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LICENSING

TOPICAL REPORT

Seismic Qualification of Class I Electric Equipment

L. D. Test

Approved: H. H. Hendon
H. H. Hendon, Manager
Control & Instrument Engineering

ATOMIC POWER EQUIPMENT DEPARTMENT • GENERAL ELECTRIC COMPANY
SAN JOSE, CALIFORNIA 95114

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ABSTRACT

This Licensing Topical Report describes the program of General Electric Company for the seismic qualification of Class I* electric equipment on all standard product line reactors. Included are discussions of design criteria and current qualification methods. Sample documentation is provided to illustrate actual application of described procedures.

1.0 INTRODUCTION

It is the goal of the General Electric Company to design and qualify the Class I electric equipment used on the boiling water reactor to assure the proper functioning of such equipment before, during, and after being exposed to a Safe Shutdown Earthquake (SSE). This report shows how that goal is reached by describing the design criteria, the qualification methods and the documentation used.

The field of seismic design and qualification is a relatively new one and requires an interesting marriage of the electrical equipment designer and the structural dynamicist. For this reason, it was not until 1969 that any national standards organization approached the problem, and it was not until 1971 that the first standard for seismic qualification was issued for trial use by the IEEE.[1]

Prior to 1971, however, the General Electric Company had begun a seismic qualification effort which did not differ markedly from IEEE 344. Since there were no guidelines at that time and since such qualification may cost an apparently disproportionate percentage of the equipment's cost, a very conservative approach was taken in the hope that as the state of the art advanced, the early effort would not be wasted.

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* Class I electric equipment as used in this report has the same meaning as defined in IEEE 344-1971, "IEEE Guide for Seismic Qualification of Class I Electric Equipment for Nuclear Power Generating Stations."

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[1] IEEE 344-1971 IEEE Guide for Seismic Qualification of Class I Electric Equipment for Nuclear Power Generating Stations, New York, NY, 1971.

2.0 DESIGN CRITERIA

All instrumentation and electric equipment required for nuclear safety for any reactor site is capable of performing all safety related functions during normal reactor operation, during anticipated transients, during design basis aciddents and during post-accident operation while being subjected to the accelerations resulting from the SSE at the point of attachment of the equipment to the building or supporting structure.

2.1 SEISMIC CONDITIONS

Since General Electric instrumentation and electric equipment are used on many nuclear power plants with differing seismic requirements and in different parts of the plants (with differing amplifications), such products are designed to meet the above criteria for a standard seismic loading chosen to exceed the requirements for any given site. The present design acceleration and frequency requirements at the point of attachment to the building structure are:

Horizontal	1.5g
Vertical	0.5g
Frequency	0.25 to 33 Hz

If any specific site requires seismic capabilities greater than the above values, the instrument and electric equipment capabilities will be evaluated on a case basis.

The standard seismic loadings were determined through a study of response spectra for many different reactor sites, equipment locations and building designs. The method used to obtain the seismic loading from the response spectra was the same as that described in IEEE 344. Since the response spectra represent the locus of maximum accelerations of single degree of freedom bodies when excited at their mountings by a given acceleration time - history, it is necessary to determine the peak excitation function that produced such a response. It is their excitation (floor acceleration) that will be used to test actual equipment. To do this, the value at the high frequency end of the spectrum (above the frequency at which the acceleration remains constant with increasing frequency) is taken as the maximum acceleration at the base of the equipment. Since it is not possible to reconstruct the time - history which produced the

response spectrum, a conservative approach is to assume the maximum acceleration to be present over the full frequency range. Figure 2-1 shows a sample ground response spectrum from which the ground acceleration could be determined as 0.15g.

The rationale for using a response spectrum to determine floor motion is based simply on the mathematical method used to generate the response spectrum. Since the plot is a composite of the peak acceleration that would be generated by single degree of freedom bodies when subjected to a particular ground or floor acceleration sequence, it is apparent that the maximum acceleration of the bodies with higher resonant frequency than those contained in the forcing acceleration will be equal to the maximum forcing acceleration. This is true since the higher frequency bodies will be relatively rigid at the lower frequencies of the forcing acceleration and will move on a one-to-one basis without amplifying the input acceleration. This is seen in the sample spectrum shown in Figure 2-1 where the forcing accelerations above approximately 13 Hz provide insignificant energy inputs.

As mentioned above, the standard values of vertical and horizontal accelerations were obtained by studying response spectra for many nuclear power plants. Some of the plants studied are listed in Table 2.1 along with the values of accelerations. The values in Table 2.1 were obtained at 20 Hz instead of the presently used value of 33 Hz because at the time this work was performed, this was generally considered the upper end of the amplified portion of the response spectrum and, as can be seen from Figure 2-1, the use of a lower frequency gives a more conservative value. It is important to note at this point that this discussion has been directed specifically at the method used to generate the standard acceleration level that was used for the qualification of Class I equipment. Each plant requirement is evaluated against the standard acceleration level to assure that the standard is in all ways in excess of the actual requirement.

2.2 EQUIPMENT PERFORMANCE

As mentioned in Section 2.0, safety related instrumentation and electric equipment must be capable of performing their safety functions during and after a Safe Shutdown Earthquake. To establish these functions, General Electric has determined which systems, subsystems, and equipment have safety related functions.

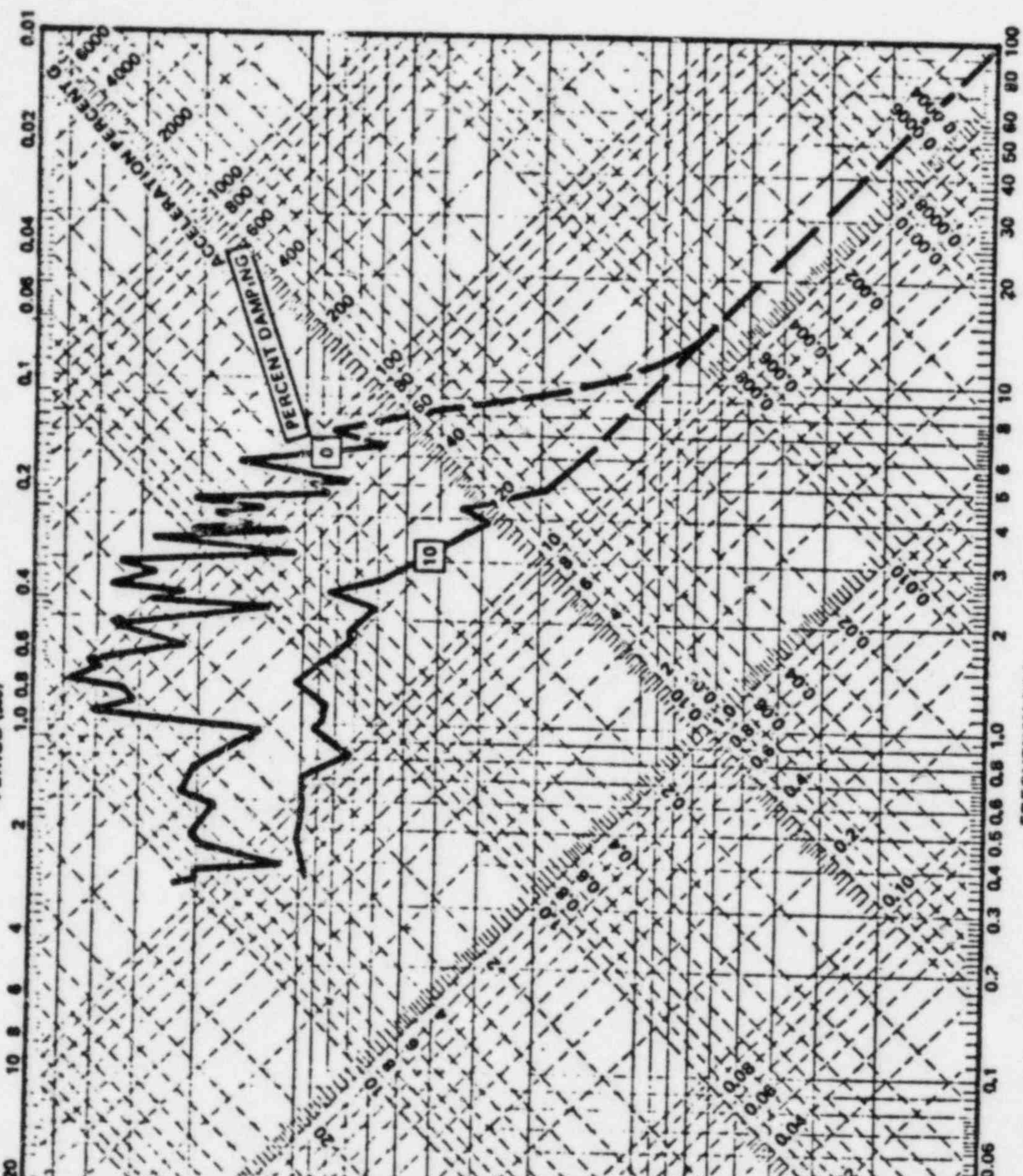

Figure 2-1. Sample Ground Response Spectrum

TABLE 2.1

Worst Case Floor Acceleration

Plant	Equip. Location (Elevation)	Floor Acceleration Resulting From SSE Vert.	Horiz.
Dresden 2/3	517 ft 6 in.	0.26g	0.52g
Quad Cities 1/2	595 ft 0 in.	0.19	0.38
Fukushima I	10.2M	0.36	0.72
Millstone	14 ft 6 in.	0.17	0.34
Monticello	939 ft 0 in.	0.17	0.34
Pilgrim	23 ft 0 in.	0.20	0.40
Vermont Yankee	272 ft 6 in.	0.30	0.60
Peach Bottom	150 ft 0 in.	0.21	0.42
TVA 1/2/3	621 ft 3 in.	0.25	0.50
	593 ft 0 in.	0.20	0.40
Copper Station	903 ft 0 in.	0.17	0.34
Hatch	164 ft 0 in.	0.13	0.22

The safety related functions are determined and qualification is performed to verify that these functions can be accomplished during and after the SSE. The mechanisms of failure and the standards of performance for Class I electric equipment differ from those of mechanical since, in most cases, mechanical failure (yield, buckling, etc.) may not affect the performance of the equipment's safety function. Conversely, mechanical properties such as stiffness, damping, and mass may have a great bearing on the accelerations seen by the electric equipment and are very important design considerations. Also, as will be discussed below, the primary safety functions of a number of components is the retention of reactor primary pressure, and the evaluation is therefore treated somewhat differently.

3.0 QUALIFICATION

One of the goals of the General Electric seismic qualification effort for Class I electric equipment is to generate data which verify that the equipment can meet its safety related performance requirements during and following an SSE. It is a further goal to do this in accordance with applicable national standards, regulatory requirements, and particular plant needs.

The accepted means of qualification are type testing, analysis, and operating experience.[2] The former is preferred, but when there are practical limitations the latter two may be used to augment or extend the type tests. General Electric's application of these methods for seismic qualification is described in the following paragraphs.

3.1 OPERATING EXPERIENCE

In general, the use of operating experience is not practical for seismic qualification due to the lack of adequate historical data and because the "worst case" or SSE has never been found to occur. Operating experience was used, however, to partially substantiate the validity of analysis and testing methods by analyzing the performance of General Electric switchgear at the Sylmar terminal of the Pacific High Voltage Direct Current intertie during and after the San Fernando earthquake of February 9, 1971.[3]

3.2 ANALYSIS

When equipment is large or structurally simple, it is often more practical to demonstrate its seismic capability by dynamic analysis. When each important sub-structure or mode of vibration can be properly represented dynamically as having one degree of freedom, analysis is particularly straight-forward, reliable, and efficient. For complicated equipment where considerable difficulties are encountered in proper mathematical modeling, testing is usually preferred.

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(2) IEEE-323 - 1971, IEEE Trial Use Standard: General Guide for Qualifying Class I Electric Equipment for Nuclear Power Generating Stations. Paragraph 4.3

(3) Boyle, Skreiner and Test, "Seismic Requirements for Electrical Equipment - An Analysis of the IEEE Seismic Guide," presented at the Pacific Coast Electrical Association Meeting, San Francisco, CA, March 16, 1972.

Dynamic seismic analysis of equipment can be considered as consisting of three parts:

1. Determination of the natural frequencies in the frequency band of interest (0.25 to 33 Hz is currently being used).
2. Determination of the appropriate seismically induced intertial forces as a function of the natural frequency of the equipment, location of the equipment, and the earthquake response spectrum.
3. Combination of the seismically induced inertial forces on the equipment with the other forces which can occur simultaneously.

3.2.1 Natural Frequency Determination

The analytically determined natural frequencies of the equipment are obtained by generating an analytical model which is representative of the equipment behavior for frequencies below 33 Hz. This may require a model with hundreds of degrees of freedom or may require only one degree of freedom. The large, complex analytical models are used on equipment which is too large to test under operational conditions with the required seismic frequency spectrum and accelerations.

For the important special case when the equipment and/or its components can be properly modeled as a single-degree-of-freedom system, the natural frequency is obtained from the relationship

$$f = \frac{1}{2\pi} \sqrt{\frac{K}{M}} \qquad (1)$$

when

f is the natural frequency in Hz

K is the effective stiffness in lb/in

M is the effective mass in lb sec^2/in.

This equation is often used in the form

$$f = \frac{3.13}{\sqrt{\delta}} \qquad (2)$$

where

δ is the deflection in inches of the center of mass when a force equal to the effective weight is applied at the center of mass.

3.2.2 Inertial Force Determination

When a multidegree-of-freedom system is analyzed, the inertial forces for each mode are obtained using the response acceleration from the response spectrum at the point where the equipment is attached to a much heavier structure (see Appendix A for description).

An important special case is a single-degree-of-freedom system. In this case, the inertial force equals the product of the mass and the response acceleration (for the natural frequency of the equipment) from the response spectrum at the point where the equipment is attached to a much heavier structure.

Another important special case occurs when the natural frequencies of the equipment are all greater than 33 Hz. In this case, the inertial force equals the product of the mass times the maximum acceleration at the point where the equipment is attached to a much heavier structure.

3.2.3 Combination of Forces

The seismically induced forces are combined with the other forces according to the requirements of IEEE-344.

When a multi-degree-of-freedom system is analyzed by the response spectrum method, the seismically induced inertial forces are obtained from the square root of the sum of the squares of the modal forces (see Appendix A for description).

3.2.4 Pressure Boundary Devices

Class I pressure boundary devices are qualified in accordance with Section III of the ASME Boiler and Pressure Vessel Code. When applying this Code, stresses due to seismically induced inertial forces are treated as primary stresses. Stresses due to differential movement of heavy supporting structures or equipment are treated as secondary stresses.

The seismically induced inertia forces for use in the Code analysis are determined by dynamic analysis, tests, or a combination thereof.

3.2.5 Combined Test and Analysis

Often equipment capability is demonstrated by a combination of tests and analysis. When this is done, the tests are performed in the manner described in Section 3.3 and the analysis in accordance with Section 3.2.

Many of the tests are performed on a shake table which has minimum frequency limit of 5 Hz. The equipment tested at frequencies above 5 Hz is analyzed to demonstrate that there are no components that affect the Class I functions that have natural frequencies below 5 Hz. This is done by first separating the components into those which, by inspection, obviously have natural frequencies greater than 5 Hz and those which might have a natural frequency less than 5 Hz. Those which might have a natural frequency below 5 Hz are analyzed with sufficient accuracy to demonstrate that there are no natural frequencies below 5 Hz (see example in Appendix B). If this is not possible, the component is modified, tested at a lower frequency, or replaced by an alternate design.

Another use of combined test and analysis occurs with equipmemt which is structurally simple except for a few complex components. In this case, the acceleration at the component locations is calculated and the component is tested to demonstrate its functional capability at the calculated accelerations and frequencies.

3.2.6 Static Analysis

If the above analysis or the tests described below show that the equipment is rigid (does not contain resonances in the frequency band of concern), a statis analysis may be performed.[4] For rigid control panels (the basic structures are a standard design), analysis has shown that the floor mounting bolts are the points of highest stress. The static analysis on all control panels consists of an analysis of the bolts and is performed as described in Appendix C. The stress determination for a typical set of pannels is shown in Table 3.1.

3.3 TESTING

The testing of Class I electric equipment is accomplished in one of two ways depending on whether the equipment is a device or an assembly of devices.

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[4] IEEE 344-1971, op cit, 3.1.3.

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Table 3.1
Sample Stress Determination for a Typical Set of Panels

UNLESS OTHERWISE SPECIFIED USE THE FOLLOWING — APPLIED PRACTICES | SURFACES ✓ | TOLERANCES ON MACHINED DIMENSIONS

PANEL DESIGNATION	ARRANGEMENT DRAWING	PANEL HEIGHT (INCHES)	PANEL WIDTH (INCHES)	PANEL DEPTH (INCHES)	PANEL ESTIMATED WEIGHT (POUNDS)	PANEL ESTIMATED WEIGHT PLUS 10% (POUNDS)	NUMBER OF BASE MOUNTING BOLTS	SEISMIC DESIGN GUIDE CURVE 225A4582: CURVE SH. 8	SEISMIC DESIGN GUIDE CURVE 225A4582: MAXIMUM ALLOWABLE WT/BOLT (POUNDS) SH. 6,7,8	POUNDS PER BOLT TIMES NUMBER OF BASE MOUNTING BOLTS (POUNDS)	SAFETY FACTOR
H11-P601(9-3)	807E115A	96	144	54	3,900	4,290	33	C7	910	30,030	7.00
H11-P602(9-4)	791E588A	96	144	54	3,400	3,740	36	C7	910	32,760	8.75
H11-P603(9-5)		96	144	54	4,000	4,400	32	C7	910	29,120	6.62
B21-P600(9-11)	115D6144A	90	24	36	700	770	4	C1	465	1,860	2.42
H11-P606(9-12)	115D6146A	90	96	36	1,500	1,650	16	C3	650	10,400	6.30
H11-P607(9-13)	115D6194A	90	48	36	1,000	1,100	8	C3	650	5,200	4.73
H11-P608(9-14)	791E597AA	90	150	36	4,500	4,840	20	C3	650	13,000	2.69
H11-P609(9-15)	807E102A	90	96	36	2,500	2,750	16	C3	650	10,400	3.78
H11-P610(9-16)	115D6225A	90	24	36	500	550	4	C1	465	1,860	3.38
H11-P611(9-17)	807E103A	90	96	36	2,500	2,750	16	C3	650	10,400	3.78
H11-P612(9-18)	115D6230	90	60	36	1,100	1,210	10	C3	650	6,[illegible]	5.37
H11-P613(9-19)	115D6065A	90	30	36	700	770	4	C2	520	2,080	2.70
H11-P614(9-21)	807E121A	90	96	36	1,700	1,870	16	C3	650	10,400	5.56
H11-P615(9-27)	115D6130A	90	84	36	2,000	2,200	14	C3	650	9,100	4.14
H11-P616(9-28)	807E100A	90	120	36	2,000	2,200	20	C3	650	13,000	5.91
H11-P617(9-32)	791E573A	90	72	36	2,200	2,420	12	C3	650	7,800	3.22
H11-P618(9-33)	791E574A	90	72	36	2,200	2,420	12	C3	650	7,800	3.22
H11-P619(9-38)	115D6180A	90	30	36	700	770	8	C2	520	4,160	5.40
H11-P620(9-39)	115D6224A	90	36	36	1,100	1,210	6	C3	650	3,900	3.22
H11-P621(9-30)	115D6199A	90	24	36	700	770	4	C1	465	1,860	2.41
H11-P622(9-41)	115D6272A	90	36	24	500	550	4	C2	520	2,080	3.78
H11-P623(9-42)	115D6273A	90	36	24	500	550	4	C2	520	2,080	3.78
H11-P626	115D6186A	90	24	36	1,100	1,210	4	C1	465	1,860	1.54
H11-P627	115D6187A	90	24	36	1,100	1,210	4	C1	465	1,860	1.54
H11-P628	115D6178A	90	36	36	1,100	1,210	6	C3	650	3,900	3.22
C71-P002(5-7)	115D6190A										
H21-P003(25-04)	791E598A	90	30	36	700	770	4	C2	520	2,080	2.70
H21-P007(25-9)	145C3196A	90	30	36	700	770	8	C2	520	4,160	5.40
H21-P012(25-22)	791E598A	90	30	36	700	770	4	C2	520	2,080	2.70
H21-P008(25-14)	145C3062	84	60	12	400	440	6				

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MAXIMUM ALLOW
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SAFETY FACTOR
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r a Typical Set of Panels

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	1749011
TITLE	BOLT STRESS ANALYSIS FOR "STANDARD PLANT" PANELS
FIRST MADE FOR	STANDARD PLANT

SS OTHERWISE SPECIFIED USE THE FOLLOWING —

(POUNDS)	NUMBER OF BASE MOUNTING BOLTS	SEISMIC DESIGN GUIDE CURVE 225A4582		POUNDS PER BOLT TIMES NUMBER OF BASE MOUNTING BOLTS (POUNDS)	SAFETY FACTOR
		CURVE SH. 8	MAXIMUM ALLOWABLE WT/BOLT (POUNDS) SH. 6,7,8		
30	33	C7	910	30,030	7.00
40	36	C7	910	32,760	8.75
00	32	C7	910	29,120	6.62
70	4	C1	465	1,860	[illegible]
40	16	C3	650	10,400	6.30
00	8	C3	650	5,200	4.73
40	20	C3	650	13,000	2.69
50	16	C3	650	10,400	3.78
50	4	C1	465	1,860	3.38
50	16	C3	650	10,400	3.78
10	10	C3	650	6,500	5.37
70	4	C2	520	2,080	2.70
70	16	C3	650	10,400	5.56
00	14	C3	650	9,100	4.14
00	20	C3	650	13,000	5.91
20	12	C3	650	7,800	3.22
20	12	C3	650	7,800	3.22
70	8	C2	520	4,160	5.40
10	6	C3	650	3,900	3.22
70	4	C1	465	1,860	[illegible]
50	4	C2	520	2,080	3.78
50	4	C2	520	2,080	3.78
10	4	C1	465	1,860	1.56
10	4	C1	465	1,860	1.56
10	6	C3	650	3,900	3.22
[illegible]	4	C2	520	2,080	2.70
[illegible]	8	C2	520	4,160	5.40
[illegible]	4	C2	520	2,080	2.70
[illegible]	6				

TYPICAL ANALYSIS - PANEL H11-P601 (9-3)

APPLIED HORIZONTAL ACCELERATION	1.5 G
APPLIED VERTICAL ACCELERATION	0.5 G
TENSION STRESS (MAXIMUM SAFE)	30,000 PSI
SHEAR STRESS (MAXIMUM SAFE)	21,000 PSI
WEIGHT OF PANEL FROM STANDARD CONTROL ROOM ARRANGEMENT DRAWING 730E811, REVISION 5, (GROSS SHIPPING PLUS 10%)	4,290 LBS
NUMBER OF BASE MOUNTING BOLTS	33
PANEL HEIGHT (ASSUMED CENTER OF GRAVITY)	96 INCHES
MAXIMUM ALLOWABLE WEIGHT PER BOLT (FROM CURVE NO. C7 ON PAGE 8 OF SEISMIC DESIGN GUIDE, 225A4582)	910 LBS
MAXIMUM ALLOWABLE ENCLOSURE WEIGHT 910 LBS./BOLT x 33 BOLTS	30,030 LBS

$$\text{SAFETY FACTOR} = \frac{\text{MAXIMUM ALLOWABLE WEIGHT}}{\text{WEIGHT}} = \frac{30,030}{4,290} = 7.00$$

WELL WITHIN CRITERIA.

REVISIONS

PRINTS TO: 68, 3

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By "device" is meant the basic electric building block such as a relay, motor, or sensor which may become a part of the more complex "assembly" (such as a control panel or large switchgear). Since the devices are basically simple in function, input, and electrical connections, seismic testing in an operating condition is very practical. The larger assemblies may contain pieces of various operating systems and subsystems and are impractical to test in an operating condition. For this reason, the following test procedures are used.

3.3.1 Device Testing

As mentioned in paragraph 2.2, the safety related systems are established and the Class I electric devices determined. In General Electric's seismic qualification effort, seventy-two types of devices were identified as Class I. Table 3.2 lists those devices and indicates which were tested. Note that this is an ongoing effort and, as plant designs change, more devices are added to the list (or deleted) with the result that several have yet to be tested.

The test procedure for devices requires that the devices be mounted on the table of the vibration machine in a manner similar to which it will be installed. The device is tested in the operating states that it will be used while performing its Class I functions and these states are monitored before, during, and after the test to assure proper function and absence of spurious function. In the case of a relay, both energized and de-energized states and normally open and normally closed contact configurations are tested if the relay is used in those configurations in its Class I functions.

The seismic test itself is the so-called "continuous" test in which the vibration is applied in the form of a sinusoidal table motion at a fixed peak acceleration and a single frequency at any given time. Each frequency and acceleration combination is maintained for at least 30 seconds except when a resonance search is being made.

The vibratory excitation is applied in three orthogonal axes individually with the axes chosen as those coincident with the most probable mounting configuration.

The first step is to search for resonances in each device. This is done since resonances cause amplification of the input vibration and are the most likely cause of malfunction. The resonance search is usually run at low acceleration levels (0.2g) in order to avoid destroying the test sample in

case a severe resonance is encountered. The resonance search is currently run from 5 Hz to 33 Hz in accordance with IEEE-344 in no less than 7 minutes; if the device is large enough, the vibrations are monitored by accelerometers placed at critical locations from which resonances are determined by comparing the acceleration level with that at the table of the vibration machine. Usually, the devices are either too small for an accelerometer, have their critical parts in an inaccessible location, or have critical parts that would be adversely affected by the mounting of an accelerometer. In these cases, the resonances are readily detected by visual (strobe light), audible observation, or performance.

Following the frequency scan and resonance determination, the devices are tested to determine their malfunction limit. This test is a necessary adjunct to the assembly test as will be shown later. The malfunction limit test is run at each resonant frequency as determined by the frequency scan. In this test, the acceleration level is gradually increased until either the device malfunctions or the limit of the vibration machine is reached. If no resonances were detected (as is usually the case), the device is considered to be rigid (all parts move in unison) and the malfunction limit is therefore assumed to be independent of frequency. To achieve maximum acceleration from the vibration machine, rigid devices are malfunction tested at the upper test frequency (33 Hz) since that allows the maximum acceleration to be obtained from deflection-limited machines.

The summary of the results of tests on the devices used in Class I applications by General Electric given in Table 3.2 includes the malfunction limit and resonant frequencies for each device tested. It should be noted that, in general, the devices were not checked for such characteristics as the ability to change state and the maintenance of required accuracy, but rather were monitored for spurious operation when set close to (within 2% usually) a trip level. If these characteristics were measured, an excessive length of time would be required and the devices would be exposed to the malfunction vibration for a period which might cause fatigue failure and inaccurate results. Note also that several devices in Table 3.2 lack malfunction limits. This is because testing was in progress when this report was prepared.

The above procedures are required of purchased devices as well as those made by General Electric. Vendor test results are reviewed and if unacceptable,

Table 3.2
Seismic Class I Electric Equipment

EQUIPMENT NAME	MANUFACTURER AND MODEL NUMBER	MALFUNCTION LIMIT (G) X	Y	Z	SEISMIC QUALIFICATION METHOD TEST	ANALYSIS	RESONANT FREQUENCY
Voltage Preamplifier	GE/APED	8.5	8.5	8.5	X		None
Tip Penetration Flange	GE/APED	(see text)					——
Intermediate Range Detector	GE/APED	(see text)					——
Tip Purge Tube	GE/APED	(see text)					——
Indicator & Trip Unit	GE/APED	15	15	15	X		31 Hz
Power Range Detector	GE/APED	1.5	1.5	0.14		X	(2)
Tip Guide Tube Valve Assy	GE/APED	10	10	10	X		None(1)
Condensing Chamber	GE/APED	1.5	--	0.14		X	N.A.
Relay	GE/PSMD HGA	0.96	1.2	1.4	X(3)		33 Hz
Relay	GE/PSMD HFA	1.1	4.5	4.7	X(3)		30 Hz
Flow Switch	PERCO RT	10	4	10	X		None
Level Switch	Robertshaw 83482	5	5	5	X		None
Temperature Switch	Fenwal 17000	4	4	4	X		None
PRESSURE TRANSMITTER	GE/UPAD 551	2	2	2	X		None
PRESSURE TRANSMITTER	GE/UPAD 555	12	12	12	X		None
PRESSURE SWITCH	Barton 289	15	15	15	X		None
PRESSURE SWITCH	Barton 288	10	5	10	X		None
PRESSURE SWITCH	Barksdale B2T	15	15	15	X		None
PRESSURE SWITCH	Static-O-Ring 5N, 6N	15	15	15	X		None
PRESSURE SWITCH	Static-O-Ring 12N	15	15	15	X		None
CONTROLLER	GE/UPAD GEMAC 540	5	5	5	X		32 Hz
MILLIVOLT/CURRENT CONVERTER	GE/UPAD GEMAC 550	3	3	3	X		30 Hz
SQUARE ROOT CONVERTER	GE/UPAD GEMAC 565	11	11	11	X		33 Hz
POWER SUPPLY	GE/UPAD GEMAC 570	11	11	11	X		31 Hz
TEMPERATURE ELEMENT	NECI N145C3023	5	5	5	X		None
TEMPERATURE SWITCH	Transmation 610A, 630A	1.5	0.5	1.5	X		None
TEMPERATURE SWITCH	FENWAL 22000	0.5	1.5	1.5	X		NONE
INVERTER	TOPAZ GW-125	15	10	7	X		NONE
PRESSURE SWITCH	BARKSDALE DIT	13	10	13	X		NONE
TEMPERATURE EQUALIZING COLUMN	YARWAY	(see text)					——
LEVEL INDICATOR/SWITCH	YARWAY 4418	10	8	1	X		31 Hz
SWITCH	GE/PSMD SB-1	10	10	10	X		16.5 Hz/22 Hz
RELAY	GE/GPCD CR2820	25	25	25	X		NONE
RELAY	GE/GPCD CR120A	12	12	12	X		NONE
RELAY	AGASTAT 2400	18	6	18	X		NONE
DELAY UNIT	GE/GPCD CR120KTO	12	12	12	X		NONE
SWITCH	GE/GPCD CR2940	20	20	20	X		NONE
RELAY	GE/GPCD CR120K	25	25	25	X		NONE
TIMER	EAGLE SIGNAL HP-5	10	10	10	X		NONE
PRESSURE SWITCH	BARKSDALE D2H	13	10	13	X		NONE
LEVEL SWITCH	ROBERTSHAW 83843	5	5	5	X		NONE
LEVEL SWITCH	ROBERTSHAW 83844	2	2	5	X		NONE
SWITCH	GE/PSMD 6BM	25	25	25	X		NONE
PRESSURE SWITCH	MELETRON 2122	20	20	20	X		NONE
PRESSURE TRANSMITTER	BARTON 393	6	6	4	X		NONE
PRESSURE TRANSMITTER	BARTON 386	6	6	4	X		NONE
RELAY	POTTER-BRUMFIELD KH	17	17	17	X		NONE
CONTROL STATION	GE/UPAD GEMAC 547	5	5	5	X		32 Hz
CONTROL UNIT	GE/UPAD GEMAC 547	5	5	5	X		32 Hz
CONTROL AMPLIFIER	GE/UPAD 543	5	5	5	X		32 Hz
CONTRACTOR	GE/GPCD CR105	12	12	12	X		27 Hz
FLOW ELEMENT	DANIELS 150RW	(see text)					——
TEMPERATURE MONITOR	SCRAM 86	4.5	4.5	5	X		None
RELAY	AGASTAT 2122	10	10	10	X		None
RELAY	AGASTAT 7000	18	6	18	X		None
TEMPERATURE ELEMENT	NECI N145C3224	5	5	5	X		None
FLOW SWITCH	SCHUTTE & KOERTING 1900F	(see text)					——
RELAY	AGASTAT GP	3	5	2(3)	X		20, 30 Hz
MODULATOR	GE/UPAD GEMAC 543	5	5	5	X		32 Hz
PRESSURE TRANSMITTER	ROSEMOUNT ENGR. 1151D	2	2	2	X		7 Hz(5)
ALARM	GE/UPAD GEMAC 560	5	5	5	X		32 Hz
SUMMER	GE/UPAD GEMAC 563	3	3	3	X		30 Hz
RELAY	GE/PSMD HMA	2.8	2.5	4.0	X		None
SENSOR & CONVERTER	GE/APED	15	15	15	X		NONE
INTERMEDIATE RANGE MONITOR	GE/APED	5	5	4	X		(6)
RANGE SWITCH	GE/APED	8.5	8.5	8.5	X		NONE
PRM INSTALLATION HARDWARE	GE/APED	(see text)					——
GAMMA DETECTOR	GE/APED	(see text)					——
LOG. RADIATION MONITOR	GE/APED	3	3	3	X		(7)
POWER RANGE NEUTRON MONITOR	GE/APED	1.5	—	—	X(8)		MANY
DRY TUBE	GE/APED	1.5	1.5	0.14		X	(2)
TIP GUIDE TUBE	GE/APED	10	10	10	X		NONE

(1) NO RESONANCE CALCULATION WAS MADE SINCE IT IS DEPENDENT ON PIPING CONFIGURATION.

(2) STATIC CALCULATION ONLY.

(3) MALFUNCTION LIMITS ARE WORST CASE WITH RELAY DEENERGIZED.

(4) AT FREQUENCIES BELOW 20 Hz THE MALFUNCTION LIMIT IS 1.5g. THIS LOW SEISMICITY IS ONLY WHEN RELAY IS OPERATED IN THE DEENERGIZED STATE AND ASSUMING 100 MICROSECONDS CHATTER IS A MALFUNCTION.

(5) Z AXIS RESONANCE SHOWED MINOR AMPLIFICATION OF 1.4.

(6) X AXIS RESONANCE 10 Hz & 26 Hz, Y AXIS 15 & 20 Hz, Z AXIS 22 Hz.

(7) X AXIS RESONANCE 18 Hz & 25 Hz, Y AXIS 19 & 30 Hz, Z AXIS 26 & 31 Hz.

(8) CABINET CONTAINING COMPLETE SUBSYSTEM WAS TESTED IN OPERATING CONDITION.

the tests are repeated by General Electric. If the vendor tests are adequate, the device is considered qualified to the limits of the test.

3.3.2 Assembly Testing

Assemblies of devices which have had seismic malfunction limits established are tested by mounting the assembly on the table of a vibration machine in the manner it is to be mounted when in use and vibration tested by running a low level resonance search. As with the devices, the assemblies are tested in the three major orthogonal axes. The resonance search is run in the same manner as described in paragraph 3.3.1 for devices. If resonances are present, the acceleration level is gradually increased at the resonant frequency (or frequencies) until the measured acceleration at the location of the critical devices reaches the malfunction level previously determined for the devices. The lowest floor acceleration at which the malfunction level is reached is defined as the malfunction floor acceleration limit for the assemblies. If no resonances exist, the assembly may be considered a rigid body and its malfunction limit may be considered that of the device mounted on it that has the lowest seismic capability.

Since control panels and racks constitute the majority of Class I electric assemblies supplied by General Electric, seismic qualification testing of these will be discussed in more detail. There are four generic types as shown in Table 3.3. One or more of each type was tested using the above procedure.

Table 3.3
Panel Types

Panel Type	Use	Typical Number Per Plant
Vertical Board, Benchboard	Operating Information and Controls	9
Instrument Racks, Cabinets	Nuclear Steam Supply Monitoring Instrumentation	3
Local Racks	Process Instruments	15
NEMA Type 12 Enclosures	Miscellaneous	2

Figures 3-1 through 3-4 illustrate the panel types referenced above and show typical accelerometer locations. As can be seen from these illustrations,

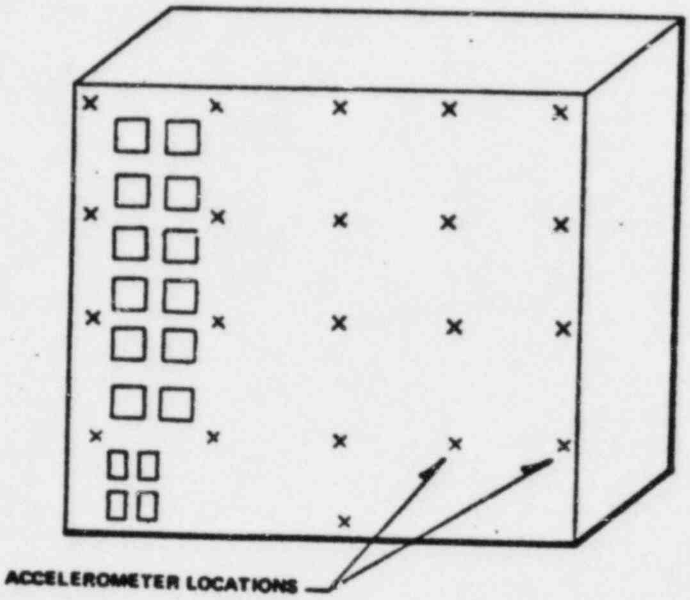


Figure 3-1. Typical Vertical Board (benchboard would be the same with a bench section protruding out about half way down).

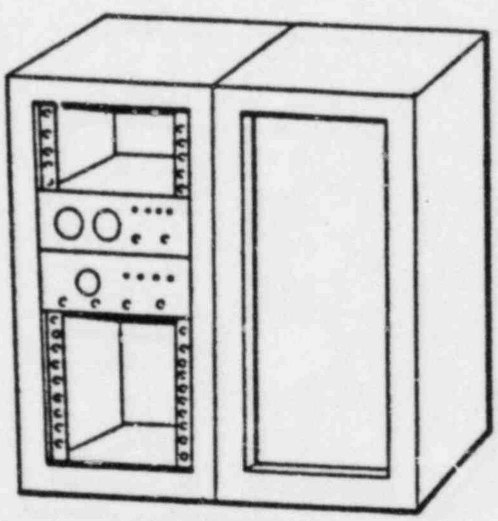


Figure 3-2. Instrument Rack (cabinet would contain pages or other special instruments instead of simply drawer type instruments).

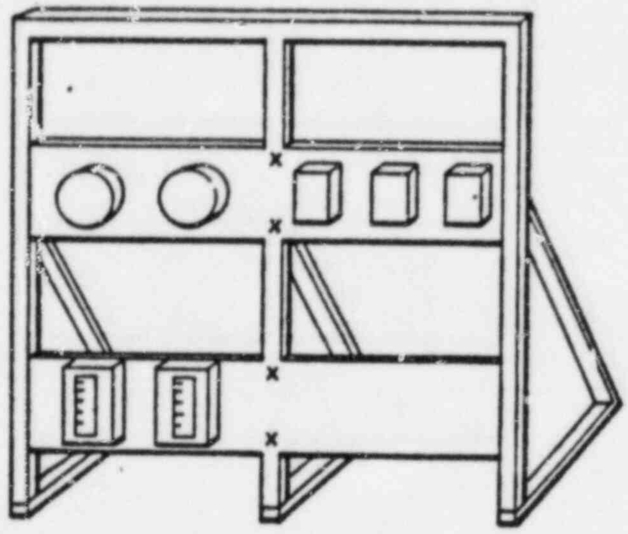


Figure 3-3. Typical Local Rack
(piping and other external connections not shown).

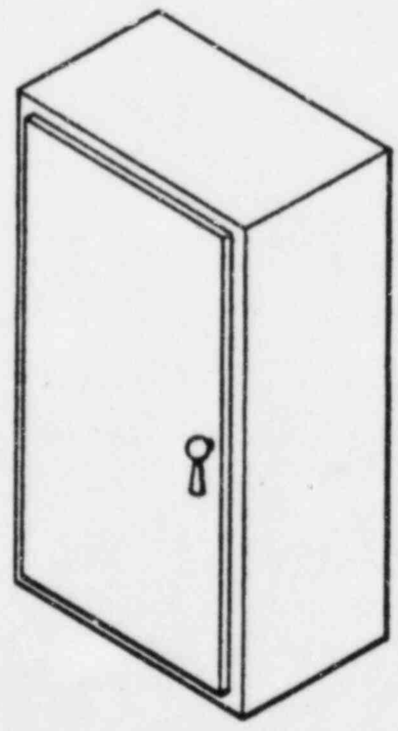


Figure 3-4. NEMA Type 12 Enclosure (instruments mounted inside on internal membrane mounted on standoffs attached to back).

there are clear differences in the four types, but as will be illustrated below, there are many minor variations on each type which do not affect the seismicity and allow a single type qualification to stand for the many variations.

As an example, a panel of the benchboard type (Figure 3-1 but with a bench) was tested in a configuration as shown in detail in Figure 3-5. As can be seen from the illustration, the panel contains electrical devices for the following major systems:

Isolation Valves
Auto Depressurization
RCIC
Reactor Water Cleanup
Reactor Recirculation
Nuclear Steam Supply

The panel was tested as shown in Appendix D and resonances were found to exist at 10.1, 12.6, and 14 Hz with amplification factors of 1.1, 2.6, and 1.5 respectively. These resonances were such that the Class I electrical devices on the panel (SBM switches and HFA relays) would perform their functions as determined by the device tests (1.1g). Note that the test of Appendix D was not run exactly as described above. This is because it was discovered by General Electric and others [(5)] that structures such as control panels tend to be fairly linear in their response to sinusoidal vibration. This means that an adequately instrumented panel can be vibrated at lower acceleration levels, and the amplification factors to each instrumented spot on the panel can be established. The acceleration at full vibration input can then be determined by multiplying the input acceleration for which the panel is to be qualified by the amplification factor and comparing the result with the qualification level of the device at that location. This method makes possible the use of a simpler testing arrangement,[(6)] specifically, that of a mounting surface physically isolated from the ground on which the panel is affixed (see Figure 3-6). A variable speed electric motor with counter-rotating eccentric

(5) Prause, R. H. and Ahlbeck, D. R., "Seismic Evaluation of Electrical Equipment for Nuclear Power Stations," Battelle Shock and Vibration Bulletin, P. 19, Jan. 1972.

(6) vonDamm, C. A., "Seismic Testing for Reliable Instrumentation and Control Systems," T72-230-6 IEEE Winter Meeting, New York, NY Jan. 30, 1972.

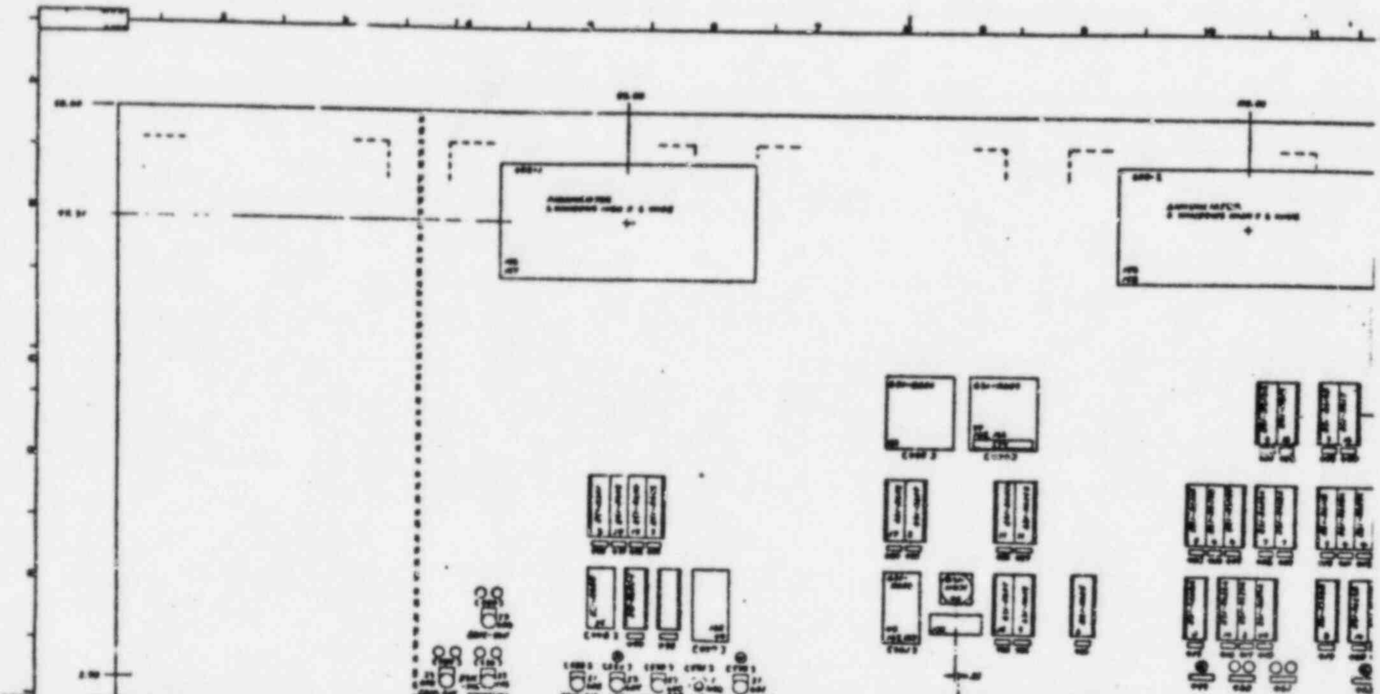
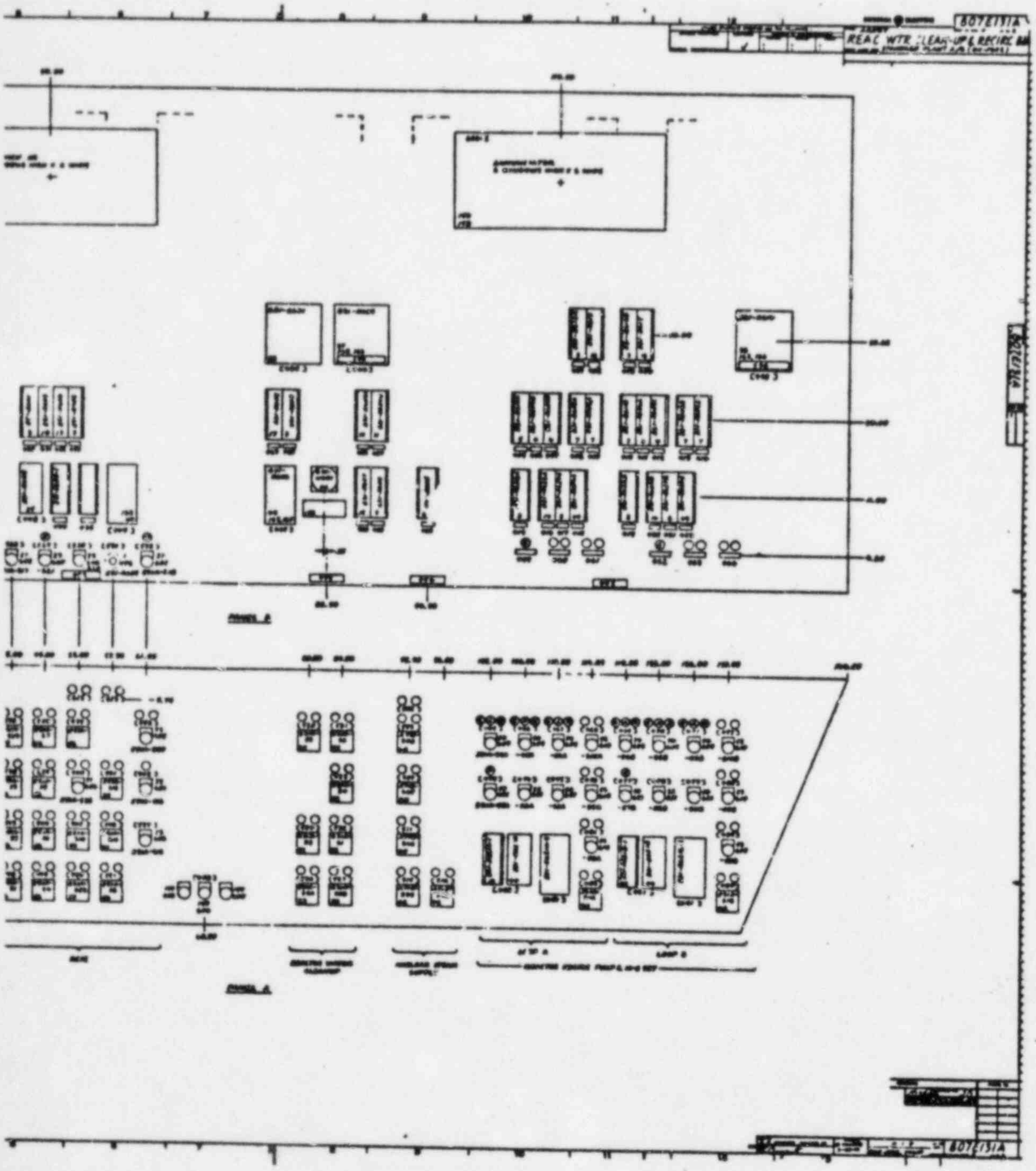


Figure 3-5. Sample Panel Configuration 1


807E131A
REAC WTR CLEAN-UP & RECIRC
807E131A

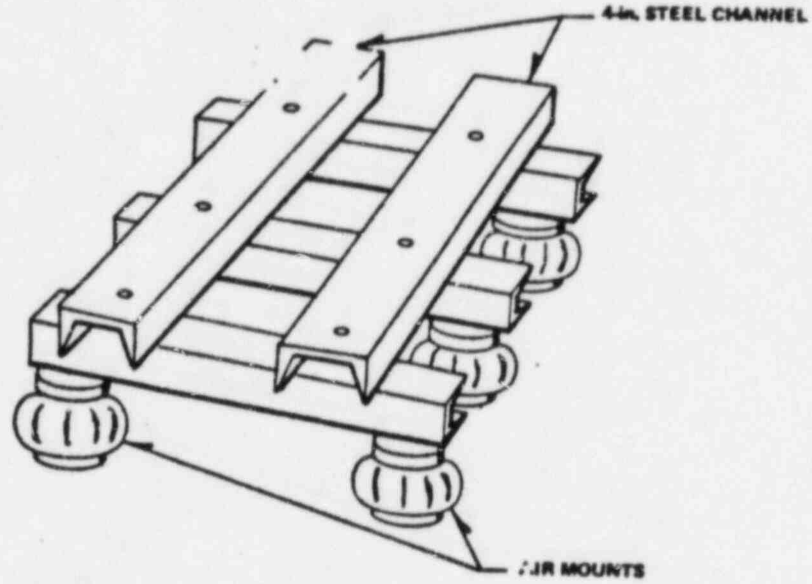


Figure 3-6. Mounting Base for Panels
Showing Isolators and Stiff Structural Members

weights is mounted in the bottom of the panel and is used to generate the variable frequency input vibrations. The level of the input acceleration varies with frequency but, since the acceleration at the device location is being measured against the input acceleration, this is not important.

The justification for this method was obtained by showing the correlation between the tests on the same panel using the regular vibration machine test and then the "soft-mount, eccentric weight" test.[7] The reason for this is that the panels are quite rigid since they are made of 3/16" steel with 1/4 X 2" stiffeners welded across the faces for flatness and with welded corner posts. At the low accelerations of seismic qualification tests (1-10g), there is rarely any indication of exceeding elastic limits so the responses tend to be linear except for a decrease at higher amplitudes due, possibly, to friction in some bolted joints (damping changes).

The subsequent panels of similar type (see Figure 3-7) were considered qualified even though they contained slightly different arrangements of electrical devices and different systems because the mechanical structure is the same and the electrical devices are a small percentage of the total panel mass.

[7] Op. Cit.

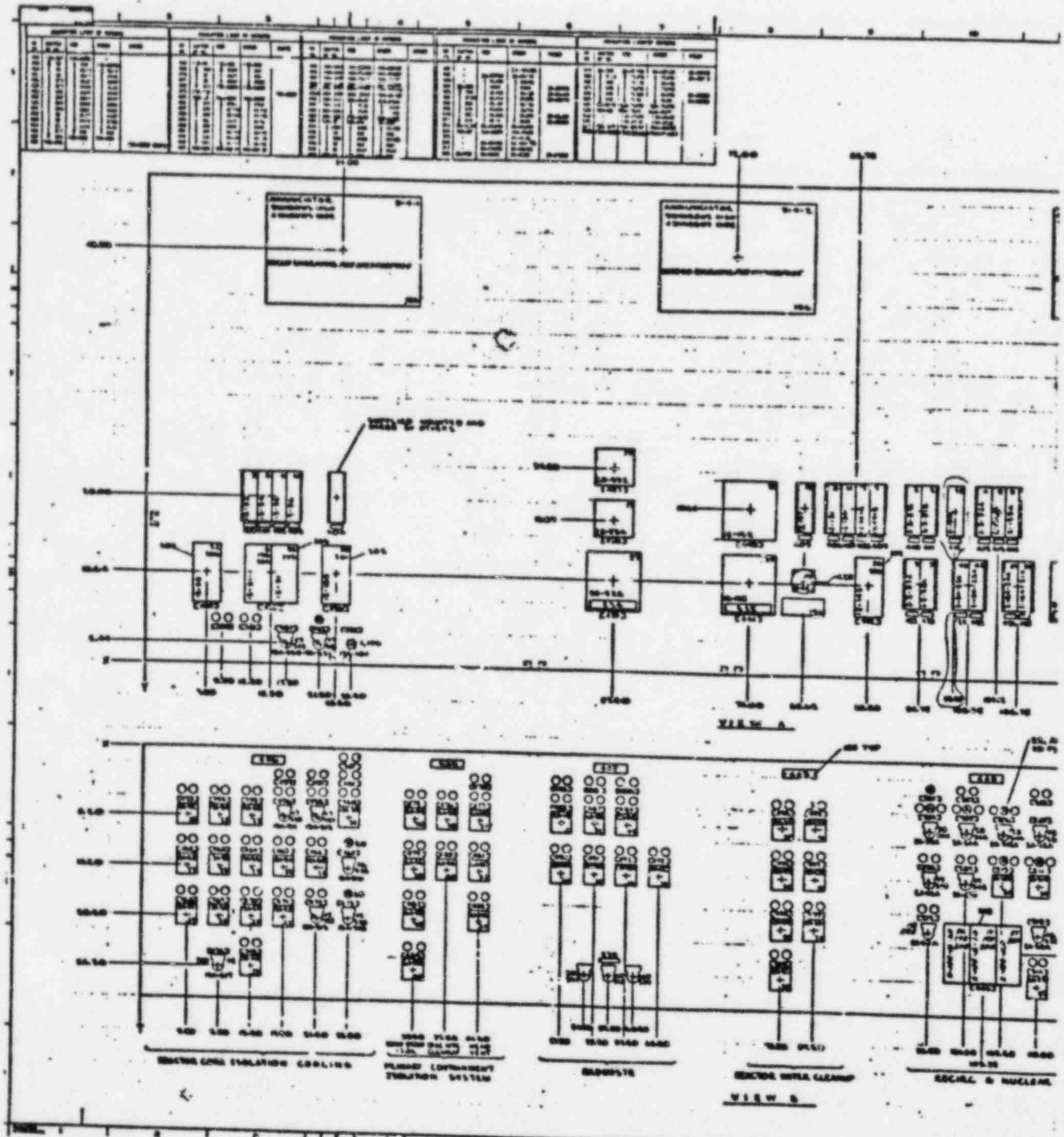
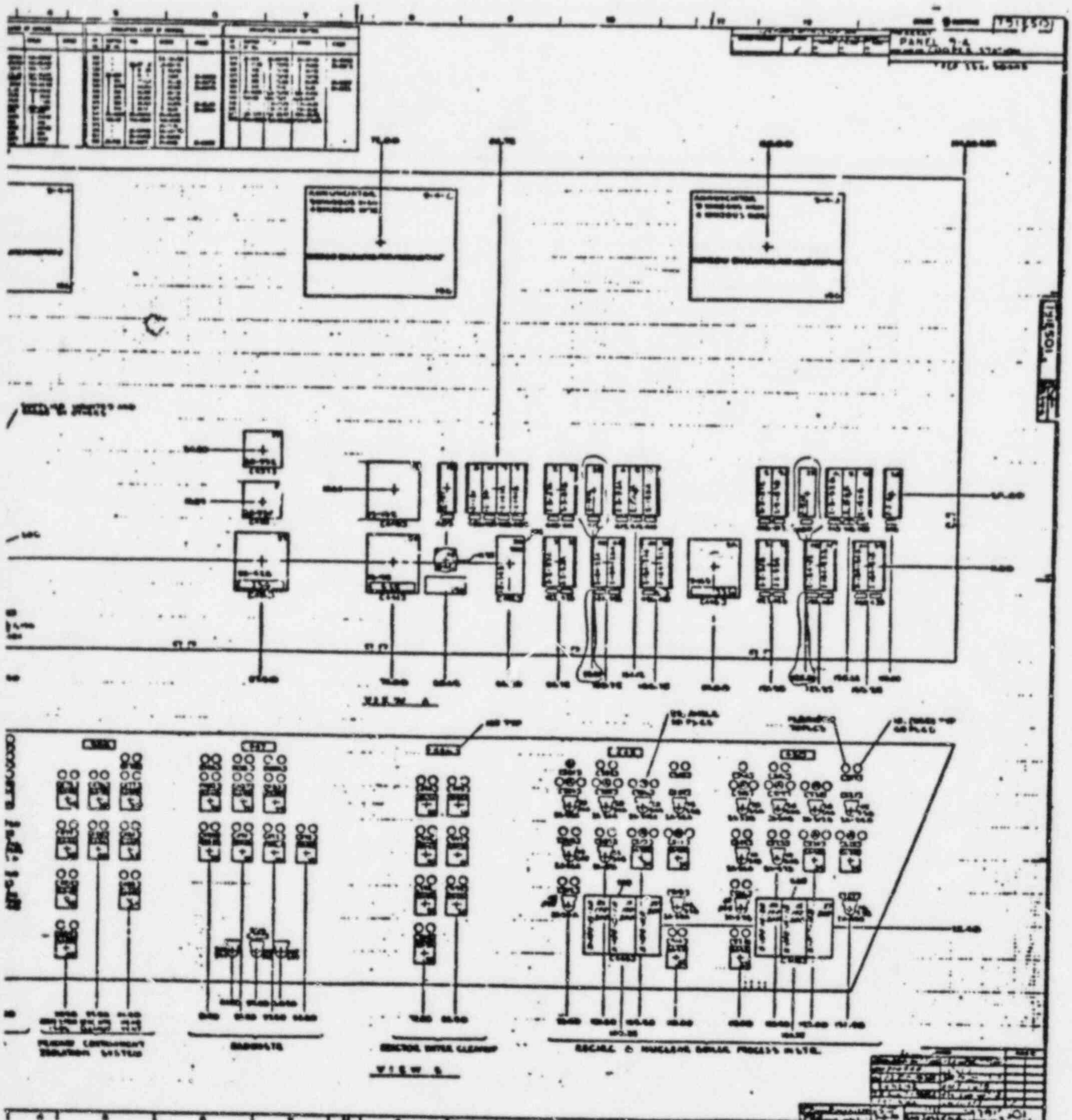


Figure 3-7. Sample Panel Configuration 2.



guration 2.

Panels with a greater instrument-to-structure mass ratio are tested using the normal vibration mac... procedure described previously rather than the "soft mount" method. An example of this is shown in Appendix E.

In all cases, the panels are tested with the devices installed so as to reproduce the weight and stiffening effects of installed equipment. A summary of qualification tests results on a typical lineup of panels for a boiling water reactor is given in Table 3.4.

3.3.3 Purchased Equipment

The seismic qualification of equipment supplied to General Electric by others is required to follow the same procedures as used by General Electric and described in paragraphs 3.3.1 and 3.3.2. The qualification data are supplied to and reviewed by General Electric for conformance to the required procedures. All such equipment is purchased using Purchased Part Drawings which contain the performance and qualification requirements. A sample is shown in Figure 3-8.

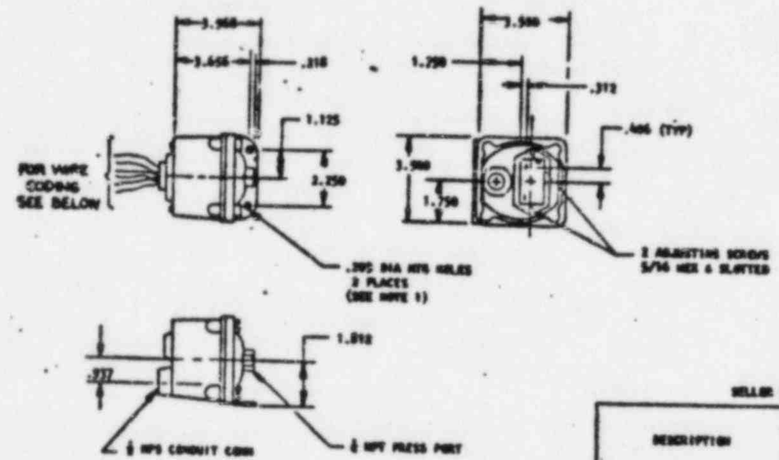
In the case of a few pieces of Class I electric equipment such as large electric motors, where proven analytical methods are available, analysis is performed. In such cases, the best analysis methods available to the supplier are used.

Table 3.4
Sample Qualification Test Results for Panels

Panel Number	Name	Type	Limiting Part	Max. Horizontal Floor Acceleration Without Failure
H11-P601	Reactor Safeguards	Benchboard	Controller (5g)	1.8g
H11-P602	Reactor Cleanup, Recirc, & Inboard Isolation Valves	Benchboard	Controller (5g)	1.8g
H11-P606	Start-Up Neutron Monitor	4-Bay Instrument Rack	Log Rad (3g)	1.5g
H11-P608	Power Range Neutron Monitor	5-Bay Instrument Rack	PRM System (1.5g)	1.5g
H11-P609/11	Protection System	3-Section Vertical Board	HFA Relays (1.1g)	1.1g**
H11-P612/13	Process Instrumentation Aux.	2-Bay Instrument Rack	GE/MAC (3g)	*
H11-P617/18	RHR & ADS	Vertical Board	HGA Relays (0.96g)	0.96g**
H11-P620	HPCI Relays	Vertical Board	HGA Relays (0.96g)	0.96g**
H11-P622/23	Inboard & Outboard Valves	Vertical Board	HFA Relays (1.1g)	1.1g**
H21-P013A/B/C/D	SRM/IRM Preamplifiers	Hoffman Enclosure	Voltage Preamp (8.5g)	3.9g
H11-P628	HPCI Relays	Vertical Board	HGA Relays (0.96g)	0.96g**
H11-P626/27	HPCI Relays	Vertical Board	HGA Relays (0.96g)	0.96g**
H11-P621	HPCI Relays	Vertical Board	HGA Relays (0.96g)	0.96g**

*Tests run on the Process Instrumentation Auxiliary Panel revealed apparent high amplifications which were found to be caused by the GE/MAC modules impacting with their cases. A mechanical restraint is being designed and a test will be performed.

**The limiting accelerations are for the relays in the deenergized mode with an acceptable contact chatter limit of 100 microseconds. Under these conditions, the relays showed a resonant failure at frequencies over 30 Hz. At 20 Hz, the HGA withstood 1.2g (6g if energized) and the HFA withstood 1.5g (7g if energized). The requirements and use of these relays are being reviewed at present for higher seismic applications.



WIRING CODING-PRESSURE
CIRCUIT#1 COMMON-PURPLE
NORMALLY CLOSED-BLUE
NORMALLY OPEN-RED
CIRCUIT#2 COMMON-BROWN
NORMALLY CLOSED-ORANGE
NORMALLY OPEN-YELLOW
NORMALLY AT ZERO(GAUGE PRESSURE)

WIRING CODING-VACUUM
CIRCUIT#1 COMMON-PURPLE
NORMALLY CLOSED-RED
NORMALLY OPEN-BLUE
CIRCUIT#2 COMMON-BROWN
NORMALLY CLOSED-YELLOW
NORMALLY OPEN-ORANGE

PART NO.	ADJUSTABLE RANGE		APPROX ACTUATION VALUE		PROOF PRESSURE		CATALOG NUMBER
	VACUUM	PRESSURE	VACUUM	PRESSURE	VACUUM	PRESSURE	
1	.06-6 IN HG VAC	.03-3 PSIG	.14-.28 IN HG VAC	.07-.15 PSIG	5 IN HG VAC	10 PSIG	[illegible]
2	-	1.5-150 PSI	-	2.3-6 PSIG	-	300 PSIG	[illegible]
3	.8-30 IN HG VAC	.4-18 PSIG	.4-8 IN HG VAC	.12-.26 PSIG	30 IN HG VAC	60 PSIG	[illegible]
4	-	.5-80 PSIG	-	1.6-3.4 PSIG	-	160 PSIG	[illegible]

TABLE 2
SELLER SUBMITTAL REQUIREMENTS

DESCRIPTION	QUALIFICATION SPECIFICATION 22SA6634		PURCHASE SPECIFICATION 22SA6635	
	REQ'D	PARA	REQ'D	PARA
MFR'S SPECIFICATION	YES	6.4.1.A	-	-
FAILURE MODE ANALYSIS	YES	6.4.1.B	-	-
SEISMIC/VIBRATION DATA	YES	6.4.1.C	-	-
MFR FLOW PLAN/QC PROC.	YES	6.4.1.F	-	-
MATERIAL CERTIFICATION	YES	6.4.1.G	-	-
WIRING PRACTICES	-	-	-	-
QUALIF TEST PROCEDURE	YES	6.4.1.D	-	-
QUALIF TEST REPORT	YES	6.4.1.E	-	-
QUALITY ASSURANCE	-	-	YES	5.1
CLEANING/PACKING	CONF	-	YES	7.3
TAG/IDENT NUMBER	YES	[illegible].4.1.H	YES	6.0
INSTRUCTION MANUAL	YES	6.4.3	-	-
CERTIF OF COMPLIANCE	-	-	YES	5.3

#1 MANUFACTURED BY: BARKSDALE
OR ENGINEERING APPROVED EQUIV.

SPECIFICATION
1.0 THE NORMAL ... REFERENCE
2.0 ENVIRONMENT
TEMPERATURE
PRESSURE
HUMIDITY
3.0 DESIGN SPE...
1) ELEMENT
2) RANGE:
3) DIFFERE...
4) ACCURAC...
5) SWITCH...
6) PROOF P...
7) RESPONS...
4.0 SELLER CLA...
5.0 SELLER SUB...
1) THE SEL...
6.0 REFERENCE
22SA6634
22SA6635
LATER
LATER

NOTES:
1. MOUNTI... POSITI...
2. ADJUS...
3. ALL ...
4. ITEMS ... PURCHA...

Figure 3-8

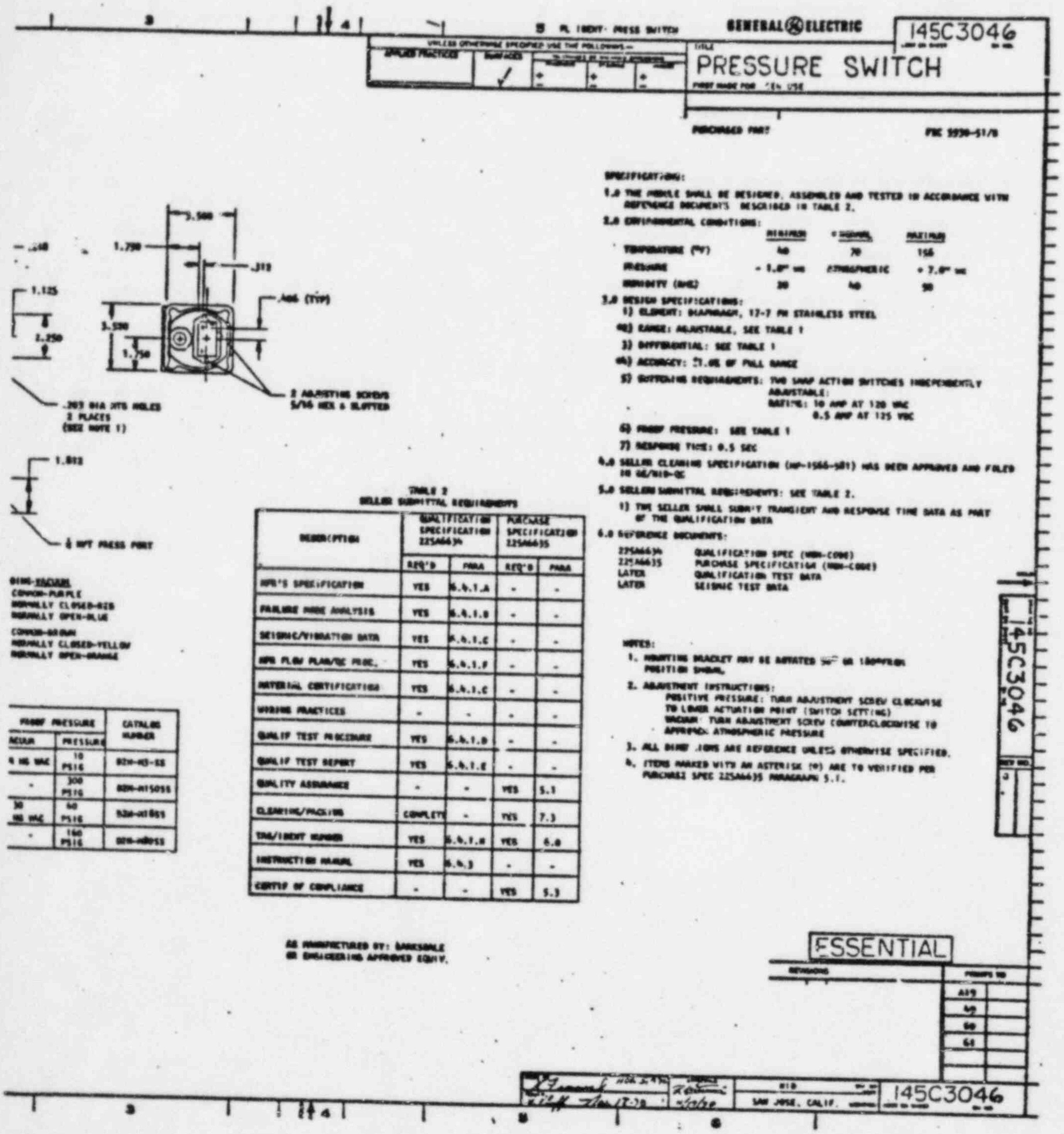


Figure 3-8. Sample Purchased Part Drawing

PRODUCT DRAWING NO. 238X905NS TYPE 12 FT BENCHBOARD

MANUFACTURER GE/NID MODEL NO. 9-5

DESCRIPTION: 12 FT SINGLE SECTION BENCHBOARD HOUSING ESSENTIAL SBM AND CR2940 SWITCHES ON BENCH

CLASSIFICATION: ESSENTIAL - SEISMIC I

QUALIFICATION REFERENCE DOCUMENTS:

REQUIREMENTS: 257HA888 AND 239X528 (APED)
TEST PROCEDURES: 225A5766 (NID)
RESULTS REFERENCES: QUALIFICATION REPORT MEMO #1 - "SEISMIC TESTING OF INSTRUMENTATION" (STANDARDS AND QUALIFICATION ENGINEERING - NID)

CALCULATIONS: NONE
TEST RESULTS: 225A6280 (CR2940 SWITCH), 225A6262 (SBM), 225A6762 (MILLSTONE 9-5) (234A9134 COOPER 9-39)

BASIS FOR QUALIFICATION: SWITCHES MOUNTED ON NEARLY HORIZONTAL PANEL OF A 3/16 STEEL CAN WITHSTAND NEARLY TWENTY TIMES MAXIMUM VERTICAL ACCELERATION TEST REQUIREMENT OF 0.14 g'S. NO BRACING IS REQUIRED BUT PANEL IS BRACED WITH CONTINUOUS 0.25 BY 4.0 INCH STIFFENERS FROM TOP TO BOTTOM OF VERTICAL PORTION OF BOARD AT 24 INCH INTERVALS. HORIZONTAL STIFFENERS ANCHOR VERTICAL STIFFENER AND BRACKET INSTRUMENTS. VERTICAL STIFFENERS ARE ALSO EMPLOYED ON BENCH.

CONFIGURATION FOR: COOPER 9-5. AS DESCRIBED ABOVE.

QUALIFICATIONS: PANEL 9-5 MEETS SEISMIC CLASS I REQUIREMENTS.

APPROVALS:
RESPONSIBLE ENGINEER [signature] DATE 11-30-70
DESIGN REVIEW BOARD CHAIRMAN [signature] DATE 11-30-70

Figure 3-9. Sample Seismic Summary

4.0 DOCUMENTATION

The seismic qualification documentation consists of the Seismic Test Report, Seismic Summary, and if analysis is used, the Stress Analysis Report.

4.1 SEISMIC TEST REPORT

An example of a Seismic Test Report can be found in Appendix D and Appendix E with the latter representing the version currently being used. The document provides a standardized format for the description of the equipment to be tested, the test itself, the results, conclusions, and recommendations. It also contains the data obtained from the test, reduced for ease of understanding. The report is on a corporate drawing form with a unique number and is retreivable from the Company's document storage system.

4.2 SEISMIC SUMMARY

The Seismic Summary is a form which contains the rationale for the qualification of any particular piece of Class I electric equipment for a particular application. As can be seen from the sample shown in Figure 3-9, the Summary identifies the equipment, the seismic requirements, the applicable results documentation, and the justification. The Summary is finally reviewed and approved by the Chairman of the Design Review Board.

4.3 STRESS ANALYSIS REPORT

This document is required by the ASME Boiler and Pressure Vessel Code for all equipment within that jurisdiction and is prepared to conform to the requirements of that code.

5.0 COMPLIANCE WITH IEEE 344 - 1971

Those sections of IEEE 344 - 1971 which give guidance for the qualification of Class I Electric Equipment are listed in the following paragraphs with a brief statement as to which procedures and practices apply and why.

5.1 ANALYSIS

As stated in subsection 3.2, the analysis method is used only for that electric equipment which can be adequately modeled to correctly predict its seismic response. Ordinarily, analysis is practical for equipment that is structurally simple, or is designed by rational stress analysis methods (e.g., pressure boundary equipment designed to Section III of the ASME Boiler and Pressure Vessel Code). Examples of calculational methods are given in Appendices A, B, and C.

5.2 TESTING

The description of the test procedures given in subsection 3.3 meets the requirements of IEEE 344-1971's paragraphs 3.2.1 (exactly), 3.2.2 (exactly), and 3.2.3 (partially). For the first two paragraphs, the method used is that of IEEE 344 as is evidenced by the description given in subsection 3.3 and paragraph 3.3.1 of this report. The requirements of paragraph 3.2.3 of IEEE 344 are met exactly by the full shaker test described in paragraph 3.3.2 of this report, but only partially as explained above when the "soft mount" test is used-although it should be noted that paragraph 3.2.3.1 of IEEE 344 mentions such an approach but does not cover the extrapolation to higher levels from such a test. Paragraph 3 of IEEE 344 does, however, allow the use of "other effective methods" if they are adequately justified. The explanation of the limited use of the "soft mount" technique in this report provides the appropriate justification.

5.3 DOCUMENTATION

As explained in section 4.0, the documentation provided by General Electric on the qualification of Class I electric equipment conforms to the requirements that 1) the documentation demonstrates meeting performance requirements (see Appendix E, 2) the documentation presents step-by-step analytical proof (see Appendix A, and 3) the documentation contains certain recommended test data (see Appendix D).

6.0 CONCLUSIONS

General Electric has adopted a verification program for the seismic qualification of Class I electric equipment on all standard product line reactors. The program assures the proper functioning of essential equipment before, during, and after a Safe Shutdown Earthquake. This report has described the equipment design criteria and the tests performed, including the specific equipment to which the tests have been or will be applied. Appropriate reference to the paragraphs of IEEE-344 have been made to signify conformance to the intent of this standard.

Appendix A

Dynamic Analysis by Response Spectrum Method

The system stiffness and mass matrices are generated using standard techniques. A seismic analysis is performed using the following equations of motion and procedure to uncouple these equations:

The equations of motion in matrix form are as follows:

$$M\,(\ddot{X} + \ddot{Y}) + C\,\dot{X} + K\,X = 0 \qquad (1)$$

where

M = mass matrix, n x n (this includes the hydrodynamic mass)

X = column vector of displacement relative to ground* (n x 1)

C = damping matrix (n x n)

K = stiffness matrix (n x n)

$\ddot{Y}$ = column vector of ground accelerations (n x 1)

$\dot{}$ = first derivative with respect to time

$\ddot{}$ = second derivative with respect to time

It should be noted that for equipment containing fluid, a hydrodynamic mass coupling exists between real structural masses. This hydrodynamic mass appears as diagonal and off-diagonal terms in the mass matrix. The overall system stiffness matrix K is determined by either the matrix force method or the matrix displacement method. The resulting stiffness matrix is similar.

Removing the driving-point acceleration vector to the right side of equation (1), the equation reduces to the classical form:

$$M\,\ddot{X} + C\,\ddot{X} + K\,X = -M\ddot{Y} \qquad (2)$$

In order to uncouple equation (2), we set:

$$X = \phi q \qquad (3)$$

Equation (2) then becomes

$$M\phi q + C\phi q + K\phi q = -M\ddot{Y} \qquad (4)$$

Pre-multiplying (4) by ϕ^T, the transpose of ϕ, and performing the coordinate transformation described in (4) such that ϕ is defined by the following orthogonality conditions:

$$\phi^T M\phi = I \tag{5}$$

$$\phi^T K\phi = \left[\diagdown \omega^2 \diagdown\right] \tag{6}$$

where I is an identity matrix (nxn) and $\left[\diagdown \omega^2 \diagdown\right]$ is a diagonal matrix of the eigenvalues. Then (4) becomes

$$\phi^T M\phi\ddot{q} + \phi^T C\phi\dot{q} + \phi^T K\phi q = -\phi^T M\ddot{Y} \tag{7}$$

$$\ddot{q} + \phi^T C\,\phi\dot{q} + \left[\diagdown \omega^2 \diagdown\right] q = -\,\phi^T M\ddot{Y} \tag{8}$$

The above procedure for uncoupling the equation of motion by using the modal matrix of the undamped system assumes that damping in the system is small. It will further be assumed that the damping matrix C is such that $\phi^T C\,\phi$ is a diagonal matrix. The elements of this diagonal-matrix are the modal damping values.

With the above assumptions, equation (8) may be written in the following uncoupled form:

$$\ddot{q}_i + 2\beta_i\ \omega_i\,\dot{q}_i + \omega_i^2\,q_i = S_i\,\ddot{U}_g$$

$$i = 1, 2, --- n \tag{9}$$

where

$$X_i = \begin{bmatrix} X_{1i} \\ X_{2i} \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ X_{ni} \end{bmatrix} \qquad \phi_i = \begin{bmatrix} \phi_{1i} \\ \phi_{21} \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \phi_{ni} \end{bmatrix}$$

The maximum physical displacement for each mass is then taken to be the square root of the sums of the squares of each of the maximum displacement responses for each mode, i.e.,

$$(X) \text{ max.} = \left[\sum_{j=1}^{n} x_{ij}^{2} \right]^{1/2}, \quad i = 1, 2, \ldots m$$

where: (X) maximum is the column vector of maximum displacements. Similarly, the maximum load response for the i^{th} mode is found from

$$L_{ji} = \beta_j X_i$$

$$L_{ji} = \begin{bmatrix} L_{1i} \\ L_{2i} \\ \cdot \\ \cdot \\ \cdot \\ L_{mi} \end{bmatrix}$$

where

β_j is the stress matrix for element j, j=1, ...m

m = total number of elements.

where

β_i = damping ratio for the i^{th} mode expressed as percent of critical damping

ω_i = i^{th} natural angular frequency of the system

S_i = modal participation factor the i^{th} mode = $-\phi_i^t MD$

$\ddot{U}_g$ = ground or floor acceleration time history

ϕ_i^t = transpose of the i^{th} mode shape

D = earthquake direction vector

The response is calculated using the response spectra specified for the location of the input to the analytical model. The analytical procedure is described briefly in the following paragraphs.

The system of one-degree-of-freedom equations represented by equation (8) or (9) can be solved by the response spectrum method. With this method, the maximum modal response for each natural frequency of interest is found from the applicable response spectra. Response spectrum curves are essentially plots of the maximum responses of single-degrees-of-freedom systems described by equation (9) with S_i = 1.0 as a function of their natural frequencies.

Having found the maximum modal displacements q, i = 1...m, the maximum physical displacement for the i^{th} mode is given by:

$$X_i = \phi_i S_i q_i$$

The maximum load response is taken to be the square root of the sums of the squares of each of the maximum responses for each mode, i.e.

$$(L_j)\ max = \left[\sum_{i=1}^{n} L^2_{ji}\right]^{1/2} : j = 1, 2, ...m$$

where (L) max. is the column vector of maximum loads.

The accelerations for each mode are determined by multiplying the displacements vector for that mode (X_i) by the natural frequency (ω_i^2) of that mode.

$$A_i = X_i \omega_i^2$$

The maximum accelerations are then determined by

$$(A)\ max = \left[\sum_{i=1}^{n} A_i^2\right]^{1/2}$$

Appendix B

Sample Panel Frequency Analysis

The method of analysis used to determine the resonant frequency of the panel is as follows:

1. Calculate the moment of inertia of the corner post structure.
2. First assume a simplified structure and calculate the frequency using the expression:

$$f = 1/2\pi \sqrt{Kg/w} = \sqrt{g}/2\pi \sqrt{k/w} = 3.13/\sqrt{w/k}$$

$$\therefore f = 3.13/\sqrt{\delta}$$

where

f = frequency

g = 386 in./sec^2

k = spring rate #/in.

w = weight #

δ = deflection = w/k

weight distribution is assumed to be uniform.

3. Additional structural components are added and the moment and frequency recalculated.

The calculated resonant frequency of 7.4 Hz for the panel and 5.9 Hz for the benchboard was obtained using only the corner posts and the top. The addition of skin (3/8-in. steel) and 2-in. x 1/4-in. steel stiffeners will raise the frequency further. This proves that resonances cannot exist in the unstable region below 5 Hertz.

FIRST APPROXIMATION

For first approximation lump the 4 corner posts together and assume the panel is a cantilever beam fixed on one end and uniformly loaded.

The natural frequency is 2.6 HZ so we will have to use more of the structure.

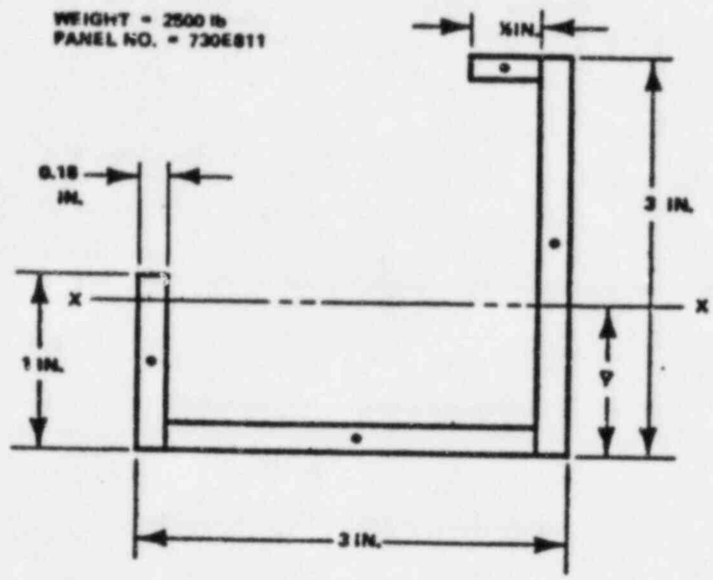


Figure 1. Corner Post

SECOND APPROXIMATION

For a second approximation, consider two 0.18" x 30" barriers in addition to the corner posts. The plan view of the panel is shown in Figure 2.

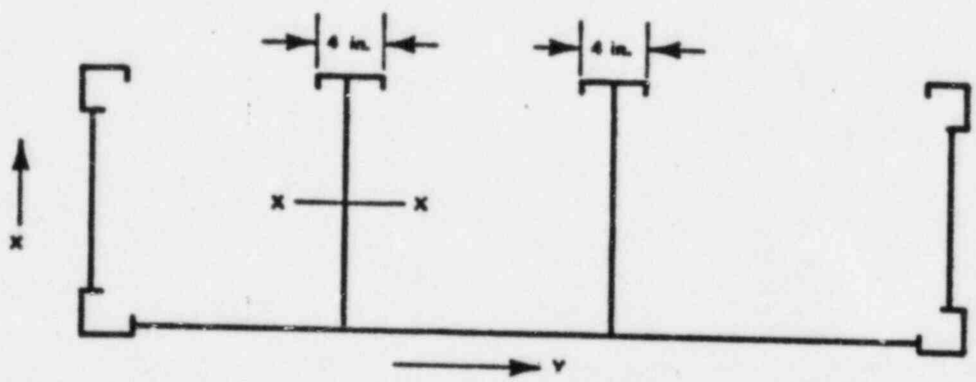


Figure 2. Plan View of Panel

In the X direction just one barrier will raise the frequency to 30 HZ. Use 4 inches of the back panel for each of the two barriers (see Figure 3) and the natural frequency in the Y direction becomes 4 HZ.

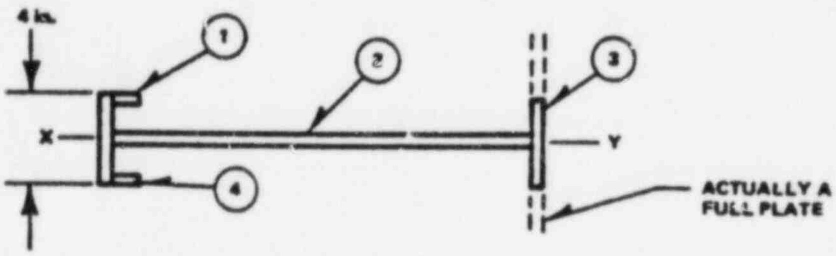


Figure 3. Barrier with Two End Plates

The deflection equation used so far is very conservative: it assumes that the 4 corner posts are lumped together and that the structure can reflect like a simple cantilever beam. Actually the corners are separated by an angle frame which is stiffer than the corner posts. This will force the structure to deflect as shown in Figure 4.

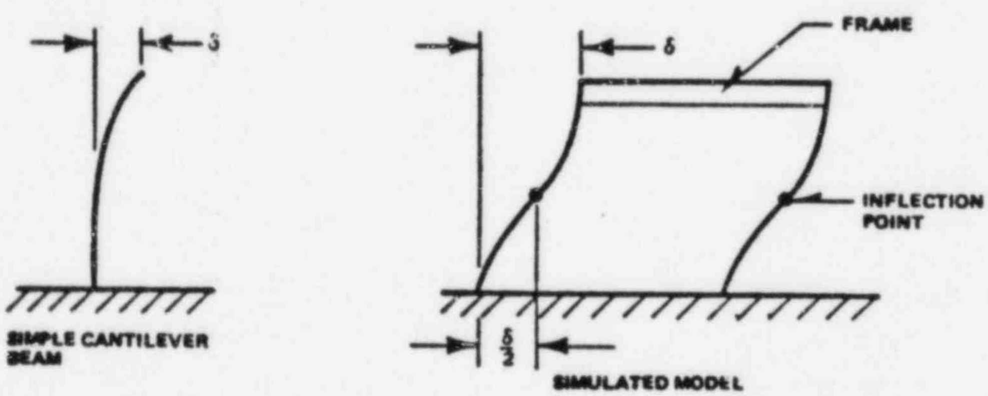
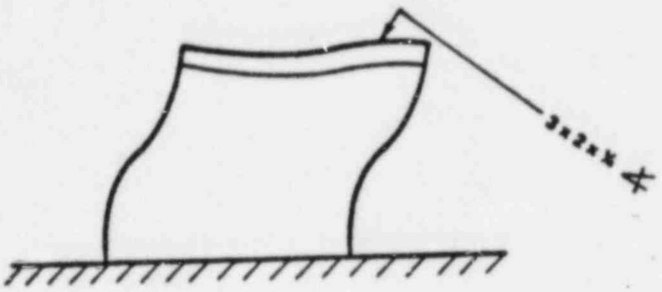


Figure 4. Panel Deflections

In the simulated model we are not conservative (if we used all of the members) but we are very close. The reason we are not quite correct is because the stiff top frame will deflect slightly as whown below. The calculated frequency is 7.4 HZ which is above the necessary 5 HZ.



For the benchboard H11 P601 which weighs 4000 pounds, the calculated natural frequency is 5.9 HZ which is still above the 5 HZ test frequency minimum.

NOTE: This neglects the barriers, the end and front panels, top plate, the stiffening of the lower part of the structure due to the bench board geometry, and all other members of the structure.

Appendix C

Sample Seismic Static Analysis

PART I

The purpose of this appendix is to provide the designer a set of curves from which static seismic analysis of standard enclosures can be quickly performed. A standard enclosure is any enclosure listed in the Enclosure Standards Manual. The enclosures are assumed to be floor mounted, using all mounting holes with 5/8 inch steel bolts or studs each having an effective area of 0.2256 in^2. Using an elastic limit of one half the ultimate strength, the bolts are assumed to have a maximum safe tension stress and maximum safe shear stress of 28,000 PSI and 21,000 PSI, respectively. The curves are based on a design basis earthquake having a horizontal acceleration of 1.5G and a vertical acceleration of 0.5G. It is assumed that each enclosure is mounted alone and not coupled directly to any other enclosure.

The static analysis consists of determining the maximum allowable safe weight of the enclosure and its components for which the mounting bolt stresses are not exceeded. The curves of Figure I-1 have been derived for this purpose. To use the curves given in Figure I-1, first determine from Table I-1 the curve designation of the enclosure being considered. Next, using the corresponding curve in Figure I-1, determine the maximum safe weight per bolt for a given height of the center of gravity. The maximum safe enclosure weight is then determined by multiplying the weight per bolt by the total number of enclosure mounting bolts. Comparison with the actual weight of the enclosure and its components then indicates whether or not the mounting bolt stresses are exceeded. If the comparison shows that the maximum safe weight per bolt is exceeded, steps should be taken to increase the effective bolt area by welding the enclosure to its mounting, increasing the number of mounting bolts, adding top braces to a wall, or using another appropriate method to insure safe operation during seismic disturbance.

TABLE I-1

STANDARD ENCLOSURES

Curve	Enclosure	Width	Depth	Mode of Failure
C1	Instrument Rack	24"	24"	
	Instrument Rack	24"	30"	
	Vertical Board	24"	24"	Side to Side
	Vertical Board	24"	30"	
	Benchboard	24"	48"	
	Benchboard	24"	54"	
C2	Instrument Rack	30"	30"	
	Instrument Rack	30"	24"	
	Instrument Rack	48"	24"	
	Instrument Rack	60"	24"	Front to Back
	Instrument Rack	72"	24"	OR
	Instrument Rack	96"	24"	Back to Front
	Vertical Board	36"	24"	
	Vertical Board	48"	24"	
	Vertical Board	60"	24"	
	Vertical Board	72"	24"	
	Vertical Board	96"	24"	
C3	Instrument Rack	48"	30"	
	Instrument Rack	60"	30"	
	Instrument Rack	72"	30"	
	Instrument Rack	96"	30"	Front to Back
	Vertical Board	36"	30"	OR
	Vertical Board	48"	30"	Back to Front
	Vertical Board	60"	30"	
	Vertical Board	72"	30"	
	Vertical Board	96"	30"	

TABLE I-1

STANDARD ENCLOSURES
(Continued)

Curve	Enclosure	Width	Depth	Mode of Failure
C4	Console	96"	42"	Back to Front
C5	Benchboard Benchboard	48" 48"	54" 48"	Side to Side
C6	Benchboard Benchboard Console	72" 96" 96"	48" 48" 48"	Front to Back
C7	Benchboard Benchboard	72" 96"	54" 54"	Back to Front

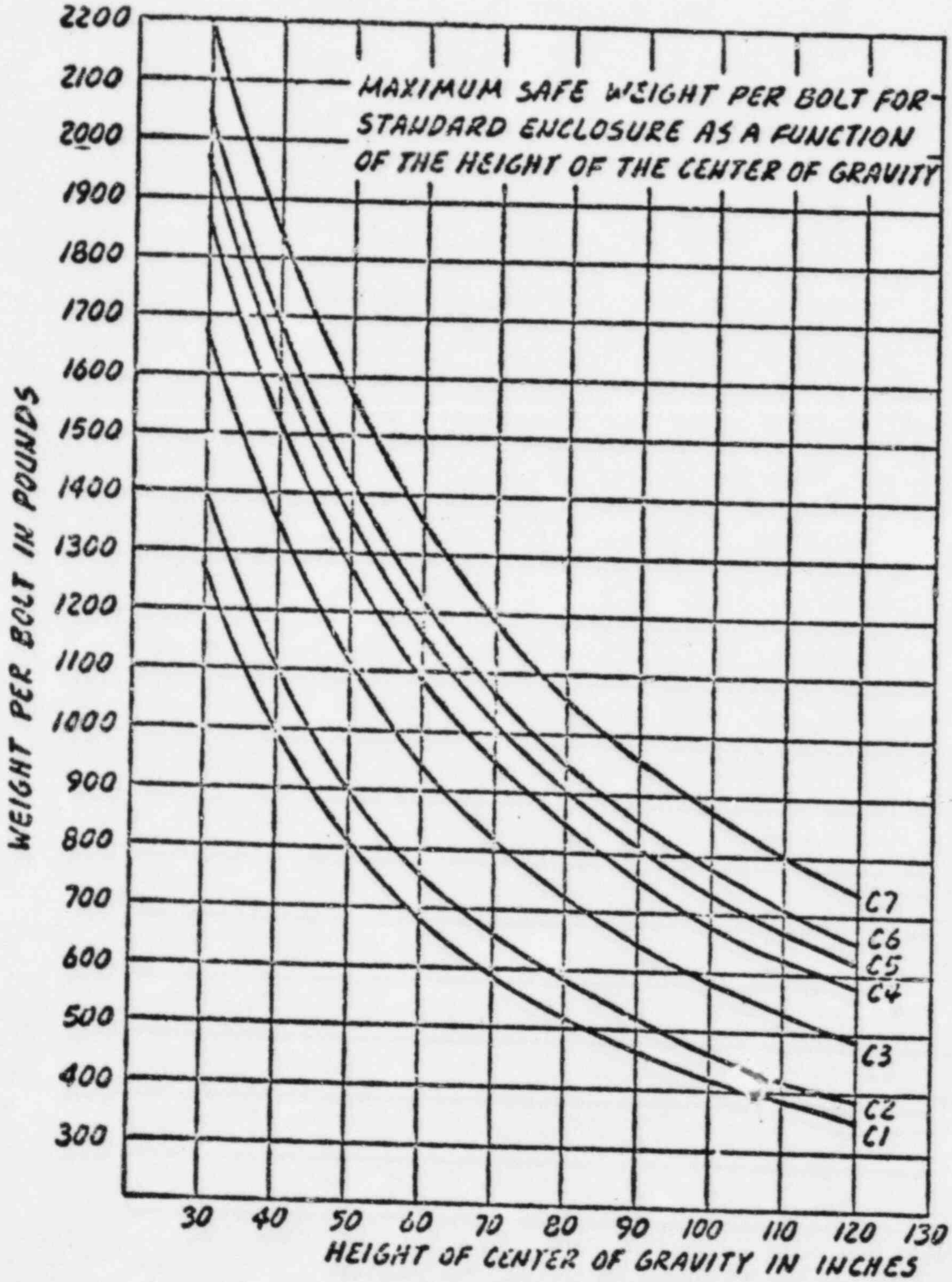

MAXIMUM SAFE WEIGHT PER BOLT FOR STANDARD ENCLOSURE AS A FUNCTION OF THE HEIGHT OF THE CENTER OF GRAVITY
WEIGHT PER BOLT IN POUNDS
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
30 40 50 60 70 80 90 100 110 120 130
HEIGHT OF CENTER OF GRAVITY IN INCHES
C7
C6
C5
C4
C3
C2
C1

Figure 1-1.

PART II

The purpose of this appendix is to present the necessary assumptions and equations for the calculation of the maximum normal and shear stresses in the mounting bolts of any enclosure under seismic disturbance. The following assumptions and conventions are made:

1. The enclosure under consideration is assumed to be a rigid body in equilibrium with respect to its mounting.
2. The forces on the enclosure due to seismic accelerations are assumed to act through the enclosure's center of gravity.
3. The enclosure is assumed to have a known weight W as well as a known center of gravity located at X, Y, Z with respect to a right-handed coordinate system.
4. The right-handed coordinate system is arbitrarily assumed to be located at the front left-hand lower corner of the enclosure with the positive X-axis to the right along the front edge, the positive Y-axis toward the back of the enclosure, and the positive Z-axis toward the top of the enclosure.
5. The stresses on the enclosure mounting bolts are assumed to be greatest when the horizontal component of the floor acceleration is perpendicular to a side of the enclosure and the vertical component of the acceleration is downward.
6. It is assumed that the enclosure tends to rotate about an axis parallel to either the X-axis or the Y-axis, dependent upon the direction of the horizontal acceleration. The location of the axis of rotation is dependent upon the mounting configuration of the enclosure.
7. There is assumed to be no friction between the enclosure and its mounting.
8. The horizontal shear force due to the horizontal component of the acceleration is assumed to be distributed equally among the mounting bolts.
9. All mounting bolts are assumed to be identical.

The following procedure outlines the equations involved in determining the mounting bolt stresses.

From the geometric configuration of the mounting bolts it is found that the tension forces in the bolts are related by

$$F_i = \frac{d_i}{d_j} F_j \quad , (1)$$

(Continued)

where F_i and F_j are the tension forces acting on the i-th and j-th bolts, respectively, and d_i and d_j are the perpendicular distances of the i-th and j-th bolts, respectively, from the axis about which the enclosure tends to rotate. When the enclosure is mounted directly to the floor, the axis of rotation will be an edge of the enclosure. For other mounting configurations, care must be exercised in determining this axis.

Summing moments about the enclosure's axis of rotation, the equation relating the unknown bolt tension forces to known quantities is found to be

$$F_1d_1 + F_2d_2 + . . . + F_Nd_N = W[A1 \cdot Z + (A2-1)L], \quad (2)$$

where N is the number of mounting bolts, A1 and A2 are the relative magnitudes of the horizontal and vertical components of the floor acceleration, respectively, and L is the perpendicular distance between the line of action of the vertical acceleration through the center of gravity and the axis about which the enclosure tends to rotate.

Substituting (1) into (2), the j-th tension force is

$$F_j = \frac{d_j \cdot W\,[A1 \cdot Z + (A2-1)L]}{d_1^2 + d_2^2 + . . . + d_N^2} \quad . \quad (3)$$

The other tension forces are determined using Equation (1).

The tension stress T_i is related to the tension force by

$$T_i = \frac{F_i}{A} \quad , \quad (4)$$

Where A is the effective cross-sectional area of a mounting bolt.

Summing forces in the direction of the horizonal force acting upon the enclosure and making use of assumptions 7 and 8, the shear stress on the i-th bolt is

$$S_i = \frac{W \cdot A1}{N \cdot A} \quad . \quad (5)$$

Due to the combined tension and shear stresses, the maximum tension stress, $(T_i)_{max}$, and the maximum shear stress, $(S_i)_{max}$, present in the i-th bolt are

$$(T_i)_{max} = \frac{T_i}{2} + \sqrt{\left(\frac{T_i}{2}\right)^2 + \left(S_i\right)^2} \quad , \quad (6)$$

(Continued)

and

$$(S_1)_{max} = \sqrt{\left(\frac{T_1}{2}\right)^2 + (S_1)^2} \qquad (7)$$

For a detailed derivation of Equations (6) and (7), the reader is directed to Strength Of Materials, By Ferdinand L. Singer, Chapter 9, Section 6.

To apply the above equations to determine the maximum tension and shear stresses, the following is required:

Total Weight	W Pounds
Center Of Gravity	X, Y, Z Inches
Horizontal Seismic Acceleration	A1 - G
Vertical Seismic Acceleration	A2 - G
Distance to CG (see eq. (2))	L Inches
Number of Bolts	N
Area Each Bolt	A Square Inches
Bolt distance From Axis Of Rotation	$d_1, d_2 \ldots d_N$ Inches

PROCEDURE:

1. Determine the axis about which the cabinet tends to rotate for a given floor motion.
2. Determine, using Equation (3), the tension force acting on the j-th mounting bolts (arbitrarily choose one).
3. Determine the tension forces acting on the remaining mounting bolts from application of Equation (1).
4. Calculate the tension stress acting on each bolt using Equation (4) and the results of Step 3.
5. Calculate the horizontal shear stress from Equation (5).
6. Determine the maximum tension stresses using Equation (6) and the results of Steps 4 and 5.
7. Determine the maximum shear stresses using Equation (7) and the results

(Continued)

of Steps 4 and 5.

8. Compare these maximum stresses and allowable stresses of one half the ultimate strength (in PSI) for the bolt material.

A computer program CALST, to implement the above steps, has been written in the BASIC language and is available on the G.E. Time Sharing System. Program CALST calculates the forces and maximum stresses acting on each bolt of a floor mounted enclosure.

PART III

Design Report: Static Seismic Analysis of Standard Cabinets

I. PURPOSE

The purpose of this report is to document a static seismic analysis which was performed to verify that the mounting bolts of the standard cabinets are capable of withstanding seismic environment.

II. SCOPE

The scope of this report is limited to the static analysis of the mounting bolt stresses of five (5) standard cabinets. The standard cabinets are:

a. Area Radiation Monitor, 236x400 (911)

b. TIP Control, 236x401 (913)

c. Start-up Neutron Monitor, 236x402 (936)

d. Power Range Monitor, 236x403 (937)

e. Rod Position Information System, 236x404 (927)

III. DISCUSSION

The Seismic Design Guide, 225A4582, was used in conducting the static seismic analysis. Each cabinet was assumed to be floor mounted using 5/8" bolts in all mounting holes. The maximum safe tension stress and maximum safe shear stress were assumed to be 28,000 PSI and 21,000 PSI, respectively.* The design basis earthquake was assumed to have a horizontal acceleration of 1.5G and a vertical acceleration of 0.5G. The weight of each cabinet was estimated using the weight of each major component listed in the parts list for each cabinet. The height of the center of gracity of each cabinet was calculated using the weight and center of gravity of each of the major components.

The following data sheets include the necessary information for determining the factor of safety for each cabinet.

*Equal to one-half the ultimate strength as given in Machinery's Handbook, Fourteenth Edition.

SEISMIC DESIGN VERIFICATION DATA SHEET

Cabinet Name: Area Radiation Monitor, 236x400

Applied Horizontal Acceleration	1.5 G
Applied Vertical Acceleration	0.5 G
Tension Stress (Maximum Safe)	28,000 PSI
Shear Stress (Maximum Safe)	21,000 PSI
Weight of Cabinet	675 Lbs.
Number of Mounting Bolts	4
Height of Center of Gravity	48 Inches
Maximum Allowable Weight Per Bolt (From Curve No. C1 on Page 8 of Seismic Design Guide, 225A4582)	830 Lbs/Bolt
Maximum Allowable Cabinet Weight 830 Lbs/Bolt * 4 Bolts =	3,320 Lbs.

$$\text{Factor of Safety} = \frac{\text{Maximum Allowable Weight}}{\text{Weight}} = 4.9$$

Cabinet Name: TIP Control, 236x401 (913)

Applied Horizontal Acceleration	1.5 G
Applied Vertical Acceleration	0.5 G
Tension Stress (Maximum Safe)	28,000 PSI
Shear Stress (Maximum Safe)	21,000 PSI
Weight of Cabinet	755 Lbs.
Number of Mounting Bolts	8
Height of Center of Gravity	50 Inches
Maximum Allowable Weight Per Bolt (From Curve No. C3 on Page 8 of Seismic Design Guide, 225A4582)	1,110 Lbs.
Maximum Allowable Cabinet Weight 1,110 Lbs/Bolt * 8 Bolts =	8,880 Lbs.

$$\text{Factor of Safety} = \frac{\text{Maximum Allowable Weight}}{\text{Weight}} = 11.7$$

SEISMIC DESIGN VERIFICATION DATA SHEET (Continued)

Cabinet Name: Start-Up Neutron Monitor, 236x402 (936)

Applied Horizontal Acceleration	1.5 G
Applied Vertical Acceleration	0.5 G
Tension Stress (Maximum Safe)	28,000 PSI
Shear Stress (Maximum Safe)	21,000 PSI
Weight of Cabinet	1,910 Lbs.
Number of Mounting Bolts	12
Height of Center of Gravity	50 Inches
Maximum Allowable Weight Per Bolt (From Curve No. C3 on Page 8 of Seismic Design Guide, 225A4582)	1,110 Lbs/Bolt
Maximum Allowable Cabinet Weights 1,110 Lbs/Bolt * 12 Bolts =	13,320 Lbs.

$$\text{Factor of Safety} = \frac{\text{Maximum Allowable Weight}}{\text{Weight}} = 11.9$$

Cabinet Name: Power Range Monitor, 236x403 (937)

Applied Horizontal Acceleration	1.5 G
Applied Vertical Acceleration	0.5 G
Tension Stress (Maximum Safe)	28,000 PSI
Shear Stress (Maximum Safe)	21,000 PSI
Weight of Cabinet	4,345 Lbs.
Number of Mounting Bolts	40
Height of Center of Gravity	46 Inches
Maximum Allowable Weight Per Bolt (From Curve No. C3 on Page 8 of Seismic Design Guide, 225A4582)	1,210 Lbs/Bolt
Maximum Allowable Cabinet Weight 1,210 Lbs/Bolt * 40 Bolts =	48,400 Lbs.

$$\text{Factor of Safety} = \frac{\text{Maximum Allowable Weight}}{\text{Weight}} = 11.1$$

SEISMIC DESIGN VERIFICATION DATA SHEET (Continued)

Cabinet Name: Rod Position Information System, 236x404 (927)

Applied Horizontal Acceleration	1.5 G
Applied Vertical Acceleration	0.5 G
Tension Stress (Maximum Safe)	28,000 PSI
Shear Stress (Maximum Safe)	21,000 PSI
Weight of Cabinet	2,500 Lbs.
Number of Mounting Bolts	20
Height of Center of Gravity	45 Inches
Maximum Allowable Weight Per Bolt (From Curve No. C3 on Page 8 of Seismic Design Guide, 225A4582)	1,225 Lbs/Bolt
Maximum Allowable Cabinet Weight 1,225 Lbs/Bolt * 20 Bolts =	24,500 Lbs.

$$\text{Factor of Safety} = \frac{\text{Maximum Allowable Weight}}{\text{Weight}} = 9.8$$

IV. CONCLUSION

Review of the Factor of Safety of each standard cabinet indicates that the mounting bolts of each cabinet are capable of withstanding seismic disturbances as specified in the Seismic Design Guide.

Appendix D
Sample Seismic Test Results - Benchboard

Appendix D

Sample Seismic Test Results - Benchboard

I ITEM IDENTIFICATION

DWG. NO. 238X904 TITLE 9-4 BENCH-BOARD

DESCRIPTION THE PANEL CONSISTS OF 180 TYPE METERS, ANNUNCIATORS AND SBM SWITCHES.

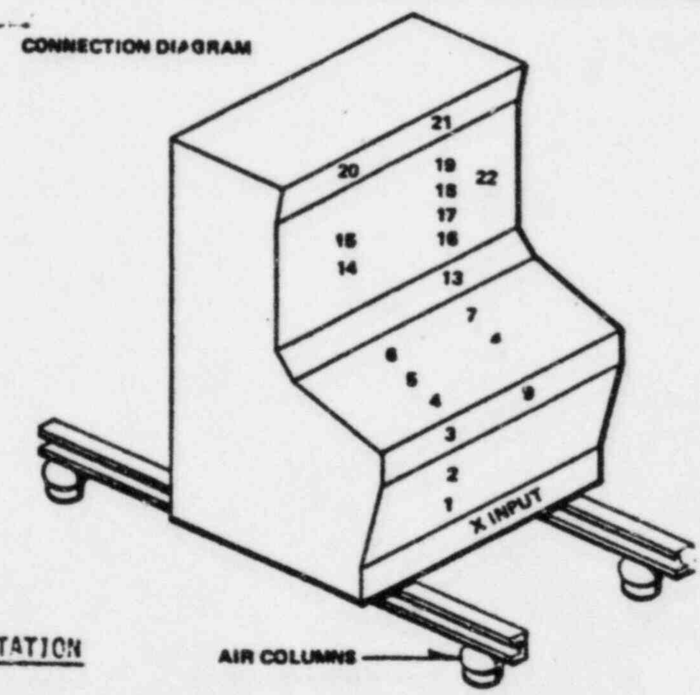
II TEST FACILITY

LOCATION SAN JOSE, BLDG B DATE 8-12-70

SHAKER TYPE MECHANICAL-ECCENTRIC WEIGHT

III OPERATIONAL TEST METHOD

TEST METHOD DESCRIPTION THE BENCH BOARD WAS SUPPORTED WITH AIR COLUMNS AND EXCITED WITH A MECHANICAL SHAKER. VIBRATION DISPLACEMENT WAS MONITORED WITH A VIBRATION PICKUP.



TEST INSTRUMENTATION

GENERAL RADIO VIBRATION PICKUP-TYPE 1553-A

FIRESTONE AIR COLUMNS.

BODINE VARIABLE SPEED D.C. MOTOR

IV VIBRATION TESTS

RESONANCE VIBRATION TEST

7-MINUTE SWEEP AMPLITUDE (HORIZONTAL - 2 AXES) 0-30.6 HZ
(VERTICAL) ______

OBSERVED RESONANCES (HORIZONTAL - AXIS 1) 12.6
(HORIZONTAL - AXIS 2) ______
(VERTICAL) ______

METHOD OF OBSERVATION GENERAL RADIO VIBRATION PICK-UP

2-MINUTE RESONANT TEST:

RESONANT FREQUENCY	AMPLITUDE AND PARAMETER	AXIS
N/A		

VIBRATION ENDURANCE TEST

SWEEP ACCELERATION AMPLITUDE (5-33hz)	AXIS
N/A	

MAXIMUM ACCELERATION AT 33hz (W/O MALFUNCTION) N/A

V RESULTS

OBSERVATIONS MADE DURING VIBRATION:

OPERATION AT RESONANT FREQUENCIES (IF ANY) LARGEST AMPLIFICATION FACTOR: AT 12.6 HZ - 2.6

OPERATION DURING ENDURANCE SWEEP N/A

LIMITS TO MAXIMUM ACCELERATION AT 33hz N/A

GENERAL OBSERVATIONS (INCLUDING MODIFICATIONS NECESSARY - IF ANY)

THE BENCH AND UPPER VERTICAL BOARD PORTION OF THE PANEL RESULTED IN AN AMPLIFICATION OF GREATER THAN ONE. LIKEWISE AN INPUT OF 1.5 g's COULD RESULT IN AN ACCELERATION OF 3.9 g's ON THE BENCH PORTION OF THE PANEL. STIFFENING OF THESE AREAS MAY BE REQUIRED IF THE DEVICES MOUNTED IN THESE AREAS WILL NOT TOLERATE THIS ACCELERATION LEVEL. THE SBM SWITCHES AND THE CONTROLLER MOUNTED ON THIS PARTICULAR PANEL WILL SUCCESSFULLY OPERATE, HOWEVER, AT THAT AMPLIFIED ACCELERATION LEVEL.

SIGNED R. E. GREEN

POSITION ENG. TECH.

DATE 12-10-70

$$Ag = .051 \times D.A. \times f^2$$

Ag = ACCELERATION
D.A. = DOUBLE AMPLITUDE
F = FREQUENCY

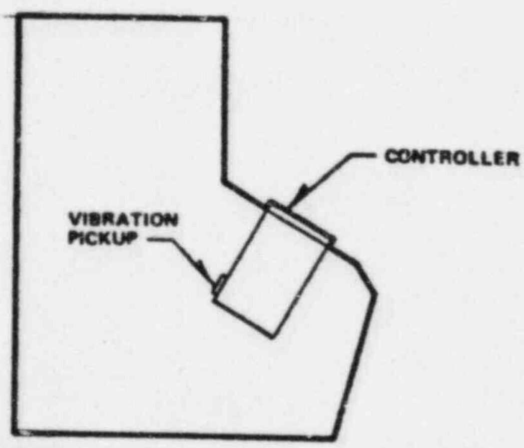
ACCEL LOCATION	1	2	3	4	5	6	7	8	9	10	11	12
FREQ / DISP	5 / 15	5 / 2	5 / 3	5 / 18	5 / 14	5 / 13	5 / 20	5 / 19	5 / 16	5 / 14	5 / 9	5 / 12
g's (MAX)	.019	.002	.003	.022	.017	.016	.025	.022	.020	.017	.013	.015
FREQ / DISP	6.2 / 20	8	2	27	24	27	27	24	21	20	19	26
g's	.038	.015	.004	.055	.049	.055	.055	.049	.041	.038	.037	.051
FREQ / DISP	10.1 / 18	8	3	17	15	21	21	19	16	12	14	20
g's	.095	.041	.015	.087	.090	.18	.18	.11	.084	.063	.073	.12
FREQ / DISP	12.6 / 14	7	3	10	12	21	20	17	13	4	10	18
g's	.11	.051	.024	.07	.10	.18	.17	.14	.11	.032	.07	.15
FREQ / DISP	15.8 / 16	10	6	3	7	22	22	19	17	15	5	19
g's	.20	.12	.07	.038	.08	.27	.27	.24	.21	.18	.06	.24
FREQ / DISP	19.3 / 18	12	11	50	22	28	30	29	29	77	21	35
g's	.35	.25	.20	1.0	.45	.55	.6	.59	.59	1.65	.45	.7
FREQ / DISP	20.5 / 22	9	9	80	45	38	46	44	39	120	35	42
g's	.50	.20	.20	2.0	1.0	.75	1.0	.95	.80	2.7	.70	.90
FREQ / DISP	20.8 / 27	13	8	100	70	47	58	58	52	180	70	55
g's	.65	.27	.17	2.4	1.9	1.1	1.4	1.4	1.30	4.3	1.6	1.35
FREQ / DISP	21.2 / 17	21	15	80	48	23	27	27	27	110	50	30
g's	.45	.6	.40	2.0	1.2	.6	.7	.7	.7	3.1	1.3	.8

ACCEL LOCATION	13	14	15	16	17	18	19	20	21	22		BASE INPUT
FREQ / DISP	5/21	/19	/16	/12	/4	/3	/4	/8	/20	/5	/	/30
g's	.026	.025	.020	.015	.013	.013	.013	.014	.025	.013		.038
FREQ / DISP	6.2/26	/22	/17	/20	/13	/6	/4	/2	/20	/7	/	6.2/31
g's	.055	.043	.033	.038	.025	011	.007	.003	.038	.013		.061
FREQ / DISP	10.1/20	/17	/15	/15	/11	/7	/4	/2	/13	/6	/	/18
g's	.12	.094	.078	.078	.055	.036	.021	.010	.067	.031		.095
FREQ / DISP	12.6/18	/14	/12	/14	/10	/8	/5	/3	/11	/7	/	/8
g's	.14	.11	.10	.11	.07	.065	.040	.024	.08	.06		.065
FREQ / DISP	15.8/21	/18	/14	/14	/12	/11	/10	/9	/11	/10	/	/14
g's	.27	.22	.18	.18	.15	.14	.12	.11	.14	.12		.18
FREQ / DISP	19.3/55	/55	/32	/27	/21	/25	/26	/26	/17	/25	/	/72
g's	1.1	1.1	.65	.51	.45	.50	.50	.51	.32	.50		1.45
FREQ / DISP	20.5/65	/65	/40	/33	/17	/30	/24	/26	/17	/30	/	/110
g's	1.4	1.4	.80	.65	.40	.60	.55	.55	.40	.60		2.5
FREQ / DISP	20.8/100	/100	/53	/40	/19	/27	/*	/*	/40	/42	/	/160
g's	2.4	2.4	1.30	0.9	.45	.65	-	-	0.9	1.0		3.75
FREQ / DISP	21.2/50	/40	/30	/16	/22	/11	/12	/19	/7	/21	/	/85
g's	1.35	1.1	0.8	.42	0.6	0.27	0.28	.5	.18	.6		2.1

* #19 & 20 POSITION AT 20.8 HZ NOT TAKEN DUE TO FAILURE OF DRIVE BELT. 1/3RD LESS WEIGHT WAS USED TO CONTINUE TEST.

ACCEL LOCATION	1	2	3	4	5	6	7	8	9	10	11	12
FREQ / DISP	30.6 / 15	/ 70	/ 15	/ 65	/ 50	/ 19	/ 19	/ 20	/ 14	/ 110	/ 55	/ 25
g's	0.7	1.25	0.7	3.2	2.5	0.9	0.9	1.0	0.7	5.5	2.8	1.2

ACCEL LOCATION	13	14	15	16	17	18	19	20	21	22		BASE INPUT
FREQ / DISP	30.6 / 32	/ 30	/ 14	/ 11	/ 22	/ 20	/ 19	/ 15	/ 13	/ 7	/	/ 95
g's	1.6	2.0	0.70	0.55	1.4	1.0	0.90	0.75	0.7	0.35		4.7



FREQ / DISP	30.6 / 40
g's	2.0

Appendix E
Sample Seismic Test Results - Panel

Appendix E

Sample Seismic Test Results - Panel

THIS DOCUMENT OVERALL REVISION NUMBER

SHEET REVISION STATUS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ECN NO.	N/A	N/A														
ISSUE DATE	[illegible]	[illegible]														
1	0	1														
2	0	1														
3	0	1														
4	0	1														
5	0	1														
6	0	1														
7	0	1														
8	0	1														
9		1														
10		1														
11		1														
12		1														

THE FOLLOWING DATA SHEET IS INTENDED TO RECORD THE RESULTS OBTAINED FROM VIBRATION TESTS PERFORMED IN ACCORDANCE WITH SEISMIC QUALIFICATION PROCEDURE 225A5766.

EQUIPMENT IDENTIFICATION

DRAWING NO. ____________ NAME START UP CABINET

DESCRIPTION 4 BOX START UP CABINET CONTAINING INMAC EQUIPMENT

TEST FACILITY

LOCATION PHILCO FORD, PALO ALTO DATE 7-22-71

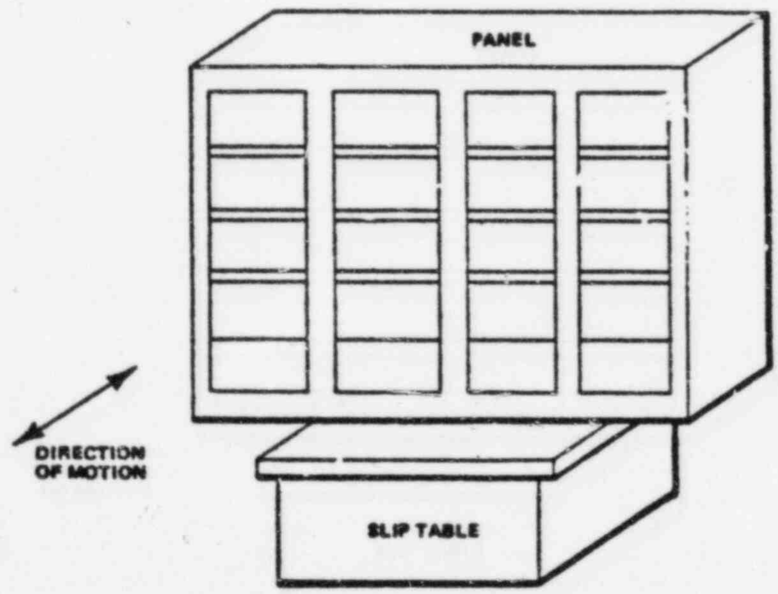
SHAKER TYPE AND CAPACITY LING A249 ELECTRODYNAM'

EQUIPMENT OPERATING CONFIGURATION

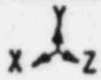
DESCRIPTION

THE 912 PANEL WAS BOLTED TO THE TEAM BEARING SUPPORTED SLIP TABLE AND MONITORED AT 14 LOCATIONS ACROSS THE FRONT OF THE PANEL. THE PANEL WAS VIBRATED IN THE FRONT-TO-REAR DIRECTION ONLY DUE TO ITS SIZE AND WEIGHT. PAST TESTS HAVE SHOWN THIS AXIS TO BE THE MOST CRITICAL AND INDICATIVE OF SUCCESS OR FAILURE OF PANEL.

SEE ATTACHED FIGURE ON PAGE B
FOR ACCELEROMETER LOCATIONS



CONNECTION DIAGRAM OR SKETCH



TEST INSTRUMENTATION IDENTIFICATION

INSTRUMENT TYPE	MODEL NO. AND MFR.	SERIAL NO.
ELECTRO DYNAMIC SHAKER	LING A-249	
ACCELEROMETERS	ENDEVCO	
CHARGE SENSITIVE AMPS	ENDEVCO	
STRIP RECORDER	HONEYWELL	

VIBRATION TEST DATA

OBSERVED RESONANT FREQUENCIES

HORIZONTAL X AXIS 9, 12, 15, 26

HORIZONTAL Z AXIS

VERTICAL Y AXIS

VIBRATION TEST DATA (CONTINUED)

MODES OF VIBRATION AT RESONANCE

THE HIGH TRANSMISSABILITIES OF PARTS OF THE PANEL RESULTED IN SUCH SEVERE RESPONSES THAT THE INPUT SWEEP WAS LIMITED TO LOW LEVEL INPUTS.

PERFORMANCE OF VIBRATION ENDURANCE TEST YES [ ] NO [X]

ENDURANCE TEST NOT REQUIRED FOR PANELS, VIBRATIONS AT RESONANCE IS TOO SEVERE IN ANY CASE.

MALFUNCTION LIMIT TEST

OBSERVED MALFUNCTION LIMIT NA

FACTORS LIMITING OPERATION NA

LOW FREQUENCY ANALYSIS

IT IS HIGHLY IMPROBABLE FOR A RESONANCE TO EXIST BELOW 5Hz (ONCE MODULE RESTRAINTS ARE ADDED) DUE TO THE SHAPE FACTOR AND WEIGHT OF THE PANEL. OTHER LARGER AND HEAVIER INSTRUMENT RACKS TESTED TYPICALLY HAVE NO RESONANCE UNTIL ABOVE 12 Hz.

STATIC ANALYSIS

SEE 174B9011

SUMMARY OF RESULTS

GENERAL OBSERVATIONS (INCLUDING MODIFICATIONS NECESSARY - IF ANY)

SEVERE AMPLIFICATION FACTORS OF OVER 20 OCCURRED AT 15 HERTZ. THE INMAC DRAWER SCREW-LATCHES LOOSENED DURING TEST DUE TO FLEXURE BENDING OF THE DRAWER FRONT PANELS. THE ARM GEMAC CASE DEVELOPED VIOLENT UP AND DOWN MOTION AT THE CANTILEVERED REAR OF UNIT WHICH CAUSED FRONT PANEL DISPLACEMENT IN THE CENTER OF ALMOST AN INCH. IN SPITE OF THE SEVERITY OF THE RESPONSES NOTED DURING THE TEST, HOWEVER, DUE TO THE CAPABILITIES OF THE INDIVIDUAL ESSENTIAL INSTRUMENTS THE PANEL IS SATISFACTORY FOR SERVICE WITH A BASE INPUT ACCELERATION OF 1.5 g's. THE ADDITION OF A FEW MINOR MODIFICATIONS TOO WOULD FURTHER IMPROVE THE PANEL CAPABILITY. SEE THE ATTACHED ANALYSIS FOR FURTHER DETAILS.

CONCLUSIONS

ANALYSIS OF RESULTS

THE CONTINUOUS SINUSOIDAL INPUT APPLIED TO THE PANEL BASE RESULTED IN WORST-CASE RESPONSE TRANSMISSABILITIES AT RESONANCE (15Hz) AT THE INPUTS OF THE THREE ESSENTIAL TYPE INSTRUMENTS CONTAINED IN THE PANEL AS SHOWN IN THE FIRST COLUMN OF THE FOLLOWING TABLE (SEE PAGE 6):

INSTRUMENT	INSTRUMENT INPUT RESULTING TRANSMISSABILITIES	EQUIVALENT RESPONSE AT 1.5g INPUT	INSTRUMENT MALFUNCTION LIMIT	SINE-BEAT RESPONSE DAMPING=2%
1. TRIP AUXILIARY RELAY PANEL	>20***	>30 g's	* 17 g's	>15 g's
2. IRM(MSV) DRAWER	6	9	** 5.0	4.5
3. LOG. RAD. MONITOR	1.5	2.3	† 3.0	1.2

WITH AN INPUT ACCELERATION AT THE BASE OF 1.5 g's THEN THE RESPONSE WOULD BE AS SHOWN IN COLUMN 2. VIBRATION TESTS PERFORMED INDIVIDUALLY ON THE INSTRUMENTS RESULTED IN MALFUNCTION LIMITS AS SHOWN IN COLUMN 3. (SEE FOOTNOTES FOR DETAILS REFERENCES).

IF A SINE-BEAT 1.5g INPUT USING 10 CYCLES/BEAT AND ASSUMING A DAMPING FACTOR OF 2% (REASONABLE FOR WELDED STEEL - SEE AEC DOCUMENT TID7024 P.148) WERE APPLIED IN PLACE OF THE SINUSOIDAL STEADY-STATE INPUT THEN THE RESPONSES WOULD BE AS SHOWN IN COLUMN 4. (SEE CURVES OF P.7 AND USE 2% DAMPING SO THAT MULTIPLICATION FACTOR BETWEEN STEADY-STATE AND 10 CYCLES/BEAT IS APPROXIMATELY 2). THE RESULTS SHOW THAT THE EQUIVALENT SINE-BEAT INPUT WOULD ALLOW SATISFACTORY EQUIPMENT OPERATION.

FROM THE STANDPOINT OF PANEL RESPONSE THE FOREGOING ARGUMENT SHOWS THE PANEL TO BE QUALIFIED TO OPERATE AT 1.36 g's INPUT.
MODIFICATIONS, HOWEVER, WOULD MAKE THE MARGIN OF CONSERVATIVENESS MORE ACCEPTABLE:

1. ADD BRACE ON REAR OF ARM GEMAC CASE TO ELIMINATE CANTILEVER ACTION.
2. ADD STIFFENER BEHIND EACH INMAC DRAWER FRONT PANEL TO REDUCE BENDING AND THEREFORE PREVENT LATCH LOOSENING.
3. ADD RESILIENT MATERIAL BEHIND TRIP AUXILIARY PANEL DOOR TO HOLD IN THE RELAYS.

* -
** - } SEE SHEET 5
† -
*** -

SINE-BEAT TESTING IS AN ACCEPTABLE APPROACH IN ACCORDANCE WITH IEEE JCNPS GUIDE #344, AND THE ABOVE ANALYSIS IS CONSERVATIVE IN THAT SINUSOIDAL LEVELS WERE ASSUMED FOR THE MALFUNCTION LIMIT OF THE INSTRUMENTATION.

THE APPARENT TRANSMISSIBILITY OF 20 AS SHOWN BY SENSOR #14 WAS MOST LIKELY DUE TO A LOOSE DOOR LATCH. NOTE THAT SENSOR #1, AT THE SAME ELEVATION SHOWS A TRANSMISSIBILITY OF ONLY 2. THE SAME IS ALSO TRUE FOR SENSORS #2, 4 AND 11.

---

* SEE 225A6605. IT IS RECOMMENDED THAT A RESILIENT PAD BE ADDED BETWEEN THE RELAY PANEL DOOR AND THE RELAYS TO KEEP THE RELAYS IN THE SOCKETS.

** TESTED MALFUNCTION LEVEL FOR INSTRUMENT AT ITS RESONANCE. EXTREME FLEXURING OF FRONT PANEL OCCURRED WHICH BENT AND LOOSENED HOLD-IN CLAMPS FOR DRAWER.

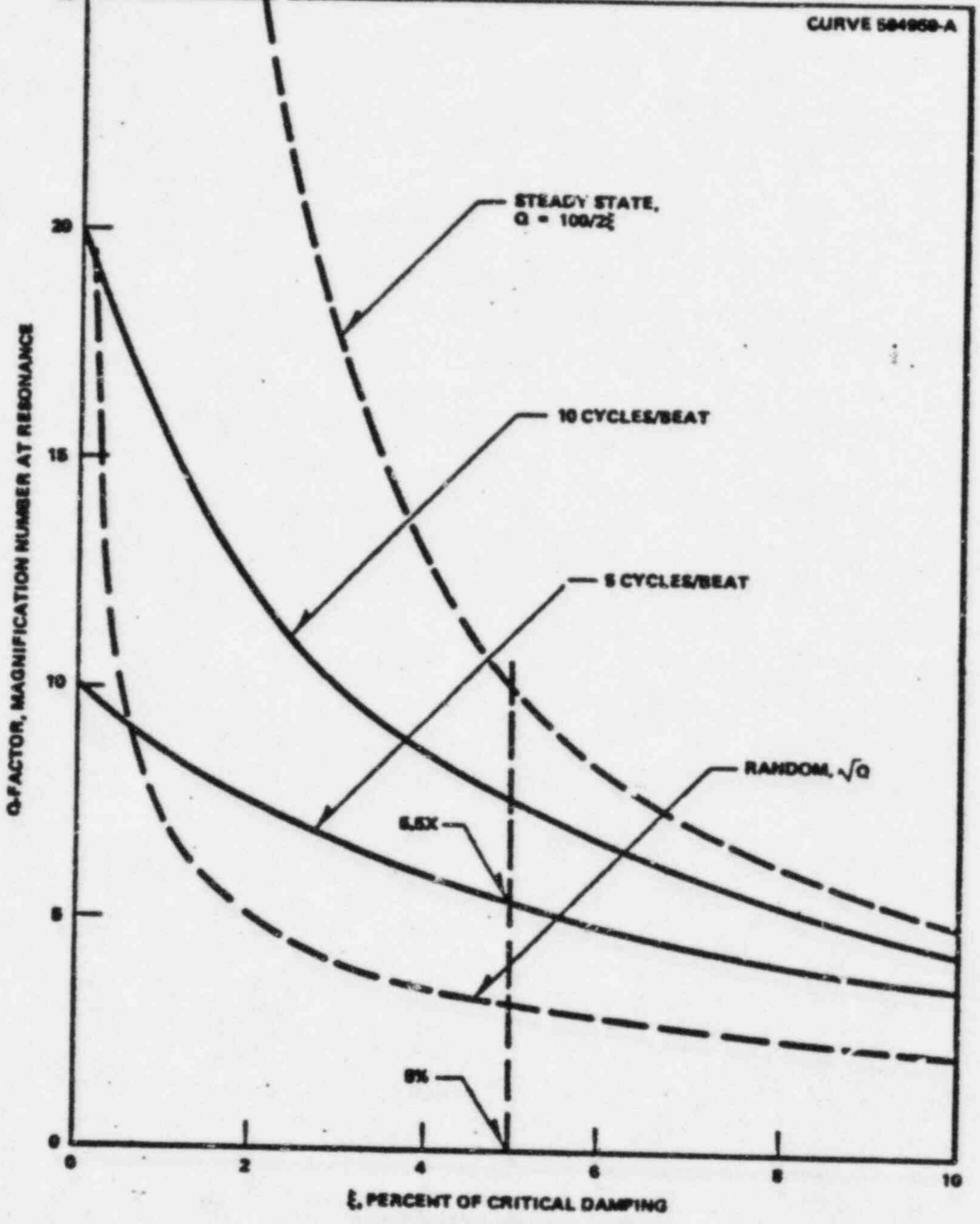
† SEE 225A6609.

*** THE READOUT RECORDER SATURATED AT 10 G'S WITH 0.5 G INPUT. WITH AN ASSUMED DAMPING OF 2 PERCENT THE MAXIMUM POSSIBLE RESPONSE IS 12.5 G'S OR A TRANSMISSIBILITY OF 25.

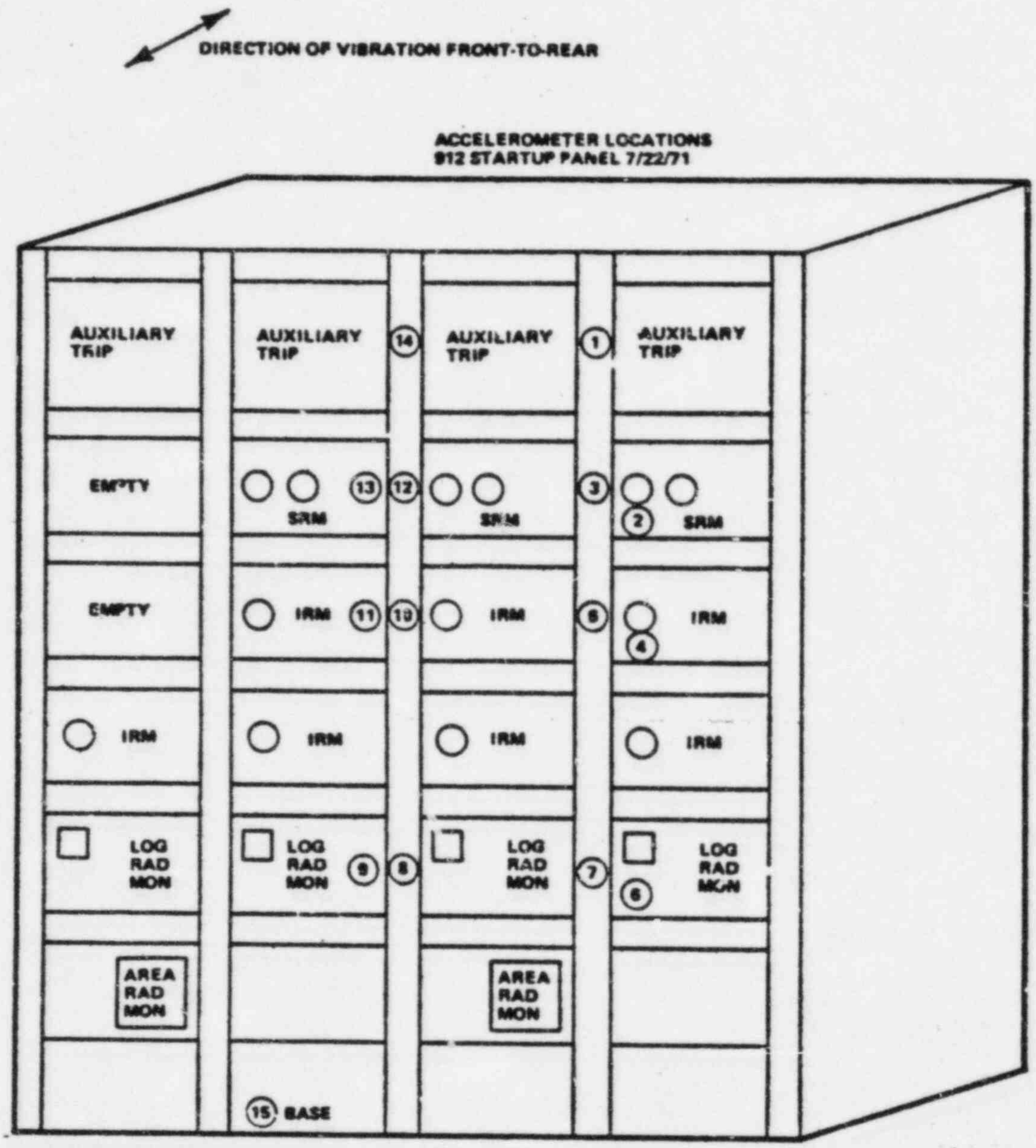
TRANSMISSABILITY

FREQUENCY	Accelerometer Locations 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
5Hz (0.5g)	1.0	1.5	1.0	1.0	1.0	1.0	1.2	1.0	0.4	1.0	1.2	1.2	0.4	1.2	1.0
9Hz (0.5g)	1.2	3.0	1.2	2.0	1.2	1.5	1.2	1.0	0.4	1.0	1.2	1.0	0.4	2.0	1.0
12Hz (0.5g)	1.5	7.0	1.5	4.0	1.2	1.5	1.0	1.0	0.4	1.0	1.4	1.0	0.4	2.0	1.0
15Hz (0.5g)	2.0	20.0	3.0	16.0	1.5	2.0	1.5	1.2	0.4	6.0	20.0	10.0	0.4	>20.0	1.0
13Hz (0.25g)	1.5	6.0	1.5	3.0	1.0	1.5	1.0	1.0	0.5	1.0	2.0	1.0	0.5	1.6	1.0
17Hz (0.25g)	2.0	7.0	1.5	4.0	1.5	1.5	1.0	1.0	0.5	1.5	3.2	2.0	0.5	6.0	1.0
26Hz (0.25g)	0.8	1.0	0.8	0.8	0.6	1.0	0.5	0.5	0.5	0.5	2.0	0.8	0.5	4.0	1.0
5Hz (0.25g)	1.0	1.5	1.0	1.0	1.0	1.0	1.0	0.5	1.0	1.0	1.0	1.0	0.5	1.0	1.0
7Hz (0.25g)	1.0	4.0	1.0	1.5	1.0	1.0	1.0	1.0	0.5	1.0	1.0	1.0	0.5	1.0	1.0
10Hz (0.25g)	1.5	4.1	3.0	1.5	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	1.5	1.0

TRANSMISSABILITY VS FREQUENCY AT DESIGNATED ACCELEROMETER LOCATIONS



COMPARISON OF VIBRATION MAGNIFICATIONS AT RESONANCE



ACCELEROMETER LOCATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
TRANSMISSIBILITIES AT 15 Hz	2.0	20	3.0	16	1.5	2.0	1.5	1.2	0.4	6.0	20	10	0.4	>20	[illegible]
RESPONSES WITH 1.5 g BASE INPUT	3g's	30	4.5	24	2.3	3.0	2.0	1.8	0.6	9.0	30	15	0.6	>30	[illegible]

TABLE OF TRANSMISSIBILITIFS AND ACCELERATION AT WORST-CASE FREQUENCY

.5g SCAN

PANEL 912 DATE 7/22/71

DWG # DATA BY William F. Sobecki[?]
Bob Grellen[?]

ACCELEROMETER LOCATIONS

	1	2	3	4	5	6	7	8	9	10	11	12	13
FREQ	5 →												→
ACCEL	.50	.75	.5	→	→	→	.6	.5	.125	.5	.6	.6	.125

	14	15
FREQ	5 →	
ACCEL	.60	.5

	1	2	3	4	5	6	7	8	9	10	11	12	13
FREQ	9 →												→
ACCEL	.60	1.5	.6	1.0	.6	.75	.6	.5	.125	.5	.6	.5	.125

	14	15
FREQ	9 →	
ACCEL	1	.5

	1	2	3	4	5	6	7	8	9	10	11	12	13
FREQ	12 →												→
ACCEL	.75	3.5	.75	2.0	.6	.75	.5	.5	.125	.5	.7	.5	.125

	14	15
FREQ	12 →	
ACCEL	1.0	.5

#15 input

.5g SCAN

PANEL 9/2 DATE 7/22/71

DWG # ____________ DATA BY William H. Dudley[illegible]
Bob Girch

ACCELEROMETER LOCATIONS

	1	2	3	4	5	6	7	8	9	10	11	12	13
FREQ	15	→											→
ACCEL	1.0	10.0	1.5	8.0	.75	1.0	.75	.6	.125	3.0	10	5	.125

	14	15											
FREQ	15	→											
ACCEL	GREATER THAN 10	.5											

FREQ													
ACCEL													

FREQ													
ACCEL													

FREQ													
ACCEL													

FREQ													
ACCEL													

#15 input

.25g SCAN

PANEL 912 DATE 7/22/71

DWG #. ________ DATA BY [illegible signature]
Bob Green

ACCELEROMETER LOCATIONS

	1	2	3	4	5	6	7	8	9	10	11	12	13
FREQ	13	→											→
ACCEL	.375	1.5	.375	.75	.25	.375	.25	.25	.125	.25	.50	.25	.125

	14	15											
FREQ	13	→											
ACCEL	.40	.25											

	1	2	3	4	5	6	7	8	9	10	11	12	13
FREQ	17	→											→
ACCEL	.50	1.75	.375	1.0	.375	.375	.25	.25	.125	.375	.80	.50	.125

	14	15											
FREQ	17	→											
ACCEL	1.25	.25											

	1	2	3	4	5	6	7	8	9	10	11	12	13
FREQ	26	→											→
ACCEL	.20	.25	.20	.20	.15	.25	.125	.125	.125	.125	.75	.20	.125

	14	15											
FREQ	26	→											
ACCEL	1.0	.25											

#15 - INPUT

.25g SCAN

PANEL 9/2 DATE 7/22/71

DWG #

DATA BY William F Soluikal
Bob Green

ACCELEROMETER LOCATIONS

	1	2	3	4	5	6	7	8	9	10	11	12	13
FREQ	5 →												
ACCEL	.25	.375	.25 →						.125	.25 →			.125

	14	15
FREQ	5 →	
ACCEL	.25	.25

	1	2	3	4	5	6	7	8	9	10	11	12	13
FREQ	7 →												
ACCEL	.25	1.0	.25	.375	.25 →				.125	.25 →			.125

	14	15
FREQ	7 →	
ACCEL	.25	.25

	1	2	3	4	5	6	7	8	9	10	11	12	13
FREQ	10 →												
ACCEL	.375	1.25	.375	.75	.375	.375	.25	.25	.125	.25 →			.125

	14	15
FREQ	10 →	
ACCEL	.375	.25

#15 - INPUT

END
1 OF 1