values may not occur at the same time, SRSS combination is used to determine the final values. The resulting peak broadened spectra for Upset condition based on SRSS combinations are shown as "new RS-Broadened" in Figures 6, 7 and 8 for longitudinal, lateral and vertical directions, respectively.

For Faulted condition, a similar table can be made to summarize the TH analyses to generate the new RS, except that OBE is replaced by SSE and SRV discharge THs are replaced by Annulus Pressurization (AP), another faulted LOCA event load) THs. AP loads include nozzle jets, impingements jets, pipe whip restraint loads associated with a MS line break. They are more severe than other design breaks such as Feed water (FW); Residual Heat Removal (RHR), etc breaks in the LOCA category of loads. Similar procedures as above for the Upset condition are applied to SSE and AP THs to generate the new RS for the Faulted condition. The resulting peak broadened spectra for Faulted condition based on SRSS combinations are shown as "new RS/Broadened" in Figures 9, 10 and 11 for longitudinal, lateral and vertical directions, respectively.

5. DEMONSTRATION OF COMPLIANCE WITH THE GUIDELINES STIPULATED IN IEEE STANDARD 344-1987

The TRS, the new RS and the RRS for upset condition are shown in Figures 6, 7 and 8 for longitudinal, lateral and vertical directions, respectively. Uncertainties are covered by the broad range of frequencies selected, 35 to 55 Hz for longitudinal and lateral directions, about the natural frequency of interest (35 Long. and 50 Hz lat.) and (100 to 200 Hz) for the vertical direction based on the first natural frequency of 158 Hz.

Similarly, for Faulted condition, the load combination consists of loads due to SSE and LOCA including Annulus Pressurization (AP) loads. Since these are all dynamic loads and the peak values may not occur at the same time, SRSS combination is used to determine the final values. The TRS, the new RS and the original RRS (used as input to the test table) for Faulted condition are shown in Figures 9, 10 and 11 for longitudinal, lateral and vertical directions, respectively. The same broad range of frequencies presented above covers uncertainties. An examination of all the figures to compare the TRS and RS shows that TRS is larger than RS throughout all the frequency range except one region near 28 Hz. According to IEEE Std. 344 1987 the TRS may, on occasion, not fully envelop RS, if

1) A point of the TRS falls below the RS by 10% or less, provided the adjacent 1/6 octave points are at least equal to the RS and the adjacent 1/3 octave points are at least 10% above.
2) A maximum of 5 of the 1/6 octave analyzed points is below the RS.

Octave means a multiple of 2. It derives historically to the fact that eight notes corresponding to a factor of two in frequency (Weinstein, 2005). The sixth part of an octave is given by the ratio $2^{1/6}$ **:** 1.

For the case under consideration, as shown in Table 2, both condition 1) and condition 2) are satisfied. Thus the test performed is adequate.

From Figures 6, 7 and 8, it is clearly seen that the original RRS (generated by response spectra method) generally envelops the new RS-Broadened developed (generated by time history method) for Upset condition. Similarly, Figures 9, 10 and 11 show that the original RRS generally envelops the new RS-Broadened. In the frequency range of interest (35 to 55 Hz in the horizontal direction and 100 to 200 in the vertical), significant margin exists in the original RRS. Also, from these figures it is evident that the TRS fully envelops the new RS-Broadened at all frequencies and by a significant margin in the frequency range of interest for qualification of SRV actuator. It also meets the IEEE 344-1987, 7.6.3.1 guidelines since the new RS-Broadened values are well below the TRS at all frequencies.

6. DEMONSTRATION of COMPLIANCE with THE AGING TESTS GUIDELINES STIPULATED IN IEEE STD 382-1985

The test data for the MSSRV vibration aging test shows that in the low frequency range (5-22 Hz) the test table acceleration input was significantly higher than that suggested in the spectrum given in (IEEE, 1985), while in the higher frequency range, the acceleration input to the table dips below the IEEE curve. See Figure 12. It is not apparent whether sufficient energy was delivered to the specimen to meet the intent that the test specimen should experience sufficient energy input to represent aging effects. Therefore, it is necessary to confirm that the input to the test has delivered as much energy to the test specimen as is required in the IEEE spectrum. During the test it was reported that the shake table actuator in the direction of concern was broken trying to raise the input acceleration above the IEEE spectrum level. This is the actual indication that a large amount of energy was physically input to the table in the low frequency range (5-22 Hz) in order to achieve the acceleration level required. Guided by this observation, two approaches: (1). Comparison of strain energies and (2). Calculation of average acceleration are used as confirmatory analyses:

(1). Comparison of strain energies

For a sinusoidal motion, the displacement can be defined as:

$$x = C \cdot \sin(\omega \cdot t)$$

for which the acceleration is:

$$a = -C \cdot \omega^2 \cdot \sin(\omega \cdot t) \qquad \text{.................... (1)}$$

Substituting x in Eq.(1), it becomes,

$$a = -\omega^2 \cdot x$$

In this calculation, we are interesting in the magnitude only

$$|a| = \omega^2 \cdot |x| \qquad \text{.................... (2)}$$

For simplicity, we use $a = \omega^2 \cdot x$

and,

$$x = \frac{a}{\omega^2} \qquad \text{................ (3)}$$

Strain energy in terms of displacement is:

$$U = \frac{1}{2} \cdot k \cdot x^2 \qquad \text{....................(4)}$$

Substituting (2) and (3) into (4):

$$U = \frac{k}{2} \cdot \frac{a^2}{\omega^4} \qquad \text{...................(5)}$$

The input motion for the test and that for IEEE are defined in terms of acceleration as function of frequencies. They are shown in Figure 12.

For a given frequency, f_i or ω_i, we can calculate the displacement of the test for that frequency by Eq. (3) as:

$$x_1(i) = \frac{a_1(i)}{\omega_i^2} \qquad . \qquad \text{...................(6)}$$

Similarly, the displacement for the motion of IEEE by Eq. (3) is:

$$x_0(i) = \frac{a_0(i)}{\omega_i^2} \qquad . \qquad \text{................. (7)}$$

In the above expression, we define:

$a_1(i)$ = acceleration of the input motion of the aging test,
$a_0(i)$ = acceleration of the input motion of IEEE,
$x_1(i)$ = displacement of the input motion of the aging test,
and x_0 (i) = displacement of the input motion of IEEE.

In terms of displacement, according to Eq. (4), the total strain energy due to the motion of IEEE is.

$$U_0 = \sum_i \frac{k}{2} \cdot x_0(i)^2 \quad .... (8)$$

Similarly, in terms of displacement, according to Eq. (4), the total strain energy due to the motion of the test is:

$$U_1 = \sum_i \frac{k}{2} \cdot x_1(i)^2 \quad .... (9)$$

In Equations (8) and (9), the summation is performed from i = 5Hz to i= 100Hz.
Ratio of energy is calculated by:

$$R_U = \frac{U_1}{U_0} \quad .... (10)$$

Using Equations (8) and Eq.(9), the ratio of strain energy becomes

$$R_U = \frac{\sum_i x_1(i)^2}{\sum_i x_0(i)^2} \quad .... (11)$$

(2). Calculation of Average Acceleration:

The test data for the longitudinal direction was used and proportionality relations were derived to establish the value of the average acceleration in the test data with results summarized in Table 3.

Guided by Equations (10) and (11), we can find the ratio of strain energy for each frequency i by the following expression:

$$r(i) = \frac{\frac{k}{2} \cdot x_1(i)^2}{\frac{k}{2} \cdot x_0(i)^2} \quad .... (12)$$

It can be simplified as:

$$r(i) = \frac{x_1(i)^2}{x_0(i)^2} \quad .... (13)$$

In terms of acceleration, it can also be written as:

$$r(i) = \frac{a_1(i)^2}{a_0(i)^2} \quad .... (14)$$

Eq.(14) can also be written as:

$$a_1(i) = \sqrt{r(i)} \cdot a_0(i) \quad .... (15)$$

A displacement comparison of the test motion with that of IEEE curve has shown that the displacement of the test motion in the low frequency range is much greater than that of IEEE curve. Based on this comparison, the input motion of the test as shown in Figure 12 is more damaging to the tested articles than that the motion of IEEE in performing the aging test. To include this effect in the calculation, guided by Eq. (15), we introduce "Effective Acceleration" defined as follows:

$$a_E(i) = \sqrt{r(i)} \cdot a_1(i) \quad .... (16)$$

where
$a_E(i)$ = Effective Acceleration of the input motion of the aging test,
and r(i) is calculated by Eq.(14).

The area under the Effective Acceleration of the input motion of the aging test versus frequency is found by

$$Area = \sum_i \frac{a_E(i+1) + a_E(i)}{2} \cdot \Delta f_i \qquad \text{................ (17)}$$

It is over a frequency range of (100-5) Hz. Thus, the average value of the "Effective Acceleration" is found by

$$Accl_{ave} = \frac{Area}{(100-5)\cdot Hz}$$

As shown in Table 3, the energy content of the actual vibration aging test motion is 6.7 times greater than the corresponding energy content of the motion recommended by IEEE standard 382-1985. Presented in column 9 of Table 3, the total area under the IEEE acceleration versus frequency curve is 62.4 g*Hz over a range of (100-5) Hz. Thus, the average value of the “Effective Acceleration” for IEEE basis is calculated as 0.657g that corresponds to acceleration of 0.75g defined in 5.3.1 of (IEEE, 1985). Presented in column 14 of Table 3, the area calculated by Equation (17) under the test acceleration versus frequency curve is 65.287 g*Hz over a range of (100-5) Hz for which the “Effective Acceleration” for the test is calculated as 0.687g. By proportioning, the acceleration of the actual aging test is (0.687/0.657)*0.75g=0.78g which is above the acceleration of 0.75g stipulated in 5.3.1 of (IEEE, 1985).

7. CONCLUSIONS

(a). Margin evaluation of Seismic Testing of MSSRV.
From Figures 6, 7,8,9,10 and 11, it is clearly seen that the original RRS (generated by response spectra method and used as input to the test table) generally envelops the new RS-Broadened developed (generated by time history method) for both Upset condition and Faulted condition.
(b). Demonstration of how the acceptance criteria defined in IEEE Std 344-1987 are satisfied.
Also, from these figures it is evident that the TRS fully envelops the new RS-Broadened at all frequencies and by a significant margin in the frequency range of interest for qualification of SRV actuator. It also meets the IEEE 344-1987, 7.6.3.1 guidelines since the new RS-Broadened values are well below the TRS at all frequencies.
(c). Aging test guidelines given in IEEE Std 382-1985 are met by comparison of strain energies and calculation of the average effective acceleration of the actual aging test motion is 0.78g that is above the acceleration stipulated in IEEE standard

In conclusion, the SRV actuator qualified in this test was subjected to an input acceleration exceeding that required by the final as-designed analysis and therefore, the test results are acceptable. Since the actuator functionality was monitored throughout the test and is reported as being operational, the actuator is therefore, considered qualified for service.

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Table 1 – Example of Seismic Time History Inputs

Time History	Direction of Input Time Histories to PISYS	Direction of Output Spectra at Valve Flange	Designation
OBE	EW (X_B, 1 in PISYS) X_P	X-valve (Longitudinal)	OBEXX (Longitudinal)
		Y-valve (Vertical)	OBEXY (Vertical)
		Z-valve (Lateral)	OBEXZ (Lateral)
	Vertical (Z_B, 2 in PISYS) Y_P	same as above	OBEYX (Longitudinal)
			OBEYY (Vertical)
			OBEYZ (Lateral)
	NS (Y_B, 3 in PISYS) Z_P	same as above	OBEZX (Longitudinal)
			OBEZY (Vertical)
			OBEZZ (Lateral)
H1	EW (X_B, 1 in PISYS) X_P	same as above	H1XX (Longitudinal)
			H1XY (Vertical)
			H1XZ (Lateral)
	NS (Y_B, 3 in PISYS) Z_P	same as above	H1ZX (Longitudinal)
			H1ZY (Vertical)
			H1ZZ (Lateral)
H2	EW (X_B, 1 in PISYS) X_P	same as above	H2XX (Longitudinal)
			H2XY (Vertical)
			H2XZ (Lateral)
	NS (Y_B, 3 in PISYS) Z_P	same as above	H2ZX (Longitudinal)
			H2ZY (Vertical)
			H2ZZ (Lateral)
V1	Vertical (Z_B, 2 in PISYS) Y_P	same as above	V1YX (Longitudinal)
			V1YY (Vertical)
			V1YZ (Lateral)
V2	Vertical (Z_B, 2 in PISYS) Y_P	same as above	V2YX (Longitudinal)
			V2YY (Vertical)
			V2YZ (Lateral)

See Figure 3 for coordinate system

Table 2 – Meeting IEEE 344-1987 Criteria when TRS < New RS- Broadened at 28Hz in Figure 10

Category	Frequency (f)	TRS (g)	New RS-Broadened (g)	Acceptance Criteria
TRS < New RS-Broadened @ 28Hz	28	13.2	14.4	Meets IEEE 344-87, 7.6.3.1(14) criteria of TRS below 10% or Less to New RS-Broadened
1/3rd Octave Frequencies	22.2 35.3	24.5 16.5	14.4 6.7	Meets IEEE criteria of TRS >10% to New RS/Broadened
1/6th Octave Frequencies	25.0 31.5	24.5 13.5	14.4 10.8	Meets IEEE criteria of TRS equal or above New RS/Broadened

Table 3: Calculation of Strain Energy, Strain Energy Ratio and Average Effective Acceleration

Frq. (Hz)	Frq. Rad / sec	IEEE Accel. a_{0f} in (g)	x_0 Displ. (in.)	Accel.of Table in (g)	Accel. @ Bonnet a_{1f} in (g)	x_1 Displ. (in.)	Area under IEEE Accel _freq curve	Area under Test Accel _freq curve	x_0^2 ~Strain Energy (IEEE) [1]	x_1^2 ~Strain Energy (Test) [1]	Weighting Factor (WF) based on SQRT(Strain Energy Ratio)	Area under Test Accel _freq curve w/ WF (13)
(1)	(2)	(3)	(4)	(5)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
5	31.42	0.0316	0.0124	0.032	0.032	0.0125			1.53E-04	1.56E-04	1.010	
6	37.70	0.0455	0.0124	0.046	0.046	0.0125	0.039	0.0389	1.53E-04	1.56E-04	1.010	0.039
7	43.98	0.06	0.0120	0.06	0.061	0.0122	0.053	0.0536	1.44E-04	1.49E-04	1.020	0.055
8	50.27	0.08	0.0122	0.08	0.088	0.0135	0.070	0.0746	1.50E-04	1.81E-04	1.100	0.082
9	56.55	0.1	0.0121	0.1	0.115	0.0139	0.090	0.1015	1.46E-04	1.93E-04	1.150	0.117
10	62.83	0.125	0.0122	0.15	0.183	0.0179	0.113	0.149	1.50E-04	3.21E-04	1.464	0.218
12	75.40	0.18	0.0122	0.17	0.255	0.0173	0.305	0.438	1.50E-04	3.00E-04	1.417	0.621
14	87.96	0.246	0.0123	0.2	0.440	0.0220	0.426	0.695	1.51E-04	4.83E-04	1.789	1.243
15	94.25	0.287	0.0125	0.287	1.722	0.0749	0.267	1.081	1.56E-04	5.61E-03	6.000	6.486
16	100.53	0.3	0.0115	0.3	1.650	0.0631	0.294	1.686	1.32E-04	3.98E-03	5.500	9.273
17	106.81	0.35	0.0119	0.35	1.575	0.0533	0.325	1.6125	1.41E-04	2.85E-03	4.500	7.256
18	113.10	0.4	0.0121	0.4	1.600	0.0483	0.375	1.5875	1.46E-04	2.34E-03	4.000	6.350
20	125.66	0.5	0.0122	0.5	0.950	0.0232	0.900	2.55	1.50E-04	5.40E-04	1.900	4.845
22	138.23	0.55	0.0111	0.55	0.990	0.0200	1.050	1.94	1.24E-04	4.01E-04	1.800	3.492
24	150.80	0.65	0.0110	0.75	0.750	0.0127	1.200	1.74	1.22E-04	1.62E-04	1.154	2.008
26	163.36	0.75	0.0109	0.75	0.563	0.0081	1.400	1.3125	1.18E-04	6.63E-05	0.750	0.984
28	175.93	0.75	0.0094	0.75	0.375	0.0047	1.500	0.9375	8.77E-05	2.19E-05	0.500	0.469
30	188.50	0.75	0.0082	0.75	0.225	0.0024	1.500	0.6	6.65E-05	5.99E-06	0.300	0.180
32	201.06	0.75	0.0072	0.75	0.210	0.0020	1.500	0.435	5.14E-05	4.03E-06	0.280	0.122
34	213.63	0.75	0.0064	0.75	0.263	0.0022	1.500	0.4725	4.03E-05	4.94E-06	0.350	0.165
36	226.19	0.75	0.0057	0.75	0.338	0.0025	1.500	0.6	3.21E-05	6.50E-06	0.450	0.270
38	238.76	0.75	0.0051	0.75	0.413	0.0028	1.500	0.75	2.58E-05	7.82E-06	0.550	0.413
40	251.33	0.75	0.0046	0.75	0.750	0.0046	1.500	1.1625	2.10E-05	2.10E-05	1.000	1.163
42	263.89	0.75	0.0042	0.75	1.275	0.0071	1.500	2.025	1.73E-05	5.00E-05	1.700	3.443
44	276.46	0.75	0.0038	0.75	1.425	0.0072	1.500	2.7	1.44E-05	5.19E-05	1.900	5.130
46	289.03	0.75	0.0035	0.75	1.125	0.0052	1.500	2.55	1.20E-05	2.71E-05	1.500	3.825
48	301.59	0.75	0.0032	0.75	0.750	0.0032	1.500	1.875	1.02E-05	1.02E-05	1.000	1.875
50	314.16	0.75	0.0029	0.75	0.525	0.0021	1.500	1.275	8.62E-06	4.22E-06	0.700	0.893
55	345.57	0.75	0.0024	0.75	0.375	0.0012	3.750	2.25	5.89E-06	1.47E-06	0.500	1.125
60	376.99	0.75	0.0020	0.75	0.225	0.0006	3.750	1.5	4.16E-06	3.74E-07	0.300	0.450
65	408.41	0.75	0.0017	0.75	0.188	0.0004	3.750	1.0313	3.02E-06	1.89E-07	0.250	0.258
70	439.82	0.75	0.0015	0.75	0.150	0.0003	3.750	0.8438	2.24E-06	8.98E-08	0.200	0.169
75	471.24	0.75	0.0013	0.75	0.128	0.0002	3.750	0.6938	1.70E-06	4.92E-08	0.170	0.118
80	502.65	0.75	0.0011	0.75	0.113	0.0002	3.750	0.6	1.32E-06	2.96E-08	0.150	0.090
85	534.07	0.75	0.0010	0.75	0.150	0.0002	3.750	0.6563	1.03E-06	4.13E-08	0.200	0.131
90	565.49	0.75	0.0009	0.75	0.225	0.0003	3.750	0.9375	8.21E-07	7.39E-08	0.300	0.281
95	596.90	0.75	0.0008	0.75	0.225	0.0002	3.750	1.125	6.62E-07	5.95E-08	0.300	0.338
100	628.32	0.75	0.0007	0.75	0.525	0.0005	3.750	1.875	5.39E-07	2.64E-07	0.700	1.313
							62.405		0.0027	0.0181		65.287
						$A_{eff\text{-}IEEE}$	=0.657[2]				$A_{eff\text{-}test}$	=0.687[2]

[1] Strain Energy [based on Eq.(11)] Ratio =0.0181/0.0027=6.7
[2] Effective Acceleration of test = 0.75g*(0.687/0.657)= 0.78g

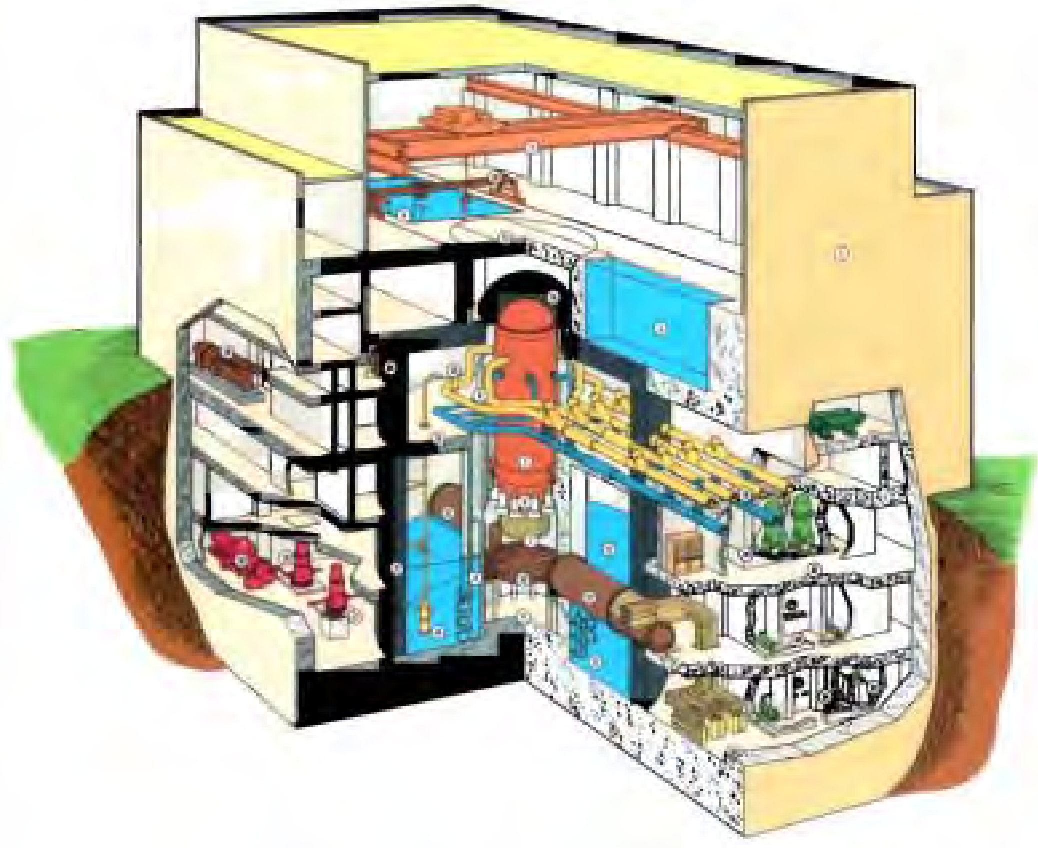

Figure 1: A cutaway view of Advanced Boiling Water Reactor (ABWR) Plant

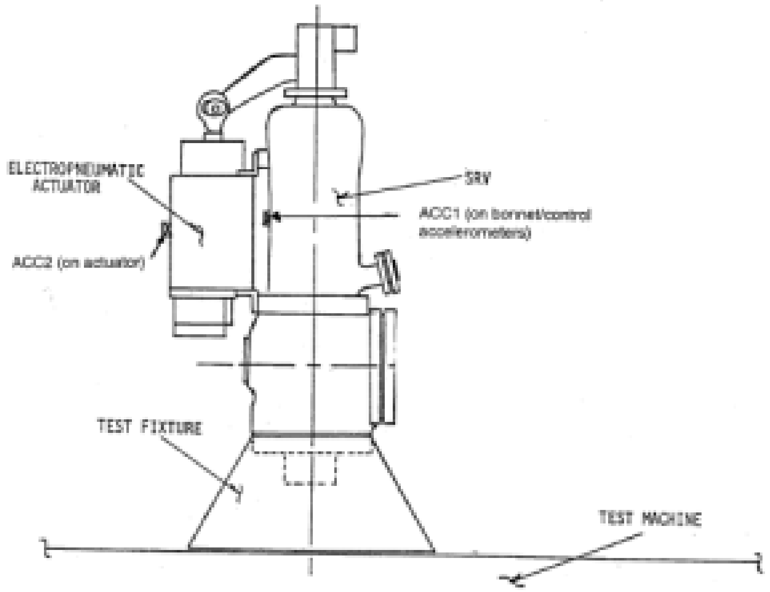

Figure 2: A typical SRV including Actuator mounted on Test Machine for Vibration and Seismic/Dynamic Tests

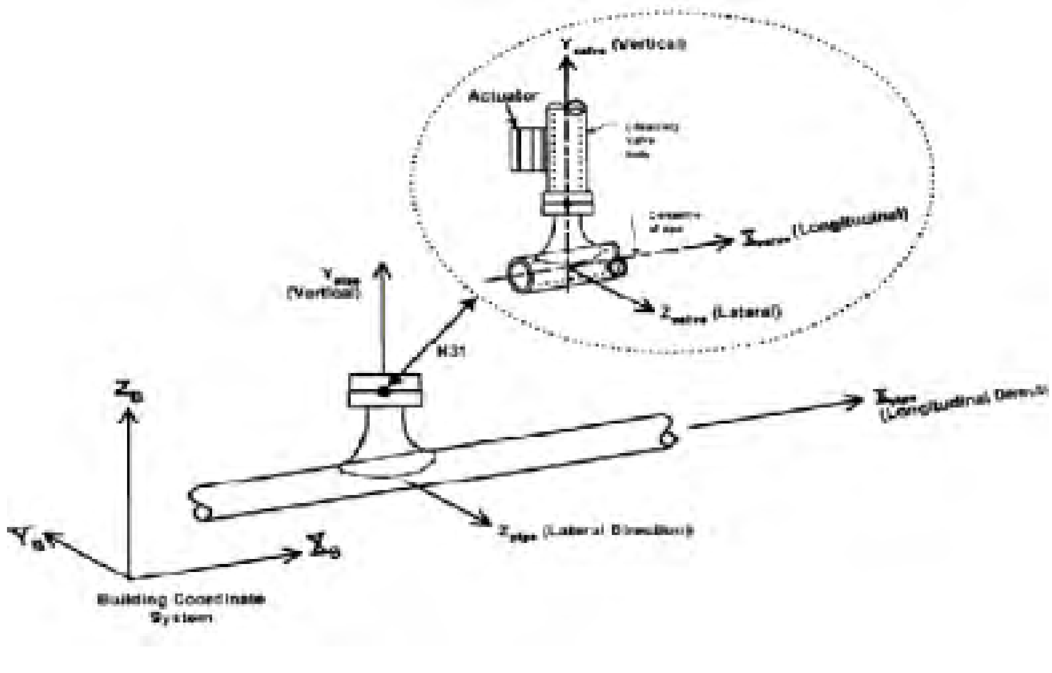

Figure 3: Coordinate system used in Table 1

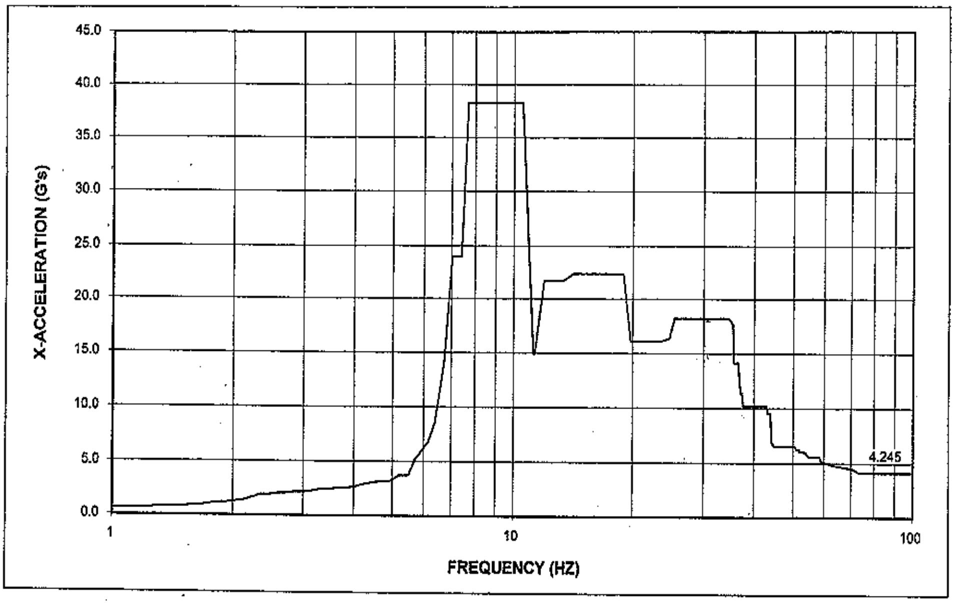

Figure 4: An Example of Required Response Spectra (RRS)

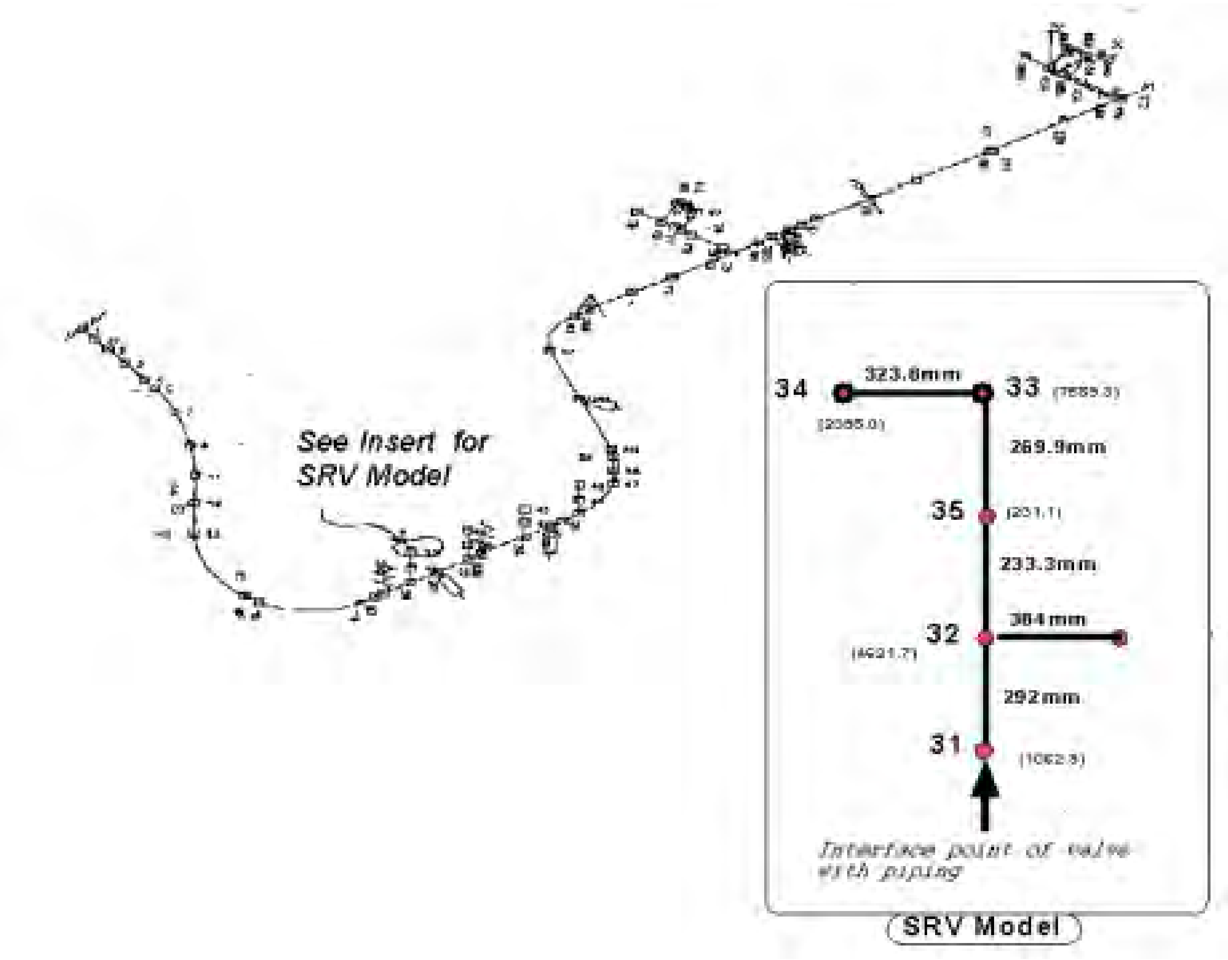

Figure 5: Main Steam Line and SRV Model

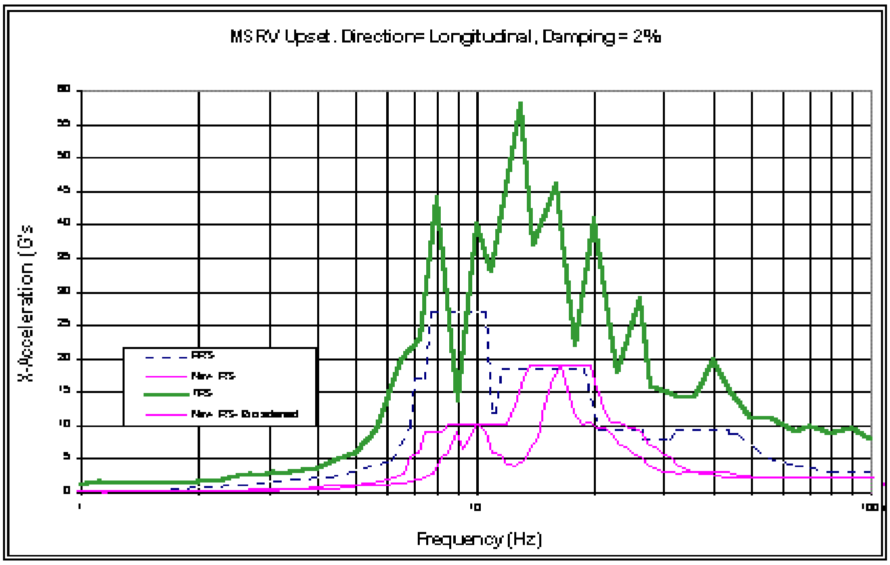

Figure 6: Comparison of Original RRS, New RS and TRS for Upset Condition – Longitudinal Direction

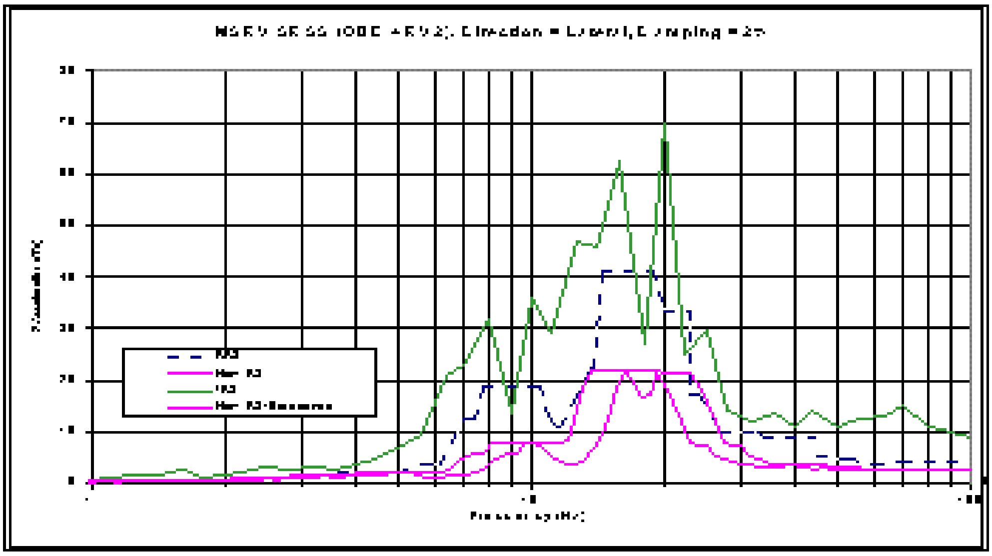

Figure 7: Comparison of Original RRS, New RS and TRS for Upset Condition
– Lateral Direction

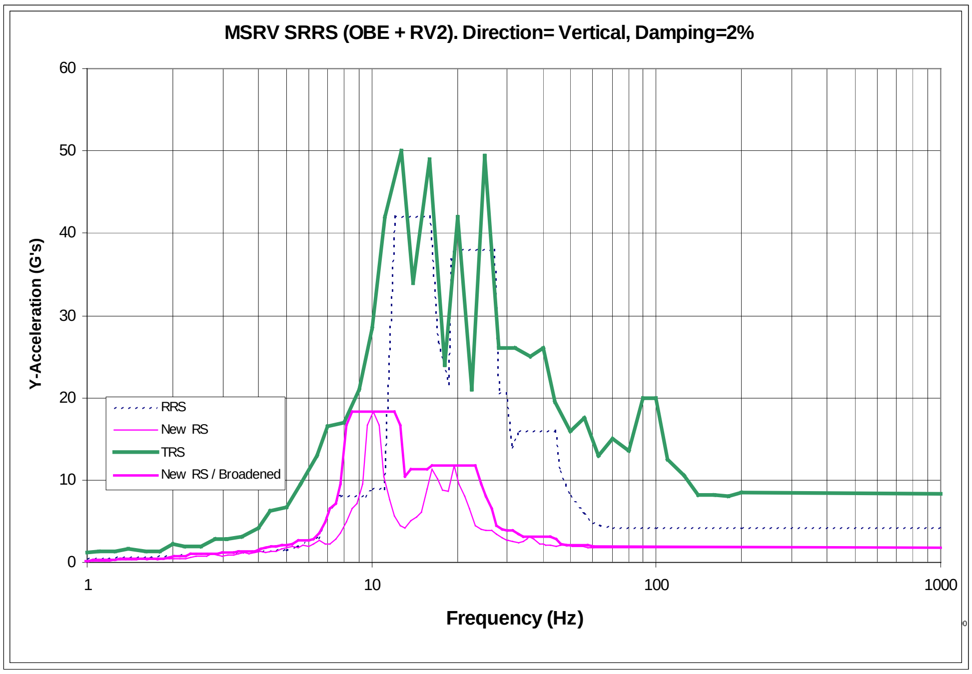

Figure 8 Comparisons of Original RRS, New RS and TRS for Upset Condition– Vertical Direction

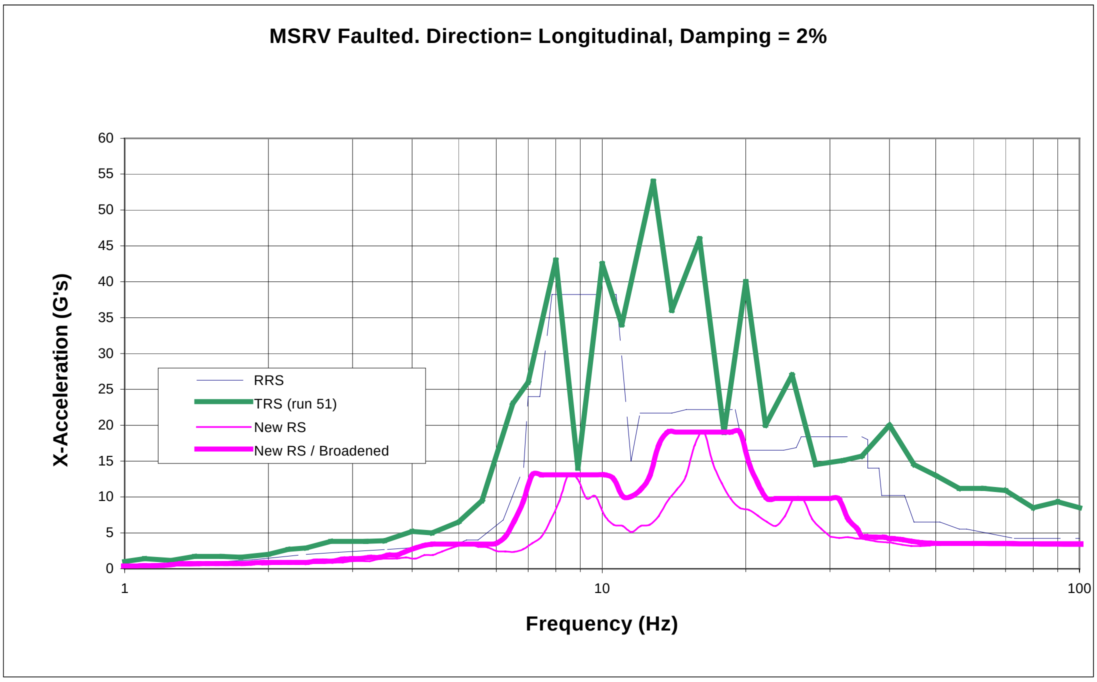

Figure 9 Comparisons of Original RRS, New RS and TRS for Faulted Condition – Longitudinal Direction

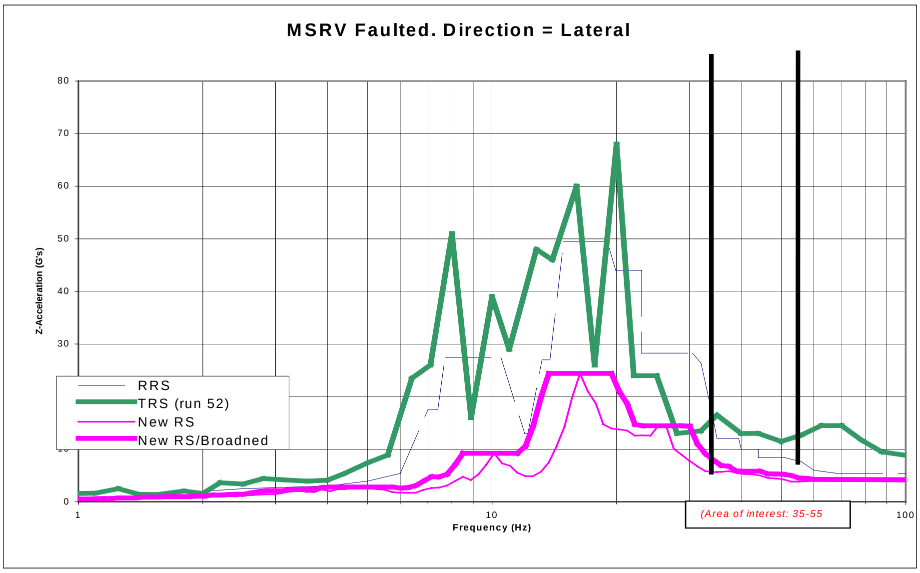

Figure 10 Comparisons of Original RRS, New RS and TRS for Faulted Condition – Lateral Direction

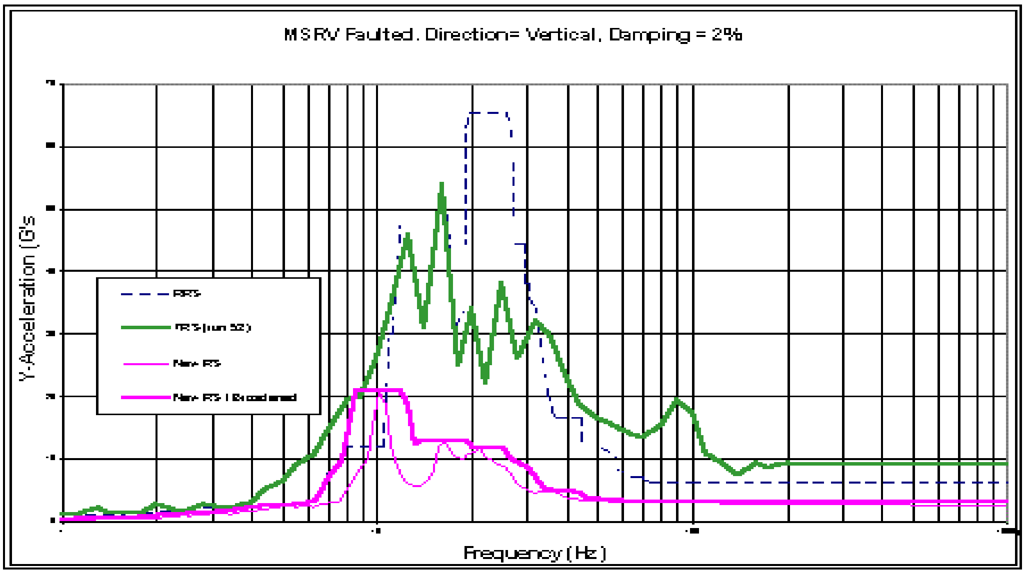

Figure 11 Comparisons of Original RRS, New RS and TRS for Faulted Condition – Vertical Direction

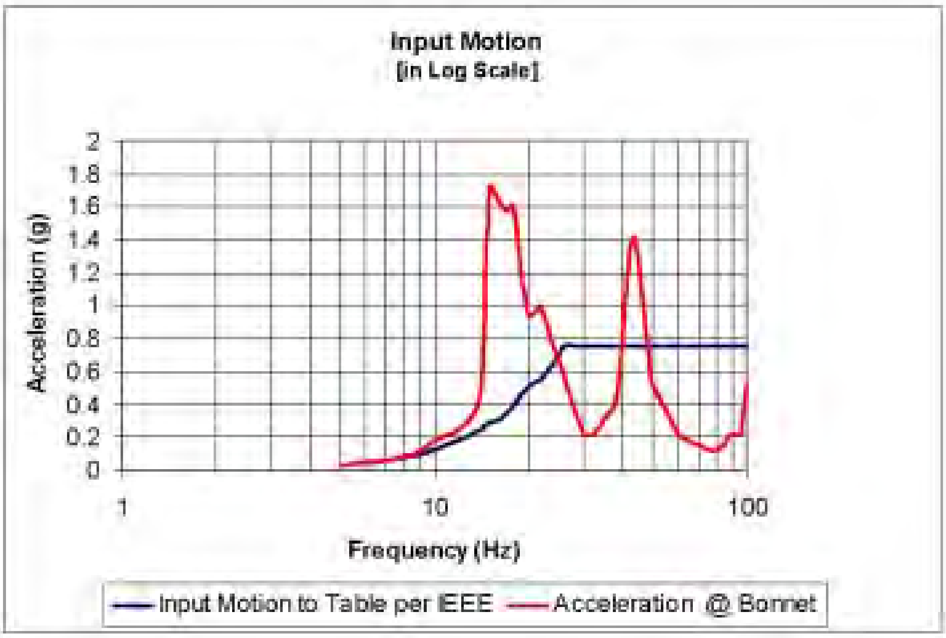

Figure 12: Input Motion to Table and Acceleration at Bonnet