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Applicability of the Generic Equipment Ruggedness Spectra (GERS) for Internationally Manufactured Equipment

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PRODUCT DESCRIPTION

The Generic Equipment Ruggedness Spectra (GERS) provides utilities with seismic capacities of equipment needed for safe shutdown of a nuclear power plant. GERS was applied directly in the resolution of Nuclear Regulatory Commission Unresolved Safety Issue (USI) A-46, "Seismic Qualification of Equipment in Operating Nuclear Plants" and in performance of plant seismic margin evaluations. This report documents the results of an EPRI study to determine the applicability of GERS to internationally manufactured equipment.

Results & Findings

With respect to the application of seismic experience internationally, this study concludes that nuclear plant equipment manufactured outside of the United States is as seismically rugged as equipment manufactured within the United States. Based on the classes of equipment reviewed in this study, there exists no evidence that the seismic capacity of equipment changes with the origin of either the testing or the manufacture of the equipment.

Challenges & Objective(s)

The test experience data has been sorted into classes of equipment and the average test response for each has been generated in the form of a GERS, which can be used to determine the seismic capacity of a component in that GERS class. While the earthquake experience database includes a wide variety of manufacturers, with many equipment items produced internationally, the test experience data was almost exclusively represented by equipment manufactured within the United States. The international members of the Seismic Qualification Utility Group (SQUG) requested that a study be conducted to evaluate representative equipment experience data to verify whether there are any fundamental differences between U.S. and international designs that could change the capacity levels generated from the test data and documented in GERS equipment classes.

Applications, Values & Use

Worldwide standards for the construction of specific types of electrical and mechanical equipment have a high degree of consistency with respect to the seismic capacity of components. Such knowledge provides a powerful tool for assessing seismic capabilities of equipment in operating nuclear plants internationally.

EPRI Perspective

The SQUG methods for use of earthquake and test experience data for seismic qualification of equipment have been successful not only in resolving USI A-46, but also in qualifying new and replacement equipment and parts for the life of A-46 plants. This study extends SQUG data obtained on U.S.-manufactured equipment to nuclear power plant equipment manufactured internationally. The study, in turn, extends the application of SQUG seismic experience methods to international equipment and confirms the applicability of those methods in countries outside the United States.

Approach

SQUG provided test data from the United Kingdom, France, Sweden, and Belgium, with equipment manufacturers, model numbers, and countries of origin cited anonymously in most cases. This EPRI study includes international test data comparisons for the following GERS classes of nuclear power plant equipment:

- Motor Control Centers
- Low Voltage Switchgear
- Medium Voltage Switchgear
- Transformers
- Battery Racks
- Battery Chargers
- Uninterruptible Power Supplies and Inverters
- Relays

In addition, investigators collected international test data for Control and Instrumentation Panels and computed an effective GERS level for this class of equipment.

Keywords

Generic Equipment Ruggedness Spectra
GERS
Unresolved Safety Issue
USI A-46
Seismic Qualification
Seismic Capabilities
Seismic Qualification Utility Group
SQUG

ABSTRACT

The use of seismic experience data has proven to be a significant enhancement to the field of seismic qualification of equipment. The Seismic Qualification Utility Group (SQUG) has sponsored a significant research effort to develop methods for using seismic experience data. These new methods offer a demonstrated cost-benefit and have been accepted by the United States Nuclear Regulatory Commission (USNRC), the Department of Energy (DOE), and several international regulatory agencies.

Seismic experience data can be grouped into two categories: 1) earthquake experience data collected from worldwide strong motion earthquakes, and 2) shake table test data on nuclear power plant equipment. The test experience data is sorted into classes of equipment and the average test response for each has been generated in the form of a Generic Equipment Ruggedness Spectra (GERS), which can be used to determine the seismic capacity of a component within that GERS class. While the earthquake experience database includes a wide variety of manufacturers, with many equipment items produced internationally, the test experience data was almost exclusively represented by equipment manufactured within the United States. SQUG international members have used the SQUG seismic experience methods in a similar fashion to their U.S. counterparts—to qualify nuclear plant equipment in their host countries. The international members of SQUG requested that a study be conducted to evaluate representative equipment experience data in order to determine whether there are any fundamental differences between U.S. and international designs. They were concerned that such differences could change the capacity levels generated from the test data and documented in GERS equipment classes.

This report documents the results of that EPRI study, which demonstrates that the seismic test levels associated with the international test data are quite similar to those from the original GERS program. No appreciable differences in international seismic capacities or class restrictions were discovered based on the data reviewed within this project. This study, in turn, extends the application of SQUG seismic experience methods to international equipment and confirms the applicability of those methods in countries outside the United States.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1
INTRODUCTION

In 1980, the U. S. Nuclear Regulatory Commission (USNRC) issued an unresolved safety issue (USI A-46) relative to the seismic adequacy of equipment in operating nuclear power plants. In response, the Seismic Qualification Utility Group (SQUG) has sponsored significant research efforts in the development of methods to use seismic experience data to demonstrate seismic adequacy and seismic qualification. These new methods have been demonstrated to have a significant cost-benefit and have been accepted by the United States Nuclear Regulatory Commission (USNRC), the Department of Energy (DOE) and several international regulatory agencies. Seismic experience data can be grouped into two categories: 1) earthquake experience data collected from worldwide strong motion earthquakes, and 2) shake table test data on nuclear power plant equipment. The earthquake experience data was demonstrated to be applicable up to a seismic response level (called the Reference Spectrum) that characterizes the approximate median response of the ground motions of four key earthquakes from which a significant part of the data originates. The test experience data is accumulated into classes of equipment and the average test response for each has been generated in the form of a Generic Equipment Response Spectra (GERS) which can be used for the seismic capacity of a component within that GERS class. While the earthquake experience database includes a wide variety of manufacturers, including many equipment items made internationally, the test experience data was almost exclusively represented by equipment manufactured within the United States.

The SQUG membership has included 12 international members over the course of its history. These international members have used the SQUG seismic experience methodology in a similar fashion to their U.S. counterparts; i.e., to qualify nuclear plant equipment in their host countries. One of the key comments that have been reported from international nuclear regulators relative to the use of the SQUG methodology relates to the validity of using experience data for equipment that is not manufactured within the United States. They have noted the lack of sufficient inclusion of non-U.S. equipment within the experience data and questioned the applicability of SQUG experience-based methods. The international members of SQUG requested that a study be conducted to evaluate representative equipment experience data to verify whether there exist any fundamental differences between U.S. and international designs that could change the capacity levels that have been generated from the test data and documented in GERS equipment classes. The purpose of this report is to document the results of that study.

The study includes international test data comparisons to the following GERS classes of equipment:

- Motor Control Centers
- Low Voltage Switchgear
- Medium Voltage Switchgear

- Transformers
- Battery Racks
- Battery Chargers
- UPS' and Inverters
- Relays

In addition, international test data was collected for Control and Instrumentation Panels (GERS are not available for this class of equipment) and an effective GERS level is computed for this class of equipment.

Contents of the Report

This report presents the results of a study of existing test reports for internationally manufactured and tested equipment, and measures those results against existing GERS.

Chapter 2 contains background material on the GERS program developed by EPRI for SQUG. Chapter 3 contains a summary of the test data on internationally manufactured equipment that were included within this study. Chapter 4 contains a comparison of this international test data to the existing GERS levels for the associated equipment classes. Chapter 5 documents a study on Control and Instrumentation Panels using data from the UK. Chapter 6 documents relay fragility test results for a large number of Swedish relays. Chapter 7 provides the conclusions for this study.

2
BACKGROUND ON GERS

The GERS program had the purpose of demonstrating the generic seismic adequacy of typical classes of nuclear power plant equipment by means of collecting and evaluating existing seismic qualification test data. These data were then used to construct "ruggedness" spectra below which equipment in operating plants designed to earlier earthquake criteria would be generically adequate. Reference 2 contains the methodology for the collection and evaluation of data which were used to construct the GERS for each equipment class considered. Associated with each GERS are inclusion rules and cautions, and checklists for field screening of in-place equipment for GERS applicability. A GERS provides a measure of equipment seismic resistance based on available test data. As such, a GERS is also appropriate for use in seismic margin and seismic fragility calculations.

GERS History

In 1984, the Electric Power Research Institute (EPRI) initiated a project to collect and evaluate test data collected as part of seismic qualification of nuclear power plant equipment. The principal goal of the project was to establish the generic ruggedness level for each equipment class for which data could be obtained. The program deliverables are 1) seismic ruggedness spectra for each identified equipment class, 2) inclusion rules and cautions for each equipment class, and 3) field checklists for screening of equipment for class applicability.

Data for a given class of equipment are evaluated in the following manner. The database is accessed to aggregate data corresponding to specific parameters of interest. The spectral data are standardized to 5% spectral damping, and the TRS are weighted according to whether they are biaxial or single-axis excitation and random or narrow-banded input motions. The similarity of the equipment represented by the test data is established and subclasses are defined, as required, which are sufficiently similar. The final step of the evaluation is to construct a Generic Equipment Ruggedness Spectra (GERS) for the specified subclass of equipment. The GERS is defined as the response to input motion at the base or support point for which equipment of a given class has been demonstrated, on the basis of test experience, to have sufficient ruggedness to perform as required.

Associated with each GERS are inclusion rules which define the characteristics of the equipment included in the class and covered by the GERS. In general, the inclusion rules will specify the characteristics (weight, size, etc.) of the equipment comprising the database and, perhaps, limitations on the manner in which the equipment is installed.

The following is a list of equipment classes for which data have been compiled by EPRI as a part of the GERS Program:

Electrical Equipment

Batteries on Racks*

Battery Chargers*

Contactors and Motor Starters*

Inverters*

Electrical Penetration Assemblies*

Distribution Panels* (Switchboards, Panelboards)

Motors

Motor Control Centers*

Manual Control Switches*

Transformers*

Switches*

Transmitters*

Switchgear*

Control Panels

Instrument Rack Components

Automatic Transfer Switches

Mechanical Equipment

Motor Valve Operators*

Air-Operated Valves*

Solenoid-Operated Valves*

Safety Relief Valves

Chillers

For equipment classes marked with an asterisk (*), GERS were developed from the collected test data. The remaining equipment classes (Control Panels, Instrument Rack Components, Automatic Transfer Switches, Safety Relief Valves and Chillers) had insufficient data to construct GERS. These remaining classes did not have extensive enough data for GERS construction, but data packaged have been documented and are used to support technical judgments that these components are substantially rugged when compared to typical seismic input motions.

The GERS developed to date have peak spectral amplitudes which are in the nominal range from 1.5g to 10g (when normalized to five percent spectral damping) for electrical equipment, and 9g to 20g for mechanical equipment. These ruggedness levels equal or exceed the amplitude of typical moderate earthquake floor spectra for many plants.

3
DISCUSSION OF INTERNATIONAL TEST DATA

This section discusses the sources from which the data for this study was obtained.

Test Data

A total of 23 seismic qualification tests were submitted to ARES Corporation by International SQUG members for inclusion in the study. All test specimens fall into the general category of electrical equipment. Table 3-1 lists the equipment tested, the test dates, and the number of axes utilized for each test. Because the range of dates extends from 1979 to 1993, the testing methods and standards to which the tests were conducted vary somewhat (as did the tests for the original GERS study). As such, depending on the vintage of the test, the number of axes along which the equipment was shaken varies between one and three axes. The specific equipment classes included in this report are listed below:

- Motor Control Centers
- Low Voltage Switchgear
- Medium Voltage Switchgear
- Transformers
- Batteries on Racks
- Battery Chargers
- Inverters

International test data for the equipment class of Control and Instrumentation Panels is also included within this report (Section 4). As noted in Section 2, SQUG does not presently recognize a GERS for the equipment class (it is treated as a "data set"), so the test results are presented separately.

Table 3-1
Equipment Surveyed

Component ID	Equipment Description	Test Date	Test Type	Damping Ratio (%)
MCC 1	415 V Four Column MCC	Mar 1985	Tri-Axial	5
MCC 2	415 V Three Column MCC	Oct 1982	Bi-Axial	5
MCC 3	Five Column Assembly & Three Column Assembly	Dec 1983	Tri-Axial	5
MCC 4	Three Column Alstom 380 Volt Type N680S	Dec 1981	Single Axis	5
LV Switchgear 1	415 V Switchgear	Dec 1989	Tri-Axial	5
LV Switchgear 2	415 V Switchgear	Dec 1989	Tri-Axial	5
LV Switchgear 3	380 V Alstom Switchgear Types N683S and N682S	Jul 1981	Single Axis	5
MV Switchgear 1	Medium Voltage Switchgear	Feb 1987	Tri-Axial	5
MV Switchgear 2	Medium Voltage Switchgear	Sep 1984	Bi-Axial	5
MV Switchgear 3	Medium Voltage Switchgear	May 1986	Tri-Axial	5
Transformer 1	1600kVA 3.3kV/433V Transformer	Oct 1986	Tri-Axial	5
Battery Rack 1	4 Tier Battery Stand Containing 32 Cells	Feb 1990	Tri-Axial	4
Battery Rack 2	3 Tier Battery Rack Containing 15 Cells	May 1995	Bi-Axial	5
Battery Charger 1	Three Unit Charger	Feb 1984	Tri-Axial	5
Battery Charger 2	Two Unit Charger	Feb 1990	Tri-Axial	5
Battery Charger 3	Two Unit Charger	Feb 1990	Tri-Axial	5
Battery Charger 4	Two Unit Charger	May 1979	Single Axis	4
UPS 1	110V DC Essential Inverter UPS	Oct 1983	Bi-Axial	5
UPS 2	110V DC Primary UPS System	Apr 1990	Tri-Axial	5
UPS 3	110V DC Secondary UPS System	May 1990	Tri-Axial	5
UPS 4	415V DC Essential UPS System	Sep 1983	Bi-Axial	5
UPS 5	110V DC Essential Inverter UPS	May 1993	Tri-Axial	5
Battery Rack 1	4 Tier Battery Stand Containing 32 Cells	Feb 1990	Tri-Axial	4

Adjustment of Damping Ratio

Although most tests are conducted using a damping ratio of 5%, some of the tests in the study used a damping ratio of 4%. In order to provide a standardized response level, those utilizing a 4% damping ratio were scaled to 5% using the conversion formula (square root of the damping ratio) referenced in the SQUG GERS Report. For tests that used 4% damping, the values presented in the Test Response Spectra (TRS) were scaled for 5% damping as follows.

$$\textbf{Scale factor} = \sqrt{\frac{4}{5}} = 0.89 \qquad \textbf{Equation 3-1}$$

Seismic Design of Tested Equipment

It should be noted that several of the equipment components from the UK included in this study had aspects specifically designed to withstand seismic loads. These areas are specifically defined in Section 4 of the report so that the TRS levels are not misinterpreted and used as capacity levels for a component without that associated upgrade. The electrical subcomponents were not upgraded, but some structural load path features such as the base framing were upgraded and thus, should not be considered to be commercial equipment.

Equipment Functionality

Functionality was monitored in all 21 tests within Table 3-1. None of the equipment suffered any structural integrity problems or electrical functionality problems at the seismic test levels included in this report. No relay chatter or equipment change of state was observed at the test levels.

4
GERS COMPARISON

The basic information for each equipment item is presented in Table 3-1. This section presents more detailed information for each test review and groups the results according to equipment class. The parameters that define the GERS equipment class are presented and compared to the parameters of the non-U.S. manufactured equipment. The data obtained from the international equipment tests were collected and overlaid on the GERS plot for each appropriate GERS equipment class. The results are presented in Figures 4-1 through 4-7.

Motor Control Centers

Four MCC tests were reviewed as part of the study. MCCs in the SQUG Equipment Class have the following inclusion parameters:

- Height up to 90 inches
- Width 20 to 24 inches
- Depth 18 to 24 inches
- Weight up to 800 lbs/section

The parameters of the international MCC's are listed in Table 4-1. Dimensional parameters and weights are noted to be similar to those that make up the U.S.-based test database.

Table 4-1
International Motor Control Center Properties

Equipment Description	Dimensions			Weight (lbs)	Country
	Height (in)	Width (in)	Depth (in)		
415 V Four Column MCC	94.5	96.1	59.1	3300	UK
415 V Three Column MCC	92.5	94.5	47.2	3740	UK
Five Column Assembly & Three Column Assembly	90.0	143.7 & 103.1	25.6	unknown	UK
Three Column Alstom 380 Volt Type N680S	92.5	102	26	3530	France

The plots for the four tests are presented in Figure 4-1. The results show that the spectra for all four of the internationally manufactured MCCs exceed the GERS, and it can be concluded that the MCC GERS are valid for non-U.S. manufactured equipment.

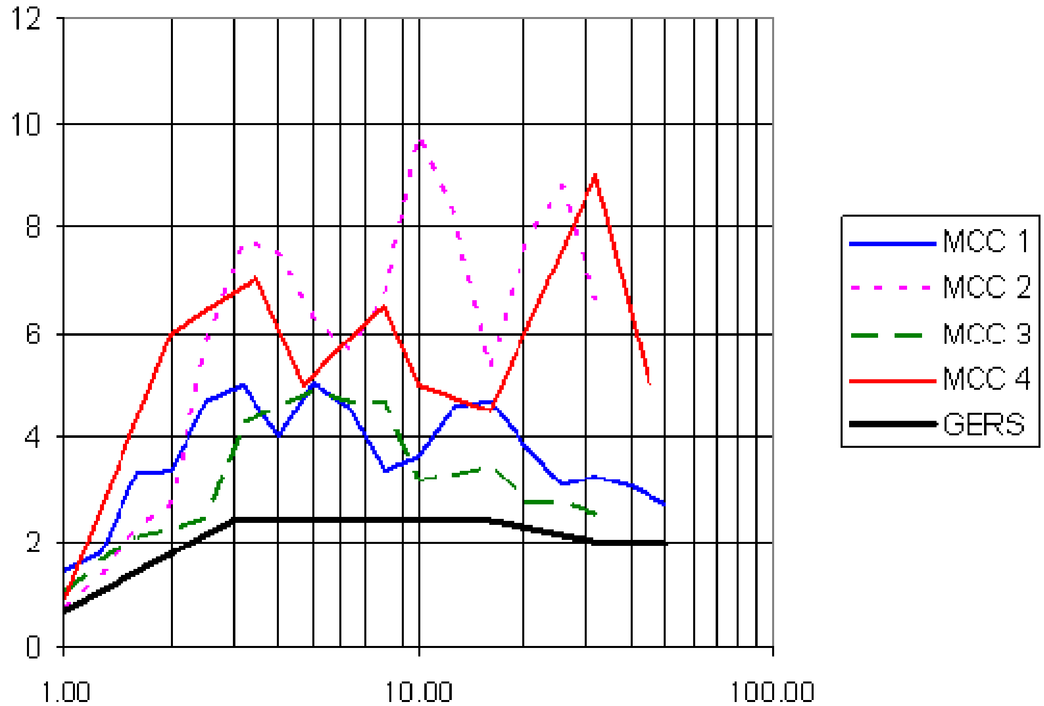

Figure 4-1
MCC Test Response Spectra

Low Voltage Switchgear

Three Low Voltage Switchgear tests were reviewed as part of the study. Low Voltage Switchgear in the SQUG Equipment Class is identified by the following parameters:

- Height up to 90 inches
- Width 20 to 30 inches (per section)
- Depth up to 60 inches
- Weight 2,000 lbs/section

The parameters of the international Low Voltage Switchgear are listed in Table 4-2. Dimensional parameters and weights are noted to be similar to those that make up the U.S.-based test database.

Table 4-2
International Low Voltage Switchgear Properties

Equipment Description	Dimensions			Weight (lbs)	Country
	Height (in)	Width (in)	Depth (in)		
415 V Switchgear	102.4	76.8	59.1	3850	UK
415 V Switchgear	102.4	76.8	59.1	3850	UK
380 V Alstom Switchgear Types N683S and N682S	92.5	102.4	25.6	3530	France

The plots for three tests of low voltage switchgear units are presented in Figure 4-2. The results show that all three of the internationally manufactured switchgear units exceed the GERS, and it can be concluded that the Low Voltage Switchgear GERS are valid for non-U.S. manufactured equipment.

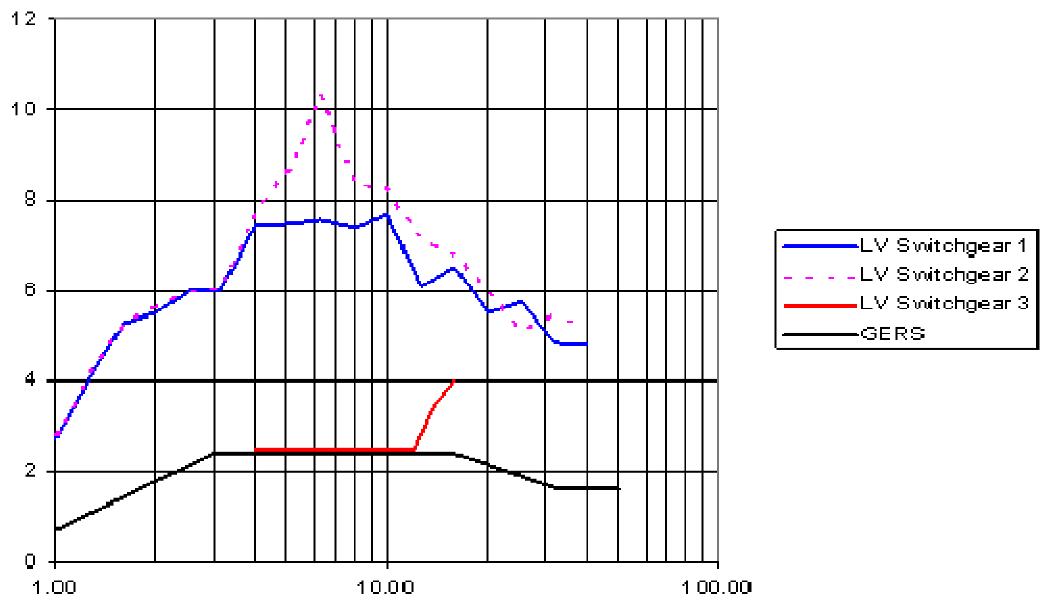

Figure 4-2
Low Voltage Switchgear Test Response Spectra

Medium Voltage Switchgear

Three Medium Voltage Switchgear units were reviewed as part of the study. Medium Voltage Switchgear in the SQUG Equipment Class is identified by the following parameters:

- Height up to 90 inches
- Width 24 to 36 inches (per section)
- Depth up to 90 inches
- Weight 2,000 to 3,000 lbs/section

The parameters of the international Medium Voltage Switchgear are listed in Table 4-3. Dimensional parameters and weights are noted to be similar to those that make up the U.S.-based test database.

Table 4-3
International Medium Voltage Switchgear Properties

Equipment Description	Dimensions			Weight (lbs)	Country
	Height (in)	Width (in)	Depth (in)		
Medium Voltage Switchgear	98.4	43.3	59.1	2640	UK
Medium Voltage Switchgear	114.3	52.4	86.6	3916	UK
Medium Voltage Switchgear	108.0	42.5	66.9	2640	UK

The plots for the three Medium Voltage Switchgear tests are presented in Figure 4-3. The results show that the spectra for the three internationally manufactured switchgears units generally match the GERS spectrum. At frequencies between 9 and approximately 25 Hz, the test spectra fall slightly below the GERS spectrum. An examination of the test results for Medium Voltage Switchgear in Reference 2 shows that four of the six tests that were used to develop the GERS also showed similar capacities at such frequencies, and in fact, the non-U.S. manufactured test results are representative of those for U.S. manufactured switchgear. Thus, it can be concluded that the Medium Voltage Switchgear GERS are valid for non-U.S. manufactured equipment.

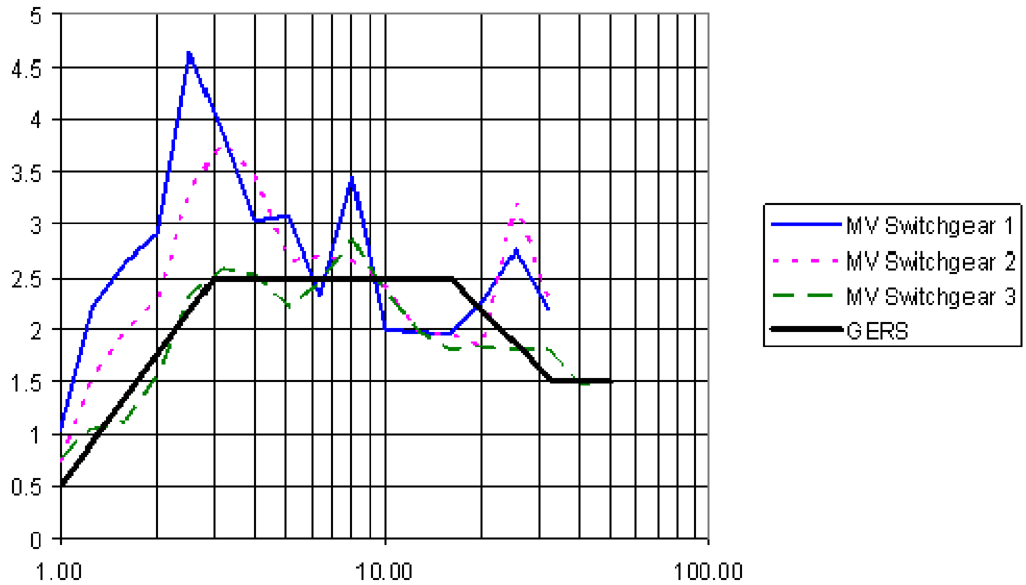

Figure 4-3
Medium Voltage Switchgear Test Response Spectra

Transformers

Two tests were reviewed for similarity to the Transformer GERS. Transformers in the SQUG Equipment Class are identified by the following parameters:

- Height 60 to 100 inches
- Width 40 to 100 inches
- Depth 40 to 100 inches

The parameters of the two international Transformers are listed in Table 4-4. Dimensional parameters and weights are noted to be similar to those that make up the U.S.-based test database.

Table 4-4
International Transformer Properties

Equipment Description	Dimensions			Weight (lbs)	Country
	Height (in)	Width (in)	Depth (in)		
1600kVA 3.3kV/433V Transformer	77.4	77.4	55.1	7810	UK
630kVA Alstom Transformer	Unknown	Unknown	Unknown	Unknown	France

The plots for two transformer tests are presented in Figure 4-4. The results show that the spectra for the two internationally manufactured switchgears units exceed the transformer GERS over all frequencies, and it can be concluded that the transformer GERS are valid for non-U.S. manufactured equipment.

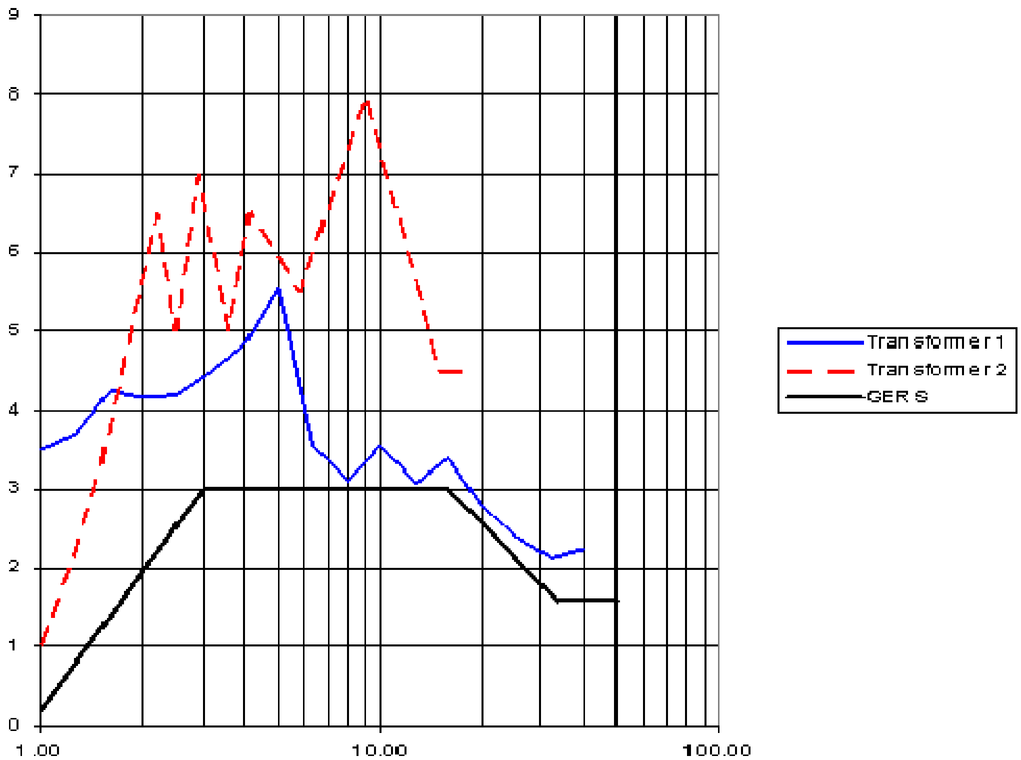

Figure 4-4
Transformer Test Response Spectra

Batteries

Two tests were reviewed for similarity to the Batteries on Racks GERS. The GERS caveats in the GIP specify two-step or single-step racks. The two tests reviewed herein consist of one four tier rack and one three tier rack. Thus, the international equipment is somewhat different from the established GIP test equipment database. However, it can be argued that the international test results represent a more conservative sample, as the center of gravity of the overall assembly would be higher. Thus, demonstration of seismic capacity exceeding the U.S.-based GERS parameters should be viewed as a confirmation of the validity of the stated capacity.

The parameters of the international racks are listed in Table 5-5. Dimensional parameters and weights are not indicated for the battery racks tested in Reference 2, but the overall configurations, i.e., side rails, number of steps, materials, are similar to those that make up the U.S.-based test database. It should be noted that the rack identified as Battery Rack 2 was a specially-designed rack, built specifically to resist the loads resulting from a significant earthquake. In addition, the cells were not filled with normal battery acid, but rather a fluid whose density was equal to that of the normal fluid contained in the battery, so that mass would be adequately represented. However, functionality was not demonstrated in this test.

Table 4-5
International Battery Rack Properties

Equipment Description	Dimensions			Weight (lbs)	Country
	Height (in)	Width (in)	Depth (in)		
4 Tier Battery Stand Containing 32 Cells	61	37.4	36.8	2464	UK
3 Tier Battery Rack Containing 15 Cells	55 (est)	54 (est)	35 (est)	Unknown	Germany

The plots for the two Battery Rack tests are presented in Figure 4-5. The results show that Battery Rack 1 exceeds the Batteries on Racks GERS at all frequencies above approximately 1.5 Hz. The Battery Rack 2 plot show two tests; the first measuring front-to-back capacity, and the second measuring side-to-side capacity. At frequencies less than 9 and 10 Hz, respectively, the test spectra fall below that of the GERS. This is due to the Required Response Spectra (RRS) requirements that the rack was tested against. In the frequency range of concern, the rack's capacity is similar to those that make up the sample group from which the GERS was generated. Therefore, it can be concluded that the Batteries on Racks GERS are valid for non-U.S. manufactured equipment.

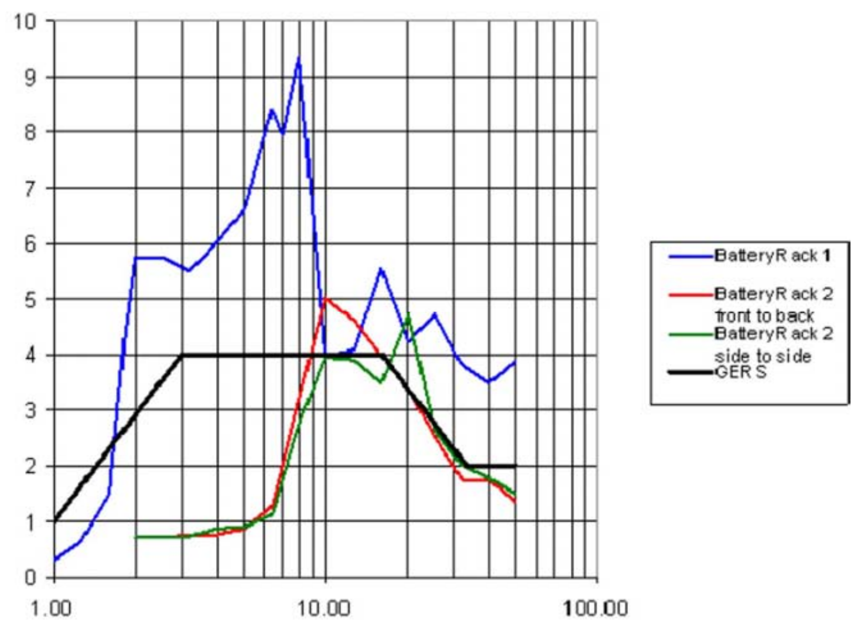

Figure 4-5
Battery Rack Test Response Spectra

Battery Chargers

Four international tests were reviewed for similarity to the Battery Chargers GERS. Battery Chargers in the SQUG Equipment Class are identified by the following parameters:

- Height 60 to 80 inches
- Width 20 to 40 inches
- Depth 20 to 40 inches
- Weight up to several thousand pounds

The parameters of the international Chargers are listed in Table 4-6. Dimensional parameters and weights are noted to be similar to those that make up the U.S.-based test database.

Table 4-6
International Battery Charger Properties

Equipment Description	Dimensions			Weight (lbs)	Country
	Height (in)	Width (in)	Depth (in)		
Three Unit Charger	76.4 76.4 76.4	36.0 48.0 48.0	33.1 45.1 45.1	880 1980 1958	UK
Two Unit Charger	82.7	72.0	23.6	2640	UK
Two Unit Charger	82.7	72.0	23.6	2640	UK
Two Unit Charger	80 (est)	60 (est)	24 (est)	unknown	France

The plots for the four Battery Charger tests are presented in Figure 4-6. The results show that the capacity is similar to those that make up the sample group from which the GERS was generated. Therefore, it can be concluded that the Battery Charger GERS are valid for non-U.S. manufactured equipment.

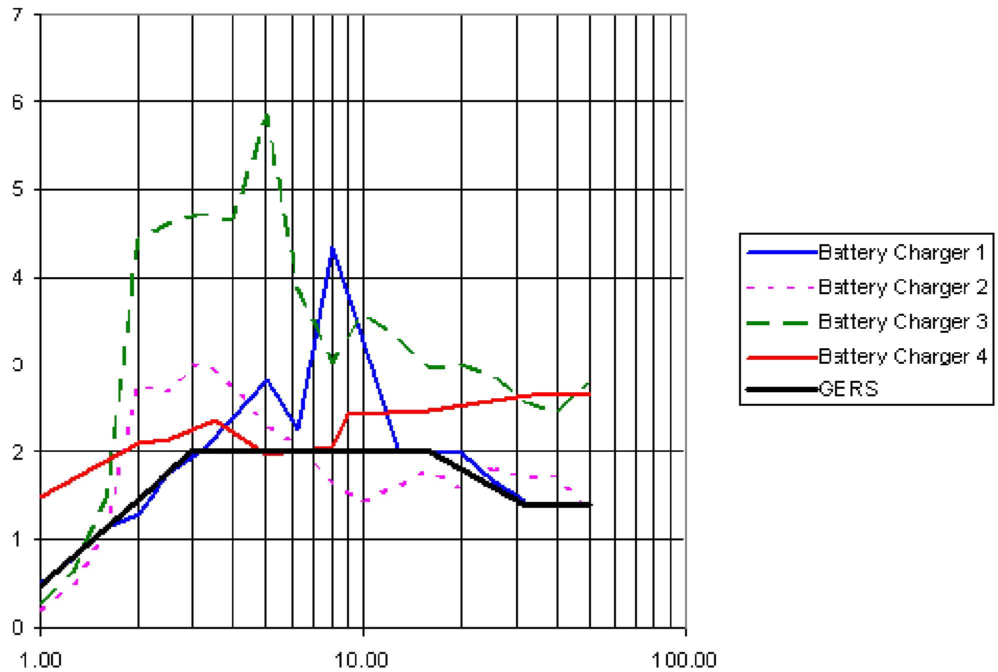

Figure 4-6
Battery Charger Test Response Spectra

Inverters

Five international tests were reviewed for similarity to the Inverters GERS. The tests were performed on Uninterruptible Power Supplies (UPS), which include Inverters. UPS units are also included in the SQUG class of Battery Chargers and Inverters. Inverters in the SQUG Equipment Class are identified by the following parameters:

- Height 60 to 80 inches
- Width 20 to 40 inches
- Depth 20 to 40 inches
- Weight up to several thousand pounds

The parameters of the international UPS units are listed in Table 4-7. Dimensional parameters and weights are noted to be similar to those that make up the U.S.-based test database.

Table 4-7
Inverter Properties

Equipment Description	Dimensions			Weight (lbs)	Country
	Height (in)	Width (in)	Depth (in)		
110V DC Essential Inverter UPS	82.7	72.0	23.6	4620	UK
110V DC Primary UPS System	76.0	144.1	24.0	9020	UK
110V DC Secondary UPS System	82.7	178.3	38.8	9020	UK
415V DC Essential UPS System	74.9	165.4	35.4	8800	UK
170kVA UPA	80 (est)	72 (est)	30 (est)	Unknown	Germany

The plots for the five international Inverter tests are presented in Figure 4-7. The results show that non-U.S. manufactured inverter capacities are similar to those that make up the sample group from which the GERS was generated. Therefore, it can be concluded that the Inverter GERS are valid for non-U.S. manufactured equipment.

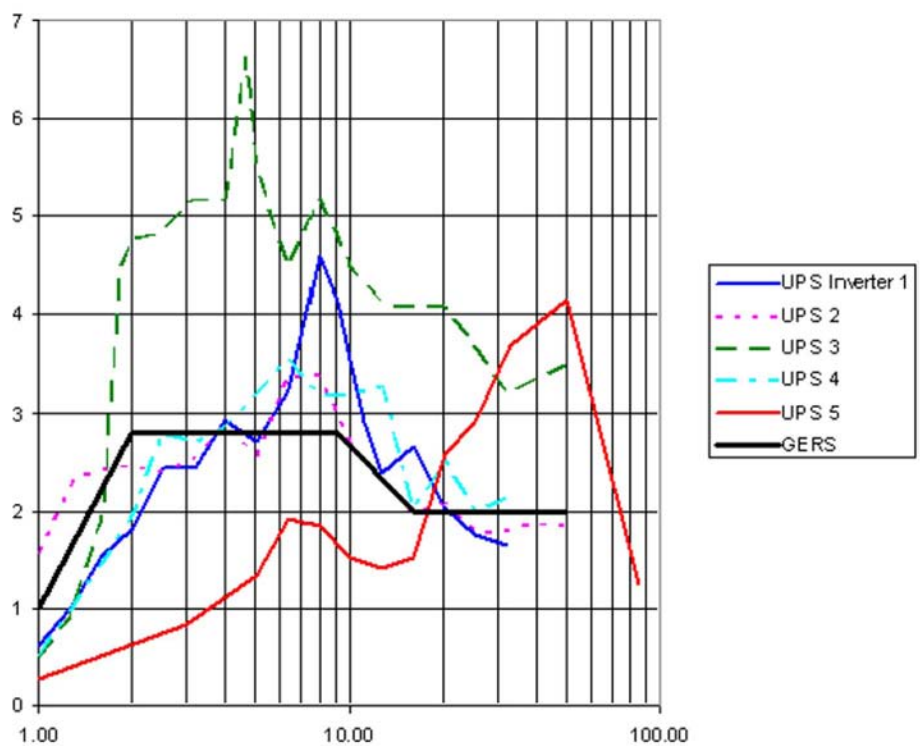

Figure 4-7
Inverter Test Response Spectra

5
CONTROL AND INSTRUMENTATION PANEL DATA

The SQUG equipment class of Control and Instrumentation Panels does not define a GERS in Reference 2. Control Panels were studied as part of the GIP project, but it was concluded that the definition of the equipment class was too broad, and control panels constitute a class whose diversity is too great to define within the bounds required to establish a GERS. However, a specific study undertaken by UK-based researchers [Reference 6] arrived at some conclusions regarding two classes of control panels and GERS for these specific test classes were developed. The background and conclusions reached in this study are presented in this section.

Control and Instrumentation Panel Test Database Origin

Extensive seismic qualification programs were started in the UK about 20 years ago to qualify the essential equipment installed in the nuclear power stations being built in the 1980's and 1990's. In the mid-1980's and beyond, the requirement for seismic qualification of essential plant and equipment on nuclear waste storage and reprocessing installations also started. This was followed in the late 1980's by a similar requirement at UK dockyards associated with the construction, maintenance, and retrofit of nuclear submarines.

Seismic qualification procedures were developed by the owners of the power stations, reprocessing installations, and dockyards. These procedures defined qualification methodologies which, in general, included qualification by a combination of analytical and full-scale testing methods.

As a result of these qualification programs, a large number of bi-axial and tri-axial full-scale seismic tests have been carried out on a wide range of mechanical and electrical equipment. Each test has been fully reported and generally covers the vibration, equipment dynamic properties, structural integrity, and electrical functional aspects. A limited amount of full-scale tri-axial seismic testing is still continuing in the UK on equipment identified to have a Class 1E safety-related category.

Using a sample of this available full-scale seismic testing data, a pilot study was carried out for the Control and Instrumentation Panel Equipment class with the goal of developing a GERS for the equipment class.

Identification of Suitable Test Data

The available test reports cover two periods in the development of UK equipment designs, i.e., the early to mid-1980's and the late1980's, together with the 1990's.It was therefore decided to separate the test reports into two groups, and to produce separate GERS for the two groups. In this report, test results from the early to mid-1980's are collated under Group I, and the late 1980's and 1990's test results under Group II.

Each I and C panel type was given a test assembly number. The basic technical information relating to each test assembly has been collated and presented in Tables 5-1 and 5-2. Table 5-1 covers the Group I test assemblies, and Table 5-2 the Group II test assemblies.

Table 5-1
Group I, I and C Panels

Test Assembly No.	Panel Description			Estimated Weight (lb)	Anchorage Details
			in.		
1	Local Control Panel	Height	71.7	3080	Ten M20
		Width	107.9		
		Depth	31.5		
2	Excitation Cubicles	Height	73.8	660	Four M12
		Width	30.0		
		Depth	23.5		
3	Heating & Ventilation C&I Panels	Height	89.6	3080	Ten M16
		Width	118.1		
		Depth	27.6		
4	Decay Heat Boiler Control Panel	Height	77.0	3080	Twelve M16
		Width	110.8		
		Depth	20.0		
5	Instrumentation and Contactor Cubicles	Height	86.6	880	Six M12
		Width	29.5		
		Depth	35.4		
6	Fueling Machine Short Break Feed Panel	Height	76.4	(1) 1166	Eight M16
		Width	63.8		
		Depth	25.6		

Note: (1) Actual Weight of Test Assembly No. 6

Table 5-2
Group II, I and C Panels

Test Assembly No.	Panel Description			Estimated Weight (lb)	Anchorage Details
			in.		
7	Gas Control Panel	Height	80.0	1650	Four M16
		Width	71.5		
		Depth	25.6		
8	EC&I Panels for Power Station Cooling System	Height	82.7	1540	Six M12
		Width	47.2		
		Depth	25.6		
9	Alternator Excitation Cubicle	Height	73.8	880	Four M20
		Width	30.0		
		Depth	35.4		
10	Local Control Cubicle	Height	72.8	3080	Ten M20
		Width	108.1		
		Depth	31.5		
11	Remote Control Cubicle	Height	72.8	3575	Sixteen M20
		Width	125.6		
		Depth	35.4		
12	Transducer Cubicle	Height	73.9	990	Six M20
		Width	59.1		
		Depth	31.5		
13	HVAC Local Control Panels	Height	86.6	1210	Eight M20
		Width	47.2		
		Depth	23.6		
14	Pressure Transmitter Electronics Cubicle	Height	82.7	900	Ten M16
		Width	31.5		
		Depth	31.5		
15	Valve Actuator Control Panels	Height	70.0	650	Eight M12
		Width	31.5		
		Depth	27.5		
16	Secondary Protection Panel	Height	86.6	(1) 3397	Eighteen M20
		Width	88.6		
		Depth	35.4		

Note: (1) Actual Weight of Test Assembly No. 16

Both Tables 5-1 and 5-2 provide the basic information relating to each test assembly, i.e., panel description, overall dimensions, base anchorage details, and estimated weights. It should be noted that in the case of Test Assemblies No. 6 and 16, the actual overall weights are known to be 530 kg (1,166 lb) and 1,544 kg (3,397 lb) respectively. The overall weights of the other test assemblies have been estimated for this study.

The sixteen selected test assemblies in this study cover I and C panels manufactured over the period of 1983 to 1997. Four of the test panels were subjected to bi-axial seismic test programs, and the remaining twelve to tri-axial test programs. All the panels contain similar electrical and electronic components, and have similar sheet steel construction.

It is important to note that the bases of each panel were upgraded with substantial steel plinths to ensure that they would survive the seismic test programs.

Extraction of Test Data

The sixteen separate full-scale seismic test reports, applicable to the sixteen test assemblies, were inspected for validity of the vibration exploratory and seismic test data. TRS's for the highest test condition, i.e., 100% RRS test or SSE test, were extracted for both horizontal and vertical directions. For this report, only the horizontal test data was tabulated. For the 4% damping ratio TRS data, the spectral data were normalized to a 5% damping ratio, using the process identified in Section 3.2, before tabulation.

The equipment horizontal vibration exploratory test data were also studied to extract test assembly measured fundamental natural frequency and damping ratio data. Where possible, these types of data were extracted in both orthogonal horizontal directions.

For the table TRS data the appropriate test level, spectral peak value between 1 Hz and 32 Hz, and the ZPA value, were extracted and tabulated.

Table 5-3 shows the data extracted from the exploratory tests and the seismic tests for the sixteen test assemblies. Where two test assemblies were on the shake table at the same time, only one set of exploratory data was tabulated (see notes with Table 5-3).

The horizontal TRS results for each test assembly are plotted in Figures 5-1 and 5-2 for the Group I and Group II I and C panels, respectively.

Table 5-3
I and C Panel Seismic Test Data

Test Assembly	Exploratory Tests		Table Seismic TRS				
	Natural Frequency Hz	Damping Ratio %	Test Level	Peak Value		ZPA	
				g	(Hz)	g	(Hz)
1	7.5 Hz (Front to Back)	7.4	100% RRS	1.67	(3.17)	1.42	(32.00)
	9.5 Hz (Side to Side)	6.1					
[(1)] 2	7.5 Hz (Front to Back)	6.2	100% RRS	3.96	(10.00)	1.62	(32.00)
	7.8 Hz (Side to Side)	7.8					
[(2)] 3	10.6 Hz (Front to Back)	5.2	100% RRS	3.30	(7.50)	1.85	(32.00)
	7.9 Hz (Side to Side)	9.0					
[(3)] 4	10.92 Hz (Front to Back)	7.8	100% RRS	3.68	(20.10)	2.33	(32.00)
	13.27 Hz (Side to Side)	6.4					
5	15.3 Hz (Front to Back)	8.4	100% RRS	4.47	(6.35)	2.10	(32.00)
	12.0 Hz (Side to Side)	4.9					
6	19.1 Hz (Front to Back)	6.7	100% RRS	6.45	(12.70)	2.11	(32.00)
	30.9 Hz (Side to Side)	4.9					
7	15.1 Hz (Front to Back)	3.0	SSE	2.86	(12.70)	0.86	(50.00)
	19.6 Hz (Side to Side)	5.5	120% SSE	3.39	(12.70)	1.01	(50.00
8	11.7 Hz (Front to Back)	4.9	100% RRS	4.55	(4.00)	2.03	(40.00)
	11.7 Hz (Side to Side)	5.7					

Notes: [(1)] Exploratory test data only presented for one cubicle
[(2)] Exploratory test data for 5 Bay Rack presented above for Test Assembly 3
[(3)] Exploratory test data only available in front to back direction on Test Assembly 4

Table 5-3 (Continued)
I and C Panel Seismic Test Data

Test Assembly	Exploratory Tests		Table Seismic TRS				
	Natural Frequency Hz	Damping Ratio %	Test Level	Peak Value		ZPA	
				g	(Hz)	g	(Hz)
9	11.0 Hz (Front to Back)	9.9	100% RRS	6.31	(5.04)	3.05	(50.00)
	14.9 Hz (Side to Side)	6.2					
10	12.6 Hz (Front to Back)	5.2	100% RRS	3.99	(4.27)	1.69	(50.00)
	9.7 Hz (Side to Side)	5.3					
11	8.8 Hz (Front to Back)	3.3	100% RRS	7.00	(5.04)	3.00	(50.00)
	10.9 Hz (Side to Side)	7.3					
12	8.1 Hz (Front to Back)	3.1	100% RRS	3.71	(4.27)	1.59	(50.00)
	23.4 Hz (Side to Side)	9.4					
13	26.5 Hz (Front to Back)	4.8	100% RRS	7.70	(7.00)	3.84	(40.00)
	12.8 Hz (Side to Side)	10.1					
14	21.4 Hz (Front to Back)	(4)	100% RRS	6.45	(3.17)	2.75	(50.00)
	29.0 Hz (Side to Side)						
15	7.6 Hz (Front to Back)	5.7	100% RRS	5.51	(8.00)	2.72	(50.00)
	33.7 Hz (Side to Side)	3.0					
16	9.8 Hz (Front to Back)	13.4	100% RRS	4.63	(3.60)	2.38	(40.00)
	8.8 Hz (Side to Side)	10.3					

Notes: (4) No exploratory test damping information available

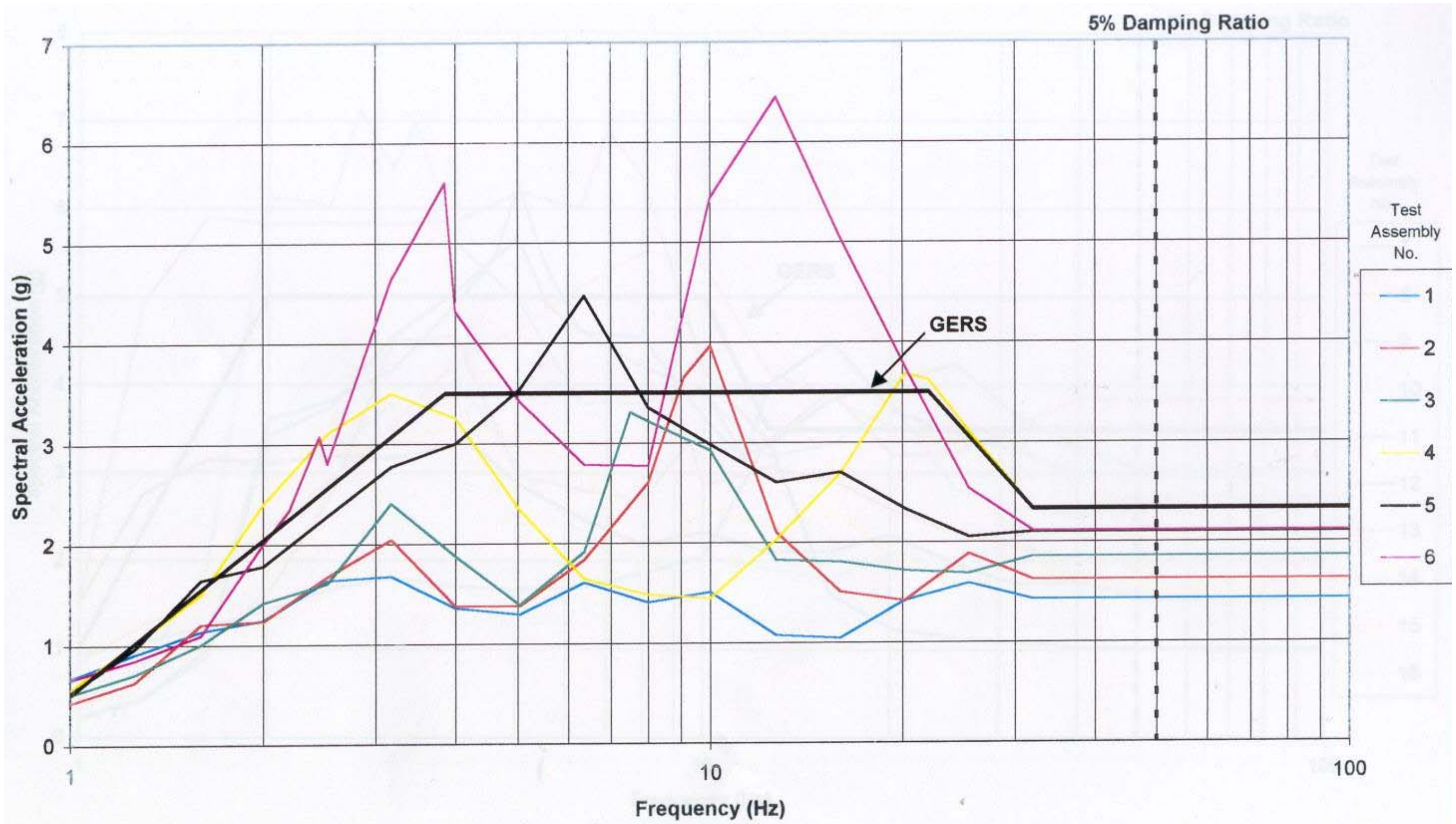

Figure 5-1
Group I, I and C Panel Horizontal TRS and GERS

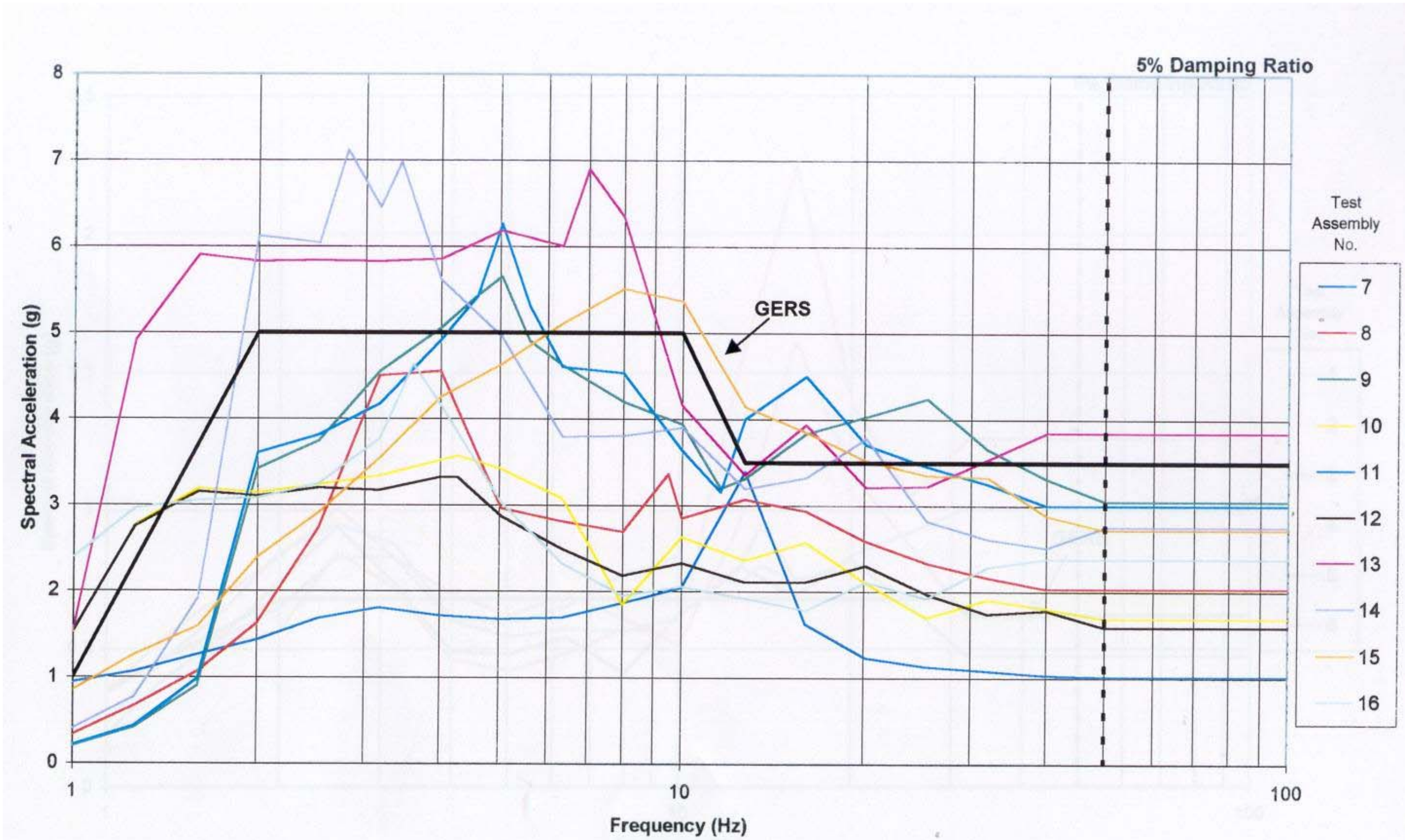

Figure 5-2
Group II, I and C Panel Horizontal TRS and GERS

Determination of GERS

Using the GERS determination rules in EPRI NP-4297, for a ‘low diversity class of more than one item’, two straight line segmented GERS plots have been produced. The resulting GERS plots have been over-plotted on Figures 5-1 and 5-2.

In developing the horizontal portion of the Group I horizontal GERS, the slight 'spectral dip' in the region of 8 Hz has been neglected. Experience with seismic testing of a wide range of equipment has shown that equipment ruggedness is not sensitive to small spectral dips. Hence, they can be bridged by a higher spectral line to eliminate the bottom of the dip.

The Group II horizontal GERS plot (Figure 5-2) has been limited in the low-frequency horizontal portion to a level of 5g. A level of 5g peak at 2 Hz is a very substantial input excitation level.

Examination of the four GERS plots yields the following results:

	Group I		Group II	
	Peak Value	**ZPA**	**Peak Value**	**ZPA**
Horizontal	3.5	2.3	5.0	3.5

These results for the Group I and II panels are consistent, showing improved values for the more recent panel designs.

The Group II horizontal GERS have similar values, showing the panel designs are equally rugged in that direction.

This data provides a valuable addition to the EPRI seismic experience database. The resulting data can be used in future UK equipment qualification programs on similar designs of I and C panels.

6
RELAYS

GERS for a number of relays were established for use in performing USI A-46 evaluations, as well as for IPEEE evaluations that were required in the U.S. Relays are important due to their presence in most plant shutdown control circuits. Chatter of low-capacity relays can result in undesired actuation of system functions, and thus, it is important to determine the levels at which relays can be expected to perform their intended function when subjected to seismic motion. A special study was initiated specifically for Swedish-manufactured relays to determine seismic capacities of specially-designed ASEA relays intended for use in the Swedish seismically-designed nuclear plants. The results of those tests presented in this section can be considered as a supplement to the existing relay test database, and thus, it was determined that it would be useful to present the results in this report.

Description of Relay Tests

The ASEA relays were tested by the National Swedish Testing Institute in 1979 and documented in ASEA report number TR RKY 79-045. Testing was performed to ANSI Standard C 37.98 in accordance with a test procedure developed by the National Swedish Testing Institute. The ANSI Standard at the time specified single axis motions in a 45-degree direction relative to the vertical and horizontal directions, thus producing equivalent horizontal and vertical components of the input motion. The relays were fixed in a rigid cubic frame, with the frame fixed to the shake table.

The relays tested and presented herein were not seismically designed. The U.S.-based relay GERS include tests performed on two models of ASEA relays, the RXMA1 and RXKE1 [7], and the capacities established in those tests were also based on non-seismically designed models.

The relays were mounted in their normal orientation, and they were tested in the vertical and each of the four orthogonal horizontal axes. Table 6-1 presents ZPA values for the following:

- X + Z direction—the smaller value of the left-right and right-left tests
- Y + Z direction—the smaller value of the front-back and back-front tests
- Overall rating—the smaller value for all directions

It should be noted that the rigid frame mounting utilized in the ASEA tests does not account for the amplification effects resulting from in-cabinet mounting. The results presented in Section 6.2 should be considered to be relay GERS at the mounting point of the relay, which is consistent with the development of the U.S. relay GERS, i.e., the data should be considered test results that indicate a fragility level for each relay.

Relay Test Results

A total of 63 relays are presented in Table 6-1. The table presents two values for each rating. The value to the left of the slash corresponds to the ANSI C 37.98 requirements of less than 2.0 ms “unauthorized electrical change of state in the output circuit”, while the value to the right of the slash corresponds to a time criterion of less than 0.1 ms interrupt, which is outside of the specification but was determined to be of use to ASEA in their investigation of relay capacity. A value of 6.5g indicates that the fragility level exceeds the maximum test capacity of the seismic vibration equipment. Comments from ASEA regarding the test results are presented below:

> “As expected the fragility level is determined mainly by a contact disturbance, and notably NC-contacts in the non-operating mode [were] found to be the weakest link. Based on our design practice in most standard auxiliary and protective relay functions NC-contacts are not used, and hence the weakest link in these applications will be the NO-contacts which have a higher fragility level. This level stated within parenthesis in [Table 6-1] for easy access is a very useful amendment when evaluating the fragility level of a relay system.”

Table 6-1
ASEA Relay Fragilities

Type and Cat. No.	SRS-Broadband Fragility ZPA Level in g Units			
	Test Directions		Overall Rating	Overall Rating Excl. NC-Cont.
	x + z	y + z		
RXMA 1				
RK 211 052-AN	6.5/5.7	5.9/5.9	5.9/5.7	6.5/6.5
RK 211 074-AN	6.5/5.7	6.1/5.9	6.1/5.7	6.5/6.5
RXMA 2				
RK 211 175-AN	5.8/2.1	4.6/2.2	4.6/2.1	6.5/6.5
RK 211 189-AN	4.6/-	4.5/-	4.5/-	6.5/6.5
RXMM 1				
RK 214 002-AN	6.1/4.4	5.2/-	5.2/-	6.5/6.5
RK 214 004-AN	6.1/4.4	5.2/-	5.2-	6.5/6.5
RXMS 1				
RK 216 237-AN	3.1/-	3.0/-	3.0/-	5.8/5.7
RK 216 265-AN	5.8/2.1	6.5/2.2	5.8/2.1	6.2/5.7
RXME 1				
RK 221 052-AN	4.2/3.4	2.4/2.1	2.4/2.1	6.5/6.5
RXME 18				
RK 221 825-AN	6.5/6.5	6.5/6.5	6.5/6.5	6.5/6.5
RXMH 2				
RK 223 069-AN	5.2/-	2.1/-	2.1/-	6.1/4.0
RXMK 1				
RK 225 051-BS	6.5/4.6	2.6/2.1	2.6/2.1	5.1/4.0
RXMT 1				
RK 241 012-AH	6.5/6.5	6.5/6.5	6.5/6.5	
RXMVB 2	6.5/6.5	6.5/6.5	6.5/6.5	
RK 251 204-AN	6.5/6.5	6.5/6.5	6.5/6.5	
RXMVB 4				
RK 251 401-AN	6.5/6.5	6.5/6.5	6.5/6.5	
RXMVE 1				
RK 257 001-AN	6.5/5.7	5.9/5.9	5.9/5.7	6.5/6.5

Table 6-1 (Continued)
ASEA Relay Fragilities

	SRS-Broadband Fragility ZPA Level in g Units			
Type and Cat. No.	Test Directions		Overall Rating	Overall Rating Excl. NC-Cont.
	x + z	y + z		
RXSF 1				
RK 271 009-AN	6.5/6.5	5.2/4.9	5.2/4.9	6.5/6.5
RK 271 019-AN	6.1/4.4	4.9/3.8	4.9/3.8	6.1/5.1
RXSL 1				
RK 273 101-AN	6.3/3.8	4.6/3.7	4.6/3.7	6.3/4.0
RXSP 1				
RK 275 401-AN	3.5	4.5	3.5	
	6.5	6.5	6.5	
RXSGA				
RK 276 001-AA	6.5/6.5	6.5/6.5	6.5/6.5	
RXSU 2				
RK 277 001-AN	6.3/3.8	4.6/-	4.6/-	
RXKT 23				
RK 311 338-AN	6.5/4.3	6.5/4.1	6.5/4.1	
RXKH 26				
RK 313 656-AN	1.3	1.3	1.3	
RXKB 1				
RK 315 733-AN	4.3/4.1	5.1/4.1	4.3/4.1	6.5/6.5
RXKP 2				
RK 323 001-BN	3.3/-	-/-	-/-	
	6.5/4.3	6.5/4.1	6.5/4.1	6.5/6.5
RXKC 2H				
RK 331 002-AN	6.5/4.3	6.5/4.1	6.5/4.1	6.5/6.5
RXKD 2H				
RK 332 001-AN	5.0/-	4.6/-	4.6/-	6.5/6.5
RXKE 1				
RK 333 001-AN	6.5/6.5	6.5/6.5	6.5/6.5	
RXIG 2				
RK 411 171-DF	4.3/2.1	5.0/1.3	4.3/1.3	6.0/6.0

Table 6-1 (Continued)
ASEA Relay Fragilities

Type and Cat. No.	SRS-Broadband Fragility ZPA Level in g Units			
	Test Directions		Overall Rating	Overall Rating Excl. NC-Cont.
	x + z	y + z		
RXEG 2				
RK 411 271-DE	4.9/-	3.4/-	3.4/-	5.2/5.2
RXEL 2				
RK 412 216-DH	< 0.9/-	< 0.9/-	< 0.9/-	
RXIB 22				
RK 413 135-BC	6.0/6.0	6.0/6.0	6.0/6.0	
RXEB 2				
RK 424 001-DN	3.5/-	2.6/-	2.6/-	5.2/5.2
RXID 1				
RK 426 440-HC	6.2/4.9	6.4/4.4	6.2/4.4	
RXNAD 2H				
RK 427 411-AN	5.5/-	4.0/-	4.0/-	
RXOTB 23				
RK 431 003-DE	6.5/-	6.5/-	6.5/-	
RXOTD 4				
RK 433 001-AB	5.4/-	6.5/5.9	5.4/-	6.5/6.5
RXIDF 2H				
RK 473 004-AA	6.5/6.5	6.5/6.5	6.5/6.5	
RXVE 43 RK 481 001-CA RXTIP 4 RK 481 003-BB	6.5/6.5	6.5/6.5	6.5/6.5	
RVAB				
RK 487 001-AS	6.5/6.0	5.6/4.6	5.6/4.6	
RXPE 40				
RK 511 013-GA	4.5/-	5.7/-	4.5/-	6.5/6.1
RXFE 4				
RK 545 001-AB	4.4/-	5.9/-	4.4/-	6.5/6.5

Table 6-1 (Continued)
ASEA Relay Fragilities

	SRS-Broadband Fragility ZPA Level in g Units			
Type and Cat. No.	Test Directions		Overall Rating	Overall Rating Excl. NC-Cont.
	x + z	y + z		
RXZF 2				
RK 556 001-AA	6.5/6.5	6.5/6.5	6.5/6.5	
RADSB				
RK 625 001-CA	6.5/-	6.4/-	6.4/-	
RAMDA				
RK 642 007-FA	4.9/3.0	4.9/2.2	4.9/2.2	
RADHA				
RK 646 005-DA	6.2/4.9	6.4/4.4	6.2/4.4	
RXTMA 1				
RK 711 008-AX			6.5	
RXTCA 1				
RK 713 041-AS			6.5	
RXTLA 1				
RK 717 011-DU			6.5	
RXTTA 2				
RK 731 002-DA			6.5	
RXTTA 1				
RK 731 003-AB			6.5	
RXTUG 2H				
RK 732 104-BA	6.5/6.5	6.5/6.5	6.5/6.5	
RXTUA 2				
RK 732 201-AF			6.5	
RQMB 040				
RK 732 226-AA			6.5	
RQMB 041				
RK 732-227-AA			6.5	
RQMA 100				
RK 732 228-AA			6.5	

Table 6-1 (Continued)
ASEA Relay Fragilities

	SRS-Broadband Fragility ZPA Level in g Units			
Type and Cat. No.	Test Directions		Overall Rating	Overall Rating Excl. NC-Cont.
	x + z	y + z		
RXTUF 2				
RK 732 251-AF			6.5	
RXTUB 2				
RK 732 301-AF			6.5	
RXTBIB 4				
RK 734 006-BA			6.5	
RXTBEA 2				
RK 734 007-BN			6.5	
RAGNA				
RK 871 020-AC	4.2/4.2	5.7/5.2	4.2/4.2	
RX 4				
RK 924 0002			6.5	
RXY				
RK 924 0005			6.5	
RTXP 18				
RK 926 003-AV			6.5	
RXTN 2-10				
RK 924-036-AB			6.5	
RTXQ				
RK 929 006-AA			6.5	

7
CONCLUSIONS

The overall conclusion from this study is that, with respect to the use of seismic experience, nuclear plant equipment manufactured outside of the United States is as seismically rugged as the equipment manufactured within the United States. Based on the classes of equipment reviewed within this study, there exists no evidence that the seismic capacity of the equipment changes with the origin of either the testing or the manufacture of the equipment. Worldwide standards for the construction of specific types of electrical and mechanical equipment have a high-degree of consistency with respect to the seismic capacity of components. Specific results and conclusions from this study include the following:

- Representative seismic test data has been collected and collated for eight separate classes of electrical equipment covered by the SQUG seismic experience database. Only test data where equipment structural integrity and functionality have been monitored and maintained, throughout each seismic test program, have been used in the study.
- The presented test data cover a period of equipment design and manufacture extending from early 1979 to 1993.
- With the exception of relays, equipment manufacturers, model numbers and countries of origin of the equipment, have remained anonymous in this study to maintain client confidentiality.
- Relay fragilities have been documented for a significant number of Swedish relays.
- The TRS data for the internationally manufactured equipment are consistent and correlate well with the U.S. GERS data. This fact supports the premise that the GERS levels are appropriate for all equipment that meet the class caveats, regardless of the country of origin.
- The caveats generated for each of the eight classes of equipment were shown to be appropriate for the international test data considered within this study. Thus, no changes to the caveats are warranted for the internationally manufactured equipment.
- Control and Instrumentation Cabinet GERS were generated for two specific classes of panels. These GERS levels were generated with the intent of providing capacity levels for seismic margin studies and for seismic PRAs when electrical equipment meet their inclusion rules.

8
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6. EQE International, Limited, Generic Seismic Ruggedness of UK Control and Instrumentation Panels, Report No 3-51-R-01, May, 2001.
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