

# SANDIA REPORT

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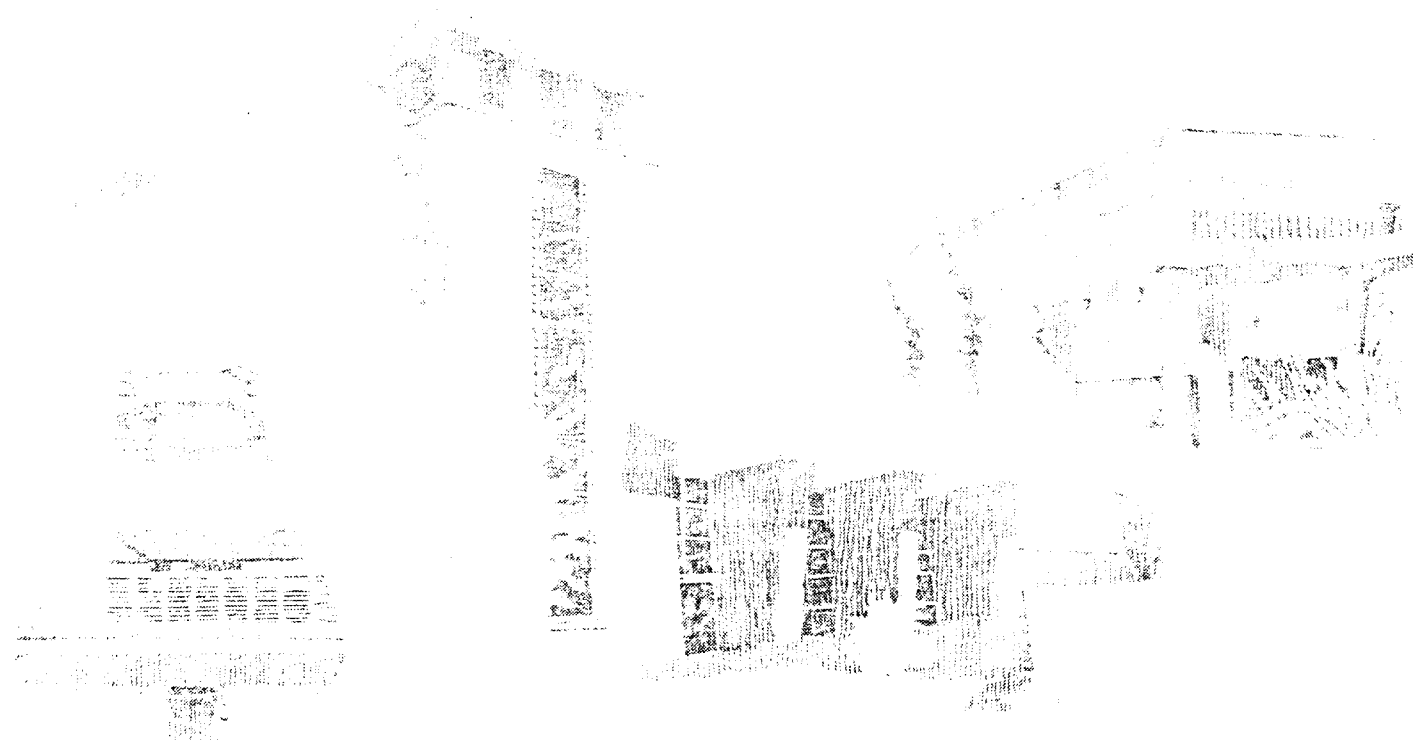
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## Part I: Use of Seismic Experience and Test Data to Show Ruggedness of Equipment in Nuclear Power Plants

## Part II: Review Procedure to Assess Seismic Ruggedness of Cantilever Bracket Cable Tray Supports

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**PART I: USE OF SEISMIC EXPERIENCE AND TEST DATA TO SHOW  
RUGGEDNESS OF EQUIPMENT IN NUCLEAR POWER PLANTS**

**PART II: REVIEW PROCEDURE TO ASSESS SEISMIC RUGGEDNESS  
OF CANTILEVER BRACKET CABLE TRAY SUPPORTS**

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**Abstract**

In December 1980, the U.S. Nuclear Regulatory Commission (NRC) designated "Seismic Qualification of Equipment in Operating Plants" as an Unresolved Safety Issue (USI), A-46. The objective of USI A-46 is to develop alternative seismic qualification methods and acceptance criteria that can be used to assess the capability of mechanical and electrical equipment in operating nuclear power plants to perform the intended safety functions. A group of affected utilities formed the Seismic Qualification Utility Group (SQUG) to work with the NRC in developing a program methodology to enable resolution of the A-46 issue. To assist in developing a program methodology, SQUG and the NRC jointly selected and supported a five-member Senior Seismic Review and Advisory Panel (SSRAP) in June 1983 to make an independent assessment of whether certain classes of equipment in operating nuclear power plants in the United States have demonstrated sufficient ruggedness in past earthquakes so as to render an explicit seismic qualification unnecessary. SSRAP operated as an independent review body with all of its findings submitted concurrently to both SQUG and the NRC.

During their period of involvement, SSRAP issued several draft reports on their conclusions. This document contains the final versions of these reports; namely, "Use of Seismic Experience and Test Data to Show Ruggedness of Equipment in Nuclear Power Plants," dated February 1991 and "Review Procedure to Assess Seismic Ruggedness of Cantilever Bracket Cable Tray Supports," dated March 1, 1991.



## FOREWORD

In December 1980, the U.S. Nuclear Regulatory Commission (NRC) designated "Seismic Qualification of Equipment in Operating Plants," as an Unresolved Safety Issue (USI), A-46. The objective of USI A-46 is to develop alternative seismic qualification methods and acceptance criteria that can be used to assess the capability of mechanical and electrical equipment in operating nuclear power plants to perform the intended safety functions. A group of affected utilities formed the Seismic Qualification Utility Group (SQUG) to work with the NRC in developing a program methodology to enable resolution of the A-46 issue. To assist in developing a program methodology, SQUG and the NRC jointly selected and supported a five-member Senior Seismic Review and Advisory Panel (SSRAP) in June 1983 to make an independent assessment of whether certain classes of equipment in operating nuclear power plants in the United States have demonstrated sufficient ruggedness in past earthquakes so as to render an explicit seismic qualification unnecessary. SSRAP operated as an independent review body with all of its findings submitted concurrently to both SQUG and the NRC.

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These combined reports are now being released to provide wide and easy access to the interested technical community.



## TABLE OF CONTENTS

1. PART I: USE OF SEISMIC EXPERIENCE AND TEST DATA TO SHOW RUGGEDNESS OF EQUIPMENT IN NUCLEAR POWER PLANTS
2. PART II: REVIEW PROCEDURE TO ASSESS SEISMIC RUGGEDNESS OF CANTILEVER BRACKET CABLE TRAY SUPPORTS





## PART I

# USE OF SEISMIC EXPERIENCE AND TEST DATA TO SHOW RUGGEDNESS OF EQUIPMENT IN NUCLEAR POWER PLANTS

### SENIOR SEISMIC REVIEW AND ADVISORY PANEL (SSRAP)

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## TABLE OF CONTENTS

	<u>Page</u>
1. INTRODUCTION .....	1
2. EARTHQUAKE EXPERIENCE DATA BASE.....	6
3. SEISMIC MOTION BOUNDING SPECTRUM FOR EARTHQUAKE EXPERIENCE DATA.....	14
4. GENERIC EQUIPMENT RUGGEDNESS SPECTRA.....	22
5. OPERABILITY OF RELAYS, CONTACTORS, MOTOR STARTERS, AND SWITCHES.....	26
6. SEISMIC WALKDOWN.....	31
7. EQUIPMENT ANCHORAGE.....	40
8. BASE ISOLATION SYSTEMS.....	51
9. SAMPLING CONSIDERATIONS FOR EQUIPMENT ANCHORAGE.....	53
10. ELECTRICAL POWER EQUIPMENT.....	59
A. Motor Control Centers.....	59
B. Low-Voltage Switchgear.....	62
C. Medium-Voltage Switchgear.....	64
D. Transformers.....	67
11. BATTERY CHARGERS AND STATIC INVERTERS.....	70
12. STATION BATTERIES ON RACKS.....	72
13. CONTROL PANELS AND INSTRUMENTATION CABINETS.....	74
14. INSTRUMENT RACKS.....	76
15. DISTRIBUTION PANELS.....	78
16. TEMPERATURE SENSORS.....	79
17. ENGINE AND MOTOR GENERATORS.....	80
18. AIR COMPRESSORS.....	82

TABLE OF CONTENTS cont'd

	<u>Page</u>
19. PUMPS.....	83
A. Horizontal Pumps.....	83
B. Vertical Pumps.....	84
20. VALVES.....	87
21. FANS AND AIR HANDLERS.....	93
A. Fans.....	93
B. Air Handlers.....	94
22. CHILLERS.....	95
APPENDIX A--COMMENTARY ON SEISMIC MOTION BOUND CRITERIA.....	97
REFERENCES.....	108
PARTIAL BIBLIOGRAPHY OF MATERIAL REVIEWED BY SSRAP.....	112

February 28, 1991

1. INTRODUCTION

Seismic design criteria and methods for the seismic qualification of mechanical and electrical equipment in nuclear power plants have undergone significant change during the history of the commercial nuclear power program. The current requirements for qualification of equipment in licensing plants are defined in the U.S. Nuclear Regulatory Commission (NRC), Regulatory Guide 1.100, "Seismic Qualification of Electric Equipment for Nuclear Power Plants," which, with some exceptions, basically endorses IEEE Standard 344-1975, "IEEE Recommended Practices for Seismic Qualification of Class IE Equipment for Nuclear Power Generating Stations," and in Revision 2 to the NRC Standard Review Plan Section 3.10, "Seismic and Dynamic Qualification of Mechanical and Electrical Equipment."

The need for a reassessment of the seismic capability of equipment in older operating plants that did not undergo the present requirements was identified as Unresolved Safety Issue A-46 (Seismic Qualification of Equipment in Operating Plants) by the NRC in December 1980. "The objective of USI A-46 is to develop alternative seismic qualification methods and acceptance criteria that can be used to assess the capability of mechanical and electrical equipment in operating nuclear power plants to perform the intended safety functions" (Reference 1). This objective was based on the recognition by the NRC that it is not practical to qualify equipment in operating plants using current seismic criteria.

All plants not reviewed to these current equipment qualification requirements are to be included in the A-46 review. For plants reviewed under the Systematic Evaluation Program (SEP), structural integrity of

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February 28, 1991

some equipment has already been covered; however, there are some SEP plants for which the equipment seismic adequacy was left to the resolution of USI A-46. The scope of the review should be established in accordance with each plant's Integrated Safety Assessment Report and related Safety Evaluation Reports (Reference 1). Furthermore, the seismic adequacy need be demonstrated only for those systems, subsystems and components required to cool down to hot shutdown within 72 hours, as given in the plant's Technical Specification.\*

A group of affected utilities has formed the Seismic Qualification Utility Group (SQUG) to work with the NRC in developing a program methodology to enable to resolve the A-46 issue.

Through their consultants, the SQUG has gathered an extensive earthquake experience data base which demonstrates the seismic ruggedness of many items of nonseismically qualified industrial grade equipment installed in fossil fuel power plants and heavy industrial facilities (called herein the data base plants) for ground motion up to about 0.5g. This data base has been extensively reviewed by both the NRC staff and by a five-member Senior Seismic Review and Advisory Panel (SSRAP).

SSRAP, whose members were jointly selected by SQUG and the NRC, was retained in June 1983 to make an independent assessment of whether certain classes of equipment in operating nuclear power plants in the U.S. have demonstrated sufficient seismic ruggedness in past earthquakes so as to render an explicit seismic qualification unnecessary. SSRAP operates as

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\* Referred to as hot shutdown in the text following.

February 28, 1991

an independent review body with all of its findings submitted concurrently to both SQUG and the NRC.

The conclusions from this initial assessment were documented in the SSRAP report, "Use of Past Earthquake Experience Data to Show Seismic Ruggedness of Certain Classes of Equipment in Nuclear Power Plants." This report was originally issued in February 1984 and reissued in January 1985 with minor revisions (Reference 2). However, Reference 2 was limited to addressing only eight classes of equipment. Since that time, earthquake experience data has been gathered for a number of additional classes of equipment together with additional data for the original eight classes of equipment. In addition, ANCO Engineers through the Electric Power Research Institute (EPRI) has developed a number of Generic Equipment Ruggedness Spectra (GERS) using available test data for a number of equipment items (Reference 3) (this report has been superseded by Reference 4), and URS Corp./John A. Blume & Associates through EPRI has developed equipment anchorage criteria (Reference 5) (this report has been superseded by Reference 6). A revision to Reference 2, entitled "Use of Seismic Experience and Test Data to Show Ruggedness of Equipment in Nuclear Power Plants," was issued on August 26, 1988, (Reference 7). The August 1988 report incorporates these additional classes of equipment with additional data for the original eight classes of equipment and also discusses the use of GERS and anchorage criteria. On April 16, 1990, the report was revised to include some changes and also to discuss the use of GERS for certain relays, which are given in Reference (8).

February 28, 1991

This issue of the report (Revision 4) incorporates some changes and additions to the previous issue.

SSRAP has reviewed the Generic Equipment Ruggedness Spectra (GERS) recommended in Reference 4 for most of the equipment classes listed in Table 2-1, the GERS for certain relays recommended in Reference 8, and equipment anchorage criteria recommended in Reference 6. SSRAP concurs with the recommendations contained in these reports and supports their usage subject to conditions placed thereon as given in Sections 4, 5, and 7 of this report.

Cable trays are an additional class of equipment being addressed by the SQUG A-46 program, although they are not included in Table 2-1. The performance of cable trays and their supports has been excellent for ground motions at least up to the seismic motion bounding spectrum shown in Figure 3.1. SSRAP has prepared a separate report on cantilever bracket cable trays (Reference 9), which presents the SSRAP philosophy in evaluating the seismic ruggedness of such systems. Reference 10, which has been reviewed by SSRAP, extends that philosophy to other cable tray support systems, and SSRAP supports its use.

Lastly, SSRAP has reviewed the recommendations made in Reference 11 for the seismic evaluation of tanks and heat exchangers, which are not included in Table 2-1, and supports the use of the seismic evaluation procedures recommended therein.

Reference 12 contains the Generic Implementation Procedure (GIP) "to provide the technical approach, generic procedures, and documentation requirements which can be used by owners of currently operating nuclear



February 28, 1991

power plants to evaluate the seismic adequacy of mechanical and electrical equipment which is needed to bring their plants to a safe shutdown condition following a safe shutdown earthquake (SSE)."

This SSRAP report consists of a discussion of the earthquake experience data base; the recommended bounding spectrum for the classes of equipment discussed in the report; a discussion of an alternate method (GERS) which may be used as a supplement or in lieu of the earthquake experience data base; a discussion on the operability of relays and contactors; some general comments and observations on performing seismic walkdown; and a discussion on equipment anchorage and base isolation systems. This is followed by the class definitions and caveats for the classes of equipment that have been reviewed.

2. EARTHQUAKE EXPERIENCE DATA BASE

The classes of equipment covered within this document from the earthquake experience data base are listed in Table 2.1. SSRAP's assessment was primarily based upon past earthquake performance data for these classes of equipment provided to SSRAP by the Seismic Qualification Utility Group (SQUG) through its consultant, EQE Incorporated, as partially documented in References 13 through 22. Basically, detailed reviews were conducted by EQE on the performance of these classes of equipment primarily at:

1. Several conventional power plants (Valley Steam Plant, Burbank Power Plant, Glendale Power Plant, and Pasadena Power Plant) and the Sylmar Converter Station subjected to the 1971 San Fernando earthquake (magnitude 6.5)
2. The El Centro Steam Plant and smaller power plants subjected to the 1979 Imperial Valley earthquake (magnitude 6.6)
3. Pumping stations and petrochemical facilities subjected to the 1983 Coalinga earthquake (magnitude 6.7)
4. Several industrial facilities subjected to the 1984 Morgan Hill earthquake (magnitude 6.2)
5. Several power plants, substations, water pumping stations, and industrial facilities subjected to the 1985 Chile earthquake (magnitude 7.8)
6. Several hydroelectric plants and industrial facilities near the epicentral region of the 1985 Mexico earthquake (magnitude 8.1)

In addition, much more limited reviews were conducted at several electrical substations for the 1971 San Fernando earthquake, the Ormond

TABLE 2-1  
CLASSES OF SAFE SHUTDOWN EQUIPMENT

Section in Report

10 .....Electrical Power Equipment

- A. Motor Control Centers
- B. Low-Voltage Switchgear
- C. Medium-Voltage Switchgear
- D. Transformers

11 .....Battery Chargers and Static Inverters

12.....Station Batteries on Racks

13 .....Control Panels and Instrumentation Cabinets

14 .....Instrument Racks

15 .....Distribution Panels

16 .....Temperature Sensors

17 .....Engine and Motor Generators

18 .....Air Compressors

19 .....Pumps

- A. Horizontal
- B. Vertical

20 .....Valves

21 .....Fans and Air Handlers

22 .....Chillers

February 28, 1991

Beach Plant and one substation subjected to the 1973 Point Mugu earthquake (magnitude 5.9), the Ellwood Peaker Plant and the Goleta Substation subjected to the 1978 Santa Barbara earthquake (magnitude 5.1), the Humboldt Bay Power Plant subjected to the 1975 Ferndale earthquake and the 1980 Humboldt earthquake, and two small power plants subjected to the 1986 Adak, Alaska, earthquake. Limited literature reviews searching for reported failures of equipment were conducted for the 1964 Alaska (magnitude 8.4), 1952 Kern County (magnitude 7.4), 1978 Miyagi-ken-oki, Japan (magnitude 7.4), 1976 Friuli, Italy (magnitude 6.5), and 1972 Managua, Nicaragua (magnitude 6.2) earthquakes. Some of this work was initiated at the request of SSRAP and all of this work was reviewed by SSRAP.

All members of SSRAP performed walk-throughs of the Sylmar Converter Station, Valley Steam Plant, and Glendale Power Plant, and the SSRAP members spoke with operators present during or shortly after the 1971 San Fernando earthquake at the Sylmar Converter Station and the Glendale Power Plant. Two SSRAP members walked through many of the data base facilities in Chile. In addition, at least one SSRAP member has familiarity with equipment in these classes at the El Centro Steam Plant and at some of the pumping stations and refineries used in the Coalingadata base. All members of SSRAP have conducted walk-throughs of at least five different nuclear power plants for the purpose of reviewing these classes of equipment. Several members have conducted similar walk-throughs of many additional nuclear power plant units. The purpose of these walk-throughs was to judge similarity between the equipment in nuclear power plants and that in the conventional plants from which past earthquake experience data

February 28, 1991

were collected. SSRAP also had discussions with representatives from vendors of some of these classes of equipment, regarding similarity between equipment installed in nuclear plants and conventional plants. A partial list of the material reviewed by SSRAP is given in the bibliography. Lastly, SSRAP relied on the extensive collective experience of its five members with these classes of equipment.

After a detailed and careful review of the full range of the available experience data base, combined with the general experience of the SSRAP members (from test data, analysis, shipping, and operational experience, etc.), the SSRAP conclusions for these classes of equipment are:

1. Equipment installed in nuclear power plants is generally similar to and at least as rugged as that installed in conventional power plants.
2. This equipment, when properly anchored, and with some reservations as discussed in subsequent sections, has an inherent seismic ruggedness and a demonstrated capability to withstand substantial seismic motion without significant structural damage.
3. Up to the levels considered in this report, functionality after the strong shaking has ended has also been demonstrated for this equipment, but the absence of relay chatter\* during strong shaking has not been demonstrated. (See Section 5 for further

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\*Throughout this report, the term "relay chatter" is used as shorthand notation to designate relay, contactor, motor starter, and switch chatter or inadvertent change of state as discussed in Section 5.

February 28, 1991

discussion of functionality of relays during strong shaking.) Other than for the exception of relay chatter, functionality during strong shaking has also been demonstrated.

Therefore, with a number of caveats and exclusions as discussed in subsequent sections, it is the judgment of SSRAP that for excitations below the seismic motion bounds described in Section 3, it is unnecessary to perform explicit seismic qualification of existing equipment in these classes (Table 2-1) for A-46 nuclear power plants to demonstrate functionality during (except for relay chatter) or after the strong shaking has ended. The existing data base reasonably demonstrates the seismic ruggedness of this existing equipment up to these seismic motion bounds. This conclusion should not be extrapolated beyond these classes of equipment or to newer commercial grade equipment without detailed review.

SSRAP is concerned that some new commercial grade equipment may not be as rugged as older models of similar equipment and, hence, may not be adequate when subjected to ground motions comparable to the reference spectra. For example, design changes in low voltage switchgear of one manufacturer allowed a draw-out type circuit breaker to move significantly more than the older model. This increased motion at vibration levels comparable to the reference spectra might allow secondary contact to malfunction or fail. Examples can also be cited where structural supports and enclosures of new electrical equipment are much more flexible than their older counterparts. Transformer coil supports for some new dry-type transformers appear to be more flexible than older models. Many modern low voltage switchgear cabinets have only frames fastened with a few sheet

February 28, 1991

metal screws instead of the older designs with substantial welded solid steel sheets surrounding each circuit breaker. Obviously, these newer cabinets are considerably more flexible than the older models. SSRAP believes these changes in some modern equipment have evolved due to economics and non-seismic issues and that this equipment is different from older equipment that has performed well in past earthquakes. None of this discussion is intended to imply that newer seismically designed (Seismic Category I) equipment is weaker than older nonseismically designed models.

The assessment of equipment ruggedness by this procedure is not the same as seismic qualification of equipment that meets standard review plan requirements. This procedure to verify seismic ruggedness of equipment was developed for the equipment in the A-46 operating nuclear power plants where, among other factors, it would be impractical to remove equipment for seismic testing. In other situations where the Regulatory Authorities agree that it is sufficient to demonstrate seismic ruggedness in lieu of explicit seismic qualification of equipment, this procedure could be used. Such extensions of this methodology should be used only for equipment similar to the experience data base equipment and made only after considering all aspects of the situation.

It should be noted that the equipment data base reviewed by SSRAP primarily consisted of U.S. manufactured equipment. In addition, the nuclear power plants walked-down by all members of SSRAP were U.S. plants with predominately U.S. manufactured equipment. Although some members of SSRAP have reviewed non-U.S. manufactured equipment performance during earthquakes and some members of SSRAP have walked-down nuclear power plants in several countries which contained primarily non-U.S.

February 28, 1991

manufactured equipment, this experience is not common to all members of SSRAP. Even though the caveats, exclusion rules, and conclusions of this report are likely to be appropriate for most non-U.S. manufactured equipment of the same class, some extra caution must be exercised in this regard and additional caveats or evaluations may be necessary. Any group extending the SQUG approach to non-U.S. manufactured equipment must be especially cognizant to situations where this equipment may differ from corresponding U.S. manufactured equipment. For example, walkdown teams should open electrical cabinets and assure themselves of a framing or other structural system to provide sufficient rigidity and an adequate load path to transfer internal seismic-induced inertial loads to the cabinet supports (particularly when such cabinets contain transformers, breakers, or other heavy components mounted away from the cabinet supports).

SSRAP recommendations are based on experience data which confirm that the equipment included within the limitations is rugged enough to maintain functionality after the strong shaking has ended. However, there have been cases where maintenance personnel have noted increased wear in bearings of vertical pump shafts several weeks following the earthquake exposure. Because wear of bearings is a normal condition and because these pumps did operate for weeks after the earthquake before maintenance was required, SSRAP feels that this potential situation is within routine maintenance and not a matter of safety concern within a few days after an earthquake. It is mentioned only as an additional consideration for post-earthquake maintenance checks. This same consideration (slight misalignment leading



February 28, 1991

to increased wear in bearings) is likely to apply as well to other mechanical equipment with rotating shafts.

The question of aging of equipment as to its affect on seismic performance has been raised in several of the SSRAP discussions. Much of the data base equipment was over 20 years old at the time of the earthquake exposure, and some of this equipment is located in reasonably high thermal and corrosive environments, so the data base addresses these aspects of the effect of equipment aging on seismic performance. However, the data base equipment was not exposed to radiation, so the aging effects from radiation exposure upon the equipment are beyond the scope of this program.

3. SEISMIC MOTION BOUNDING SPECTRUM FOR EARTHQUAKE EXPERIENCE DATA

SSRAP based its earthquake experience conclusions primarily on the earthquake experience data base from earthquakes of magnitude 6.0 and greater and from facilities for which the estimated mean peak ground acceleration (average of two horizontal components) was equal to or greater than about 0.4g as listed in Table 2.1 of Reference 22. Such ground motion was judged by SSRAP to be sufficiently severe to demonstrate adequate ruggedness of equipment to withstand input motion associated with ground motion represented by a U.S. NRC Regulatory Guide 1.60 (Reference 23) spectrum anchored to 0.25g or a NUREG/CR-0098 (Reference 24) median spectrum anchored to 0.3g when such equipment was mounted less than about 40 feet above grade in a nuclear power plant. Furthermore, an adequate data base existed at these facilities for SSRAP to reach conclusions on the seismic ruggedness of each of the classes of equipment up to this ground motion level.

In order to compare the potential performance of equipment at a given nuclear power plant with the actual performance of similar equipment in the data base plants in recorded earthquakes, SSRAP has developed a generic Seismic Motion Bounding Spectrum to facilitate comparison. The purpose of this Bounding Spectrum is to compare the potential seismic exposure of equipment in a nuclear power plant with the estimated ground motion that similar equipment actually resisted in earthquakes described in the data base. For convenience, the Bounding Spectrum is expressed in terms of ground response at the nuclear site rather than floor response or equipment response. This Bounding Spectrum represents approximately

February 28, 1991

two-thirds of the estimated average free-field ground motion to which the data base equipment was actually exposed at sites with estimated mean peak ground accelerations in excess of about 0.4g. The derivation of this Bounding Spectrum is discussed in more detail in Appendix A. The generic Bounding Spectrum is defined in terms of the 5% damped horizontal ground response spectrum in Figure 3.1 and Table 3.1. This Bounding Spectrum must be used together with the caveats and exclusions listed in the subsequent sections for each of the classes of equipment. In the case of some medium voltage switchgear and some motor-operated valves with large eccentric operator length to pipe diameter ratios, this Bounding Spectrum may be factored downward as described in Sections 10C and 20 respectively.

This spectrum bound is intended for comparison with the 5% damped design horizontal ground response spectrum at a given nuclear power plant. In other words, the experience data base demonstrates adequate seismic ruggedness when the horizontal ground response spectrum for the nuclear plant site is less than the Bounding Spectrum at a reasonably conservative lower bound estimate of the fundamental frequency of vibration of the equipment and at all greater frequencies (also referred to as the frequency range of interest). Alternately, one may compare 1.5 times the Bounding Spectrum with a given 5% damped horizontal in-structure spectrum in the nuclear plant over this frequency range of interest.

The comparison of the seismic bound with design horizontal ground response spectra is judged to be acceptable for equipment with frequencies

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\*In most cases where numerical values are given in this report, they should be considered as either "approximate" or "about" and a tolerance about the stated value is implied.

TABLE 3-1 SEISMIC MOTION BOUNDING SPECTRUM	
Frequency (Hz)	Spectral Acceleration (g) 5% Damped
2	0.65
2.5 - 7.5	0.80
8	0.75
10	0.60
12	0.53
16	0.45
20	0.39
28	0.35
> 33	0.33

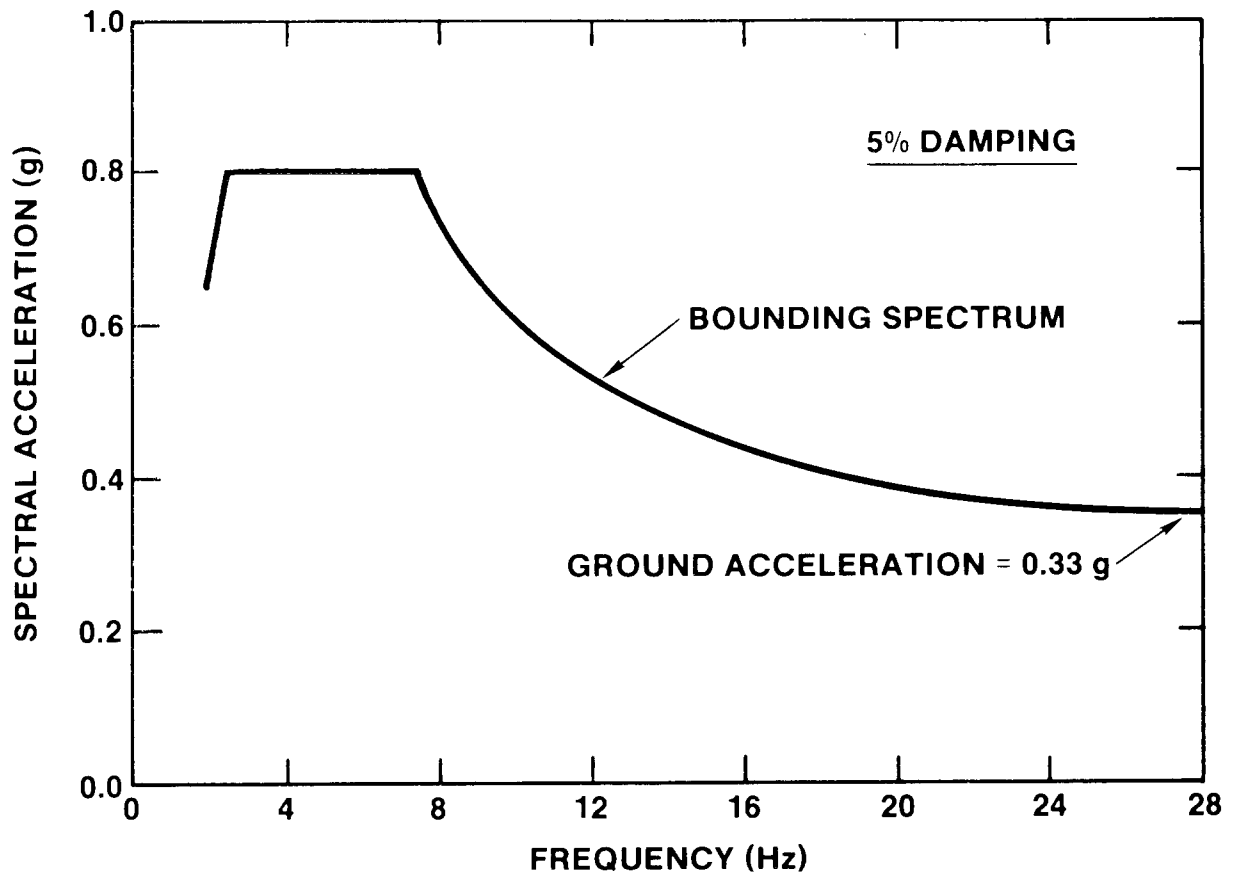


Figure 3.1 SEISMIC MOTION BOUNDING SPECTRUM  
HORIZONTAL GROUND MOTION

February 28, 1991

in excess of about 8 Hz mounted less than about 40 feet\* above grade (the top of the ground surrounding the building) and for reasonably stiff structures. If the natural frequency of the equipment is less than about 8 Hz, the floor response spectrum must be compared to 1.5 times the Bounding Spectrum even though the equipment is mounted less than about 40 feet above grade (see Appendix A.1). However, this 8 Hz frequency requirement is unnecessary in the case of valves where low frequency amplification of input motions are incorporated in the data base. For equipment mounted more than about 40 feet above grade, comparisons of 1.5 times the Bounding Spectrum with horizontal in-structure spectra is necessary. In all cases such a comparison with in-structure spectra is also acceptable. SSRAP is of the opinion that the vertical component will not be any more significant relative to the horizontal components for nuclear plants than it was for the data base plants. Therefore, it was decided that seismic bounds could be defined purely in terms of horizontal motion levels.

The criteria are met so long as the 5% damped design horizontal spectrum lies below the appropriate bounding spectrum at frequencies greater than or equal to the fundamental frequency range of the equipment. SSRAP believes that in most cases this estimate can be made judgmentally by experienced engineers without the need for analysis or testing.

The above recommendation that the seismic Bounding Spectrum can be compared with the design horizontal ground response spectra for equipment mounted less than about 40 feet above grade is based upon various judgments concerning how structures respond in earthquakes. These are discussed in Appendix A.2. SSRAP wishes to emphasize that this 40 foot

February 28, 1991

above grade criteria must be applied with some judgment, as some structures may respond in a different manner. Several examples with guidance are given in Appendix A.2.

The lower bound limit of about 8 Hz on equipment frequency for comparison of ground spectrum with the Bounding Spectrum is also discussed in Appendix A.2. The purpose of this limit is to avoid situations where both the equipment and supporting structure have frequencies close to each other and are within the frequency range of the significant power of the input motion. For typical design spectra, over 90% of the power comes from frequencies below about 7 Hz (Reference 35). The lower bound limit of about 8 Hz is intended to avoid the frequency range of below 7 Hz which contains most of the power of the input motion. If the SRT is not confident that the equipment frequency exceeds about 8 Hz, then the SRT should use the in-structure spectrum comparison with 1.5 times the Bounding Spectrum in lieu of comparing the ground response spectrum to the Bounding Spectrum.

Comparison of 1.5 times the Bounding Spectrum with a given 5% damped horizontal in-structure spectrum in the nuclear plant also requires judgment. First of all, SSRAP envisions that realistic (essentially median centered) in-structure spectra will be used for this comparison. Very conservative design spectra may be used, but their use is likely to introduce substantial conservatism. Secondly, most unbroadened computed in-structure spectra have very narrow, highly amplified peaks at the resonant frequency of the structure. In most cases these narrow, highly amplified peaks are artificially broadened to account for uncertainty in the structure's natural frequency. This process simply increases the

February 28, 1991

emphasis on these highly amplified peaks. SSRAP recommends that uncertainty in the structure's natural frequency can be better handled by shifting the frequency of these peaks rather than by spectra broadening. In this way, the narrowness of the peak can be retained and displayed. SSRAP is also of the opinion that these narrow peaks will not be as highly amplified in real structures at high ground motion levels as is predicted by linear elastic mathematical models, nor are such narrow peaked in-structure spectra likely to be as damaging to equipment as is a broad frequency input which is represented by 1.5 times the Bounding Spectrum. Therefore, SSRAP is not concerned if the in-structure spectrum slightly exceeds 1.5 times the Bounding Spectrum over a narrow frequency range. However, the average ratio of the in-structure spectrum to 1.5 times the Bounding Spectrum over a frequency range of about 10% of the frequency of interest (0.5 Hz range at 5 Hz, etc.) should not exceed unity.

A summary of SSRAP's recommendations is given in Table 3-2.



Table 3-2

Summary of SSRAP Recommendations for Seismic Demand  
To Be Used For Equipment Verification\*

1. Equipment mounted less than about 40 ft. above the effective grade
  - A. Natural frequency of equipment less than about 8 Hz  
  
Compare 5% damped horizontal floor response spectrum (largest component) (demand) with 1.5 times the Bounding Spectrum, Fig. 3.1 (capacity)
  - B. Natural frequency of equipment greater than about 8 Hz  
  
Compare 5% damped horizontal ground response spectrum (largest component) (demand) with the Bounding Spectrum, Fig. 3.1 (capacity)

NOTE--The 8 Hz frequency requirement is not necessary in the case of valves. See text.
2. Equipment mounted more than about 40 ft. above the effective grade  
  
Compare 5% damped horizontal floor response spectrum (largest component) (demand) with 1.5 times the Bounding Spectrum, Fig. 3.1 (capacity)

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\*Additional considerations exist for the following:

1. Use of Generic Equipment Ruggedness Spectra—See Section 4
2. Anchorage Evaluation—See Section 7

4. GENERIC EQUIPMENT RUGGEDNESS SPECTRA

SSRAP recognizes that the use of past earthquake experience data is not the only method by which seismic ruggedness of equipment can be demonstrated so as to make it unnecessary to perform explicit seismic qualification of existing equipment for operating nuclear power plants. An equally acceptable alternate method is through the use of Generic Equipment Ruggedness Spectra (GERS) developed by ANCO Engineers for the Electric Power Research Institute (References 4 and 8). These GERS are intended to represent the highest input levels for which one has high confidence of successful equipment performance. Except as noted below, SSRAP supports their usage so long as the applicable caveats, exclusion rules and similarity requirements that accompany each GERS (including the discussion at the start of each GERS package) are complied with and so long as the GERS are used with in-structure (floor) spectra at the support point of the equipment. All caveats, exclusion rules, and similarity requirements contained in this report for the use of past earthquake experience data also apply for use of these GERS. In addition, the caveats, exclusion rules, and similarity requirements contained in References 4 and 8 are applicable.

It should be noted that there may remain issues such as vintage, similarity, and test result repeatability for relay chatter (Reference 8). It is SSRAP's judgment that these issues are industry-wide issues beyond the scope of USI A-46 and that their eventual resolution is not likely to happen in the near future. SSRAP strongly recommends that the necessary plant seismic walkdowns and reviews to resolve USI A-46 proceed immediately without waiting for resolution of these open relay chatter

February 28, 1991

issues. If any of these open relay chatter issues are subsequently found to be sufficiently serious to warrant it, a revisiting of the relay chatter issue may be necessary in the future. Nevertheless, at this time, SSRAP supports the use of the relay GERS of Reference 8 or other available model-specific relay chatter fragility or qualification test data. For additional relay chatter considerations, see Section 5.

An issue considered by SSRAP was how large of a factor should exist between the GERS amplitude and the in-structure spectrum amplitude throughout the frequency range of interest. It should be recognized that the GERS are conservatively defined but that the degree of conservatism is not quantifiable and is likely to be variable. Thus some additional and quantifiable factor of conservatism greater than unity is necessary between the GERS and the in-structure spectrum unless the in-structure spectrum is conservatively defined. In-structure spectra, which are computed roughly in accordance with current U.S. Nuclear Regulatory Commission Regulatory Guides and Standard Review Plans, are adequately conservative so that it is acceptable to directly compare the GERS with these in-structure spectra. In other words, no additional factor of conservatism is necessary. However, if realistic (approximately median centered) in-structure spectra such as those suggested for use with the earthquake experience data are used with these GERS, then an additional factor of conservatism is necessary to cover reasonable variability in the in-structure spectra. When realistic (median centered) in-structure spectra are used, they should be multiplied by a factor of conservatism of 1.5 prior to comparison with the non-relay GERS of Reference 4. Part of

February 28, 1991

this 1.5 factor of conservatism is to cover the possibility that an item of equipment which falls into a particular equipment category might have a seismic capability slightly less than the GERS for that category because of the diversity of equipment which can fall into each of these categories. The relay GERS of Reference 8 are for specific model numbers. Therefore, the diversity is less for relay chatter GERS than it is for non-relay GERS. However, relay GERS are generally based upon fragility tests so that the degree of conservatism might be less. In addition, there is the question of relay chatter capacity variability between relays with the same model number. Based on these considerations, SSRAP judged that this same factor of conservatism of 1.5 should be used for relay chatter GERS.

For equipment mounted directly to reasonably stiff floors or walls at elevations less than about 40 feet above grade, realistic horizontal in-structure spectrum at the support of the equipment can be approximated by 1.5 times the horizontal ground response spectrum at frequencies above about 8 Hz in the same manner as this was done with the earthquake experience data base. In this case, the factored in-structure spectrum to use for comparison with GERS would be  $1.5 \times 1.5 = 2.25$  times the horizontal ground response spectrum. For valves attached to piping or relays attached to cabinets, realistic amplification through the piping or cabinets must also be included before comparison with the GERS.

For the same reasons as were discussed in Section 3, SSRAP has no concern with very narrow frequency exceedances of the GERS. Thus narrow frequency exceedances are acceptable so long as the average ratio of the factored in-structure spectrum to the GERS over a frequency range of about

February 28, 1991

10% of the frequency of interest (0.5 Hz range at 5 Hz, etc.) does not exceed unity. In addition, SSRAP believes that peak broadening of the in-structure spectra is not necessary. Rather, shifting the frequency of these peaks is recommended as discussed in Section 3.

5. OPERABILITY OF RELAYS, CONTACTORS, MOTOR STARTERS AND SWITCHES

The chatter of relays and its consequences raise several complex issues. For A-46 the issues of relay ruggedness and operability concerns only those relays needed for hot shutdown. Relay functionality is being addressed in accordance with the relay evaluation procedures (Reference 25).

The earthquake experience data base has demonstrated, except in an isolated case, that relays will survive an earthquake undamaged so that they can be expected to function after an earthquake. The data base also demonstrates that circuits can be properly reset and that the equipment can function properly after an earthquake. Shake table test data also supports these conclusions.

The earthquake data base indicates a number of instances of inadvertent change of function (circuit breaker trip, etc.) due either to chatter\* of protective relays or due to temporary seismic-induced transients (such as liquid sloshing, dynamic liquid pressure, or vibration) resulting in a signal that trips a protective relay.

The earthquake experience data base does not contain any well documented examples of inadvertent changes of function due to seismically-induced chatter of auxiliary relays. However, the earthquake data base is insufficient to preclude the possibility of an inadvertent change of function due to chatter of auxiliary relays. On the other hand, several different types of auxiliary relays have exhibited relay chatter when

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\*Throughout this report the term "relay chatter" is used to represent relay, contactor, motor starter, and switch chatter or inadvertent change of state.

February 28, 1991

de-energized during low level shake table tests. There are also numerous examples of non-seismic vibration-induced auxiliary relay actions in nuclear plants. SSRAP is of the opinion that either one or all of the following exist:

1. Chatter of auxiliary relays, to the extent that it exists, has had negligible consequences in the data base facilities; however, this still leaves open the question of consequences of relay chatter in nuclear power plants as their circuits may be different.
2. The inadvertent changes of function observed in the data base facilities is not adequately documented.
3. Conservatism in the criteria used to define chatter in shake table tests may overstate the effect of the chatter when relays are incorporated in equipment.

There are several issues related to the evaluation of relays including the use of relay GERS, relay sensitivity to high frequencies, relay designation, relay adjustments, and the use of similarity.

- The Use of Relay GERS

To use relay GERS in assessing the operability of relays in cabinets, it is necessary to amplify the in-structure spectra at the base of the cabinet by an effective amplification factor appropriate for the mid-frequency range (less than about 20 Hz) to obtain the amplified input to the relay. SSRAP's review of amplification data for motor control centers (References 26-29) indicates an amplification screening factor of 3 is appropriate. For benchboards and vertical control panels, which meet the

criteria given in Reference 30, an amplification screening factor of 4.5 can be used. Because of the limited amount and variability of test data for switchgear and other cabinets with comparable size panels, it is difficult to arrive at an amplification screening factor; an amplification screening factor of 6 or slightly greater appears to be reasonable.

- Relay Sensitivity to High Frequencies

SSRAP believes that there is a class of relays that have shown themselves to be very sensitive to higher frequency excitation and that these can be identified and excluded by reference to documented operating experience in which these relays have been accidentally activated by bumping or hitting their cabinets.

Rattling of equipment components may cause higher amplification above 20 Hz. Relays that are sensitive to high frequencies are being identified through a joint effort of SQUG and the NRC staff.

- Relay Designation

Each manufacturer has a format of characters to denote a relay type or family and a subtype or application design. Additional characters may denote contact, coil, and case mounting configuration. Together they specify a unique relay model and configuration. In some cases, slight changes in the identification number will designate relays that are seismically identical while in other cases it will designate a relay with markedly different seismic performance. It is difficult to generalize how much of a relay's identification number is necessary



February 28, 1991

to identify it as being covered by a specific GERS. Guidance provided with each GERS must be carefully followed.

- Relay Adjustments

A few nonprotective relays are adjustable. The GERS level may be very sensitive to the adjustment setting. Information on this topic is given in the relay GERS Report (Reference 8).

- Use of Similarity

SSRAP believes that the use of similarity to establish the ruggedness of relays must be done with great care. Because of the specialized knowledge required, SSRAP believes that a small, select standing panel with intimate knowledge of the design, operation, seismic testing and use of relays should be established to evaluate relay similarity. In addition, a small percent of the relays judged to be rugged by reasons of similarity should be tested to verify the validity of the methodology.

SSRAP has also some concerns that relate to specific equipment.

SSRAP has a particular concern for some types of motor control centers. Equipment that contains critical relays and has long panels, often called 'buckets,' at the rear of the compartment as viewed from the front, and are only anchored at the top, should be evaluated to assure functionality of the relays during the earthquake. SSRAP is concerned that impacting of the rear panel as its bottom swings in and out may cause relay malfunction during the earthquake. Either the use of relays with high resistance to relay chatter or the anchoring of the panel to prevent impacting would address SSRAP's concerns.

February 28, 1991

SSRAP is unaware of any cases in the earthquake experience data base where contactors in motor control centers have actually tripped due to contactor chatter or cases where motors have either inadvertently started or stopped due to motor starter chatter. However, SSRAP is aware that shake table tests have often reported auxiliary contactor chatter and signal chatter for the smaller motor starter units at rather low shaking levels which are in the range that one would expect from the range of the experience data ground motion levels. Therefore SSRAP is not currently prepared to totally dismiss the issue of functionality during strong shaking due to auxiliary contactor and motor starter chatter. On the other hand, SSRAP does consider these potential chatter issues to be less important than relay chatter.

SSRAP is concerned with chatter of small, sensitive switches which have dynamic characteristics similar to relays. However, SSRAP has no concern with chatter of either manual switches or mechanically driven switches which require the application of reasonable force in order to change state.

6. SEISMIC WALKDOWN

SSRAP envisions that a detailed seismic walkdown will be an integral part of any effort which uses either earthquake experience data or GERS to assess the seismic ruggedness of equipment. Detailed walkdown criteria are to be presented in revisions to Reference 12, and there is no attempt to duplicate them in this document. It is SSRAP's opinion that the relay chatter evaluation should be performed separately from the seismic walkdown described herein and by a different group of engineers (primarily electrical and system engineers).

It is SSRAP's view that seismic walkdowns should incorporate each of the following:

- Determination of whether equipment lies within the limitations of the caveats and similarity exclusion rules defined in this document
- Judgmental evaluation of any factors which might affect the seismic performance of the equipment
- Flag for special review any unusual or nontypical conditions such as major modifications to standard equipment or equipment that is unique
- Assessment of the adequacy of equipment anchorage
- Assessment of seismic-spacial-systems interactions
- Documentation of the walkdown
- Independent review

February 28, 1991

This report does not go into detail on any of these items because this would be a duplication of the walkdown criteria to be documented in revisions to Reference 12. However, SSRAP desires to comment (primarily by example) on several of these items.

The exercise of considerable judgment and experience is necessary during a seismic walkdown. It is SSRAP's opinion that the most important ingredient is the selection of knowledgeable and practical individuals to serve on the walkdown team. One way to accomplish this goal is to have the work performed under the guidance of an experienced Seismic Review Team (SRT). Between these members, the SRT should possess the following qualifications:

- Knowledge of the failure modes and performance during strong earthquakes of components in heavy industrial process plants and fossil fuel power plants including structures, tankage, piping, process and control equipment, and active electrical components.
- Knowledge of nuclear design standards and seismic design practices for nuclear power plants including tankage, piping, process and control equipment, and active electrical components, as appropriate
- Ability to perform seismic capability evaluations including structural/mechanical analyses of the above-mentioned elements when needed

It is not necessary that each member of the team individually have strong capability in all of these areas or strong seismic experience for all of the elements identified in the success paths being considered. However, in the composite the SRT should be strong in all of these areas.

February 28, 1991

At least two members of the SRT should together "walk-by" each item of equipment for which seismic ruggedness is being assessed. Whenever possible, any issues concerning limitations, caveats, similarity, judgmental factors, nontypical conditions for further review, seismic-spacial-systems interaction, and whether equipment anchorage must be evaluated should be decided "on the spot" by these SRT members. The results of their assessment should be documented. Any requirements for additional evaluation should be carefully delineated. The emphasis should be on a careful and complete exercise of their combined judgment and experience, rather than on the filling out of extensive documentation forms. However, all seismic ruggedness decisions should be signed by the SRT members who made such decisions on each equipment item, so any documentation forms should contain space for such signatures.

SSRAP is particularly concerned with equipment anchorage and vibration isolated equipment. SSRAP believes that any attempt to justify equipment for acceptable seismic performance must ensure adequate engineered anchorage. There are numerous examples of failure of supports for vibration isolated equipment and of equipment sliding or overturning in earthquakes due to lack of anchorage or inadequate anchorage. Adequacy of lateral support is of particular concern for vibration isolated equipment. Inadequate anchorage can include short, loose or poorly installed bolts or expansion anchors, and improper welding or bending of sheet metal frames at anchors. SSRAP believes that equipment anchorage must not only be strong enough to resist the anticipated forces but should also be stiff enough to prevent excessive movement of the equipment and minimize potential resonant response with the structure and the earthquake. It is

February 28, 1991

SSRAP's opinion that any anchorage review program should include consideration of both strength and stiffness of the anchorage and its component parts. This issue deserves particular attention during the seismic walkdown. See Section 7 for further guidance.

SSRAP also has some concern for the utilities such as air, power, fuel, and cooling systems which might be supplied to the classes of equipment under consideration and which will not fail safe. The concerns are:

- Rupture of lines due to heavy objects falling onto or sliding into them
- Inadequate flexibility of lines to accommodate seismic-induced relative movements between utility support points.

A walkdown of essential utilities which are needed for the functionality of the equipment should be included in the equipment walkdown in order to address these two concerns. For instance, SSRAP has some concern for air lines to essential components which require an air supply (such as air-operated valves) if such components do not fail safe upon loss of the air supply. If the component has a nearby accumulator, the walkdown only needs to cover the air line from the check valve beyond the accumulator to the component. Otherwise it needs to cover the air line from the air compressor to the component. Only the above two listed concerns need to be addressed. Air lines in protected locations such as below-floor utility corridors are not vulnerable to falling heavy objects and do not need a walkdown. Other examples are the fuel line between the day tank and the diesel generators and electrical connections between batteries and adjacent cable anchors. Exposed portions of the fuel line should be

February 28, 1991

looked at during the walkdown. SSRAP does not envision nor desire this utility walkdown to grow into a substantial task. The SRT should exercise judgment concerning the necessary level of this walkdown; but unless significant problems are being discovered, the effort should remain small.

During the seismic walkdown, the SRT should also seek examples of poor seismic housekeeping. Any cases of unlatched latches, unsecured drawers containing safety equipment, unsecured emergency lighting, unsecured gas bottles, unanchored temporary equipment stored above or near safety equipment, and unsecured hung ceilings are examples of poor seismic housekeeping which should be noted and brought to management's attention. The purpose of noting these and other examples is to instill an attitude of "thinking seismic" among operations and maintenance personnel.

The SRT should consider adjacent equipment and conditions near to safety-related equipment to verify that impacts during a seismic event which might cause damage are precluded. This evaluation should consider clearances between the equipment and adjacent structure or equipment to preclude collisions. The data base contains cases where air-operated valves mounted on extremely flexible piping moved several inches and failed upon impact with a structural column and/or railings. The evaluation should also consider the failure or movement of adjacent equipment or objects which may not be safety-related but which might impact the equipment being considered. Examples of such problems have also been observed in earthquakes. Another example is the seismic failure of a nonseismic designed tank leading to flooding of a motor on an adjacent pump at lower elevation.

February 28, 1991

SSRAP is also concerned about flooding-induced damage or disruption associated with the failure or malfunction of fire suppression systems. Sprinkler heads can be damaged due to impact. Failure of sprinkler system piping, primarily due to flexible runs that use threaded connections, can quickly release large amounts of water. It is not only the area directly exposed to the sprinkler head or broken pipe discharge that is vulnerable, but water might spread over large areas and affect equipment at lower elevations in the structure. This can also drain fire suppression water reserves so that they are not available if truly needed.

The above-mentioned issues of essential utilities, housekeeping, equipment impacts, and seismic-induced flooding can all be lumped under the title of seismic-spacial-systems interactions (SI). During the walkdown the SRT should consider these SI issues. However, one must be careful not to allow the seismic walkdown to become dominated by SI issues. One example is that of impacts of air-operated valves into structural members. Such failures are rare (only three examples have been reported to SSRAP). These failures are credible only when these valves are supported on very flexible piping such that the valve can impact the structure with significant velocity. SSRAP does not envision checking for valve impact on every safety-related valve in the plant. It is only necessary to make such an assessment for valves on very flexible piping such that strong impacts are credible. It is SSRAP's opinion that experienced engineers should be able to quickly make judgments concerning which piping is sufficiently flexible such that strong valve impacts are credible. In nearly all cases, a review of piping analyses should be



February 28, 1991

unnecessary. However, a 100% review of all valves on very flexible piping is necessary for this impact failure mode. A sampling review will generally not catch SI issues such as valve impact in those few cases where it is credible. Thus, exercising of considerable judgment and experience by the SRT is necessary when laying out the level of work for investigating these SI issues so that the program remains cost effective. It is SSRAP's opinion that about 10 to 20% of the actual seismic walkdown should be devoted to SI issues for a typical plant.

In subsequent sections, SSRAP states its concerns with cast iron valve bodies and vibration isolators which contain cast iron components. SSRAP considers these concerns to be very important. However, SSRAP also recognizes that it is very difficult to distinguish cast iron from cast steel in the field. SSRAP envisions a sampling review of procurement specifications or contacting of manufacturers to assess the prevalence of cast iron valve bodies and vibration isolators in a specific plant. Depending upon the anticipated situation, the SRT will have to lay out the walkdown sampling program necessary to provide reasonable assurance that such cast iron components are not in the plant.

SSRAP has also requested in the sections on pumps that brief consideration be given to identify situations where pumps might be affected by gross pipe motion, differential displacements, and excessive nozzle loads. It is noted that such situations are uncommon and need only be considered if there is a long section of unsupported pipe or a heavy unsupported valve attached to the pipe near the pump. SSRAP believes that experienced engineers can assess whether an evaluation is necessary by judgment and that the number of cases needing evaluation should be small.

February 28, 1991

SSRAP is concerned that excessive analytical work (which SSRAP wishes to discourage) will result from this caveat unless strong judgment is exercised on the part of the SRT.

Lastly, the SRT must exercise their own judgment and experience to seek out any suspicious details or uncommon situations not specifically covered by SSRAP caveats. One example is that of a horizontal pump failure which resulted from a seismic-induced gearbox oil leak due to an uncommon excessive cantilever overhang (Reference 22). It is impossible to cover all such situations by meaningful caveats, and the SRT is expected to exercise their own judgments and cautions in the use of this document.

Another example is the case of attachments of internal components and subassemblies (such as relays) to equipment cabinets (such as motor control center cabinets). Such attachments should be in accordance with the manufacturer's recommendations. However, a requirement for an inspection of the adequacy of attachment of elements to the equipment cabinet would require extensive effort which does not seem to be warranted. This failure mode has not shown up as an item of serious concern in the earthquake experience data base. It is suggested that component and subassembly attachments be briefly looked at when cabinets are opened for other reasons. Obviously, if some suspicious element attachments are discovered during the walkdown, they should be investigated. However, SSRAP does not believe that an inspection of element attachments to cabinets should be required as part of the walkdown of equipment.

February 28, 1991

These examples of judgments which must be made during the seismic walkdown are far from being all-inclusive. They are intended to be only examples and to provide some SSRAP guidance on these issues. The concluding point is that the seismic walkdown must be conducted under the guidance of an experienced SRT which can make the necessary judgments on a case-by-case basis.

Since considerable judgment must be exercised by the SRT, it is important that some independent review or audit of the procedures of the SRT be incorporated into the process. The independent review can be by the NRC or by individuals of a different organization than the SRT members. The independent review team should participate in one or two days of the walkdown, review procedures and outlier resolution and briefly summarize their activities and observations for the documentation.

7. EQUIPMENT ANCHORAGE

The presence of properly engineered anchorage is perhaps the most important single item which affects the seismic performance of equipment. Earthquakes have repeatedly demonstrated that equipment will slide, overturn or move excessively when it lacks positive anchorage or when it does not have proper engineered anchorage. Anchored equipment failures in the earthquake experience data base include expansion bolts with very short embedments, friction clips (steel plates anchored to the concrete base which extend over the flange or base of the equipment without a positive connection) and base anchorage details with significant eccentricities which allow the equipment base to bend or tear or which generate large prying forces.

SSRAP recommends that equipment anchorage be verified for adequate strength as well as for adequate base stiffness. When the term engineered anchorage is used, SSRAP intends that the anchorage has both adequate strength and sufficient stiffness. The reliance on friction on equipment bases or in friction clips should not be allowed to rationalize that equipment will not slide or move in an earthquake.

Adequate strength of equipment anchorage can be determined by any one of many commonly accepted methods. Design procedures for new equipment anchorage can be used to evaluate existing anchorage strength. Alternatively, procedures have been developed to evaluate anchorage adequacy in nuclear power plants, such as EPRI-sponsored work performed by URS/John Blume. A previous issue of the EPRI Report (Reference 5) has been superseded by a new report (Reference 6); the final version of this report should be used. When anchorage is modified or new anchorage is

February 28, 1991

designed, it is generally inexpensive to add increased conservatism over that contained in Reference 6. In such cases SSRAP recommends the use of either Reference 6 or ACI 349-80, Appendix B, as modified below, whichever is more conservative for the case being considered. When using Reference 6 to evaluate expansion anchor capacities, the values based on the mean divided by four should be used for all electrical cabinets containing essential relays, for all anchors when cracking cannot be evaluated, and when reduced anchorage inspection guidelines are followed. The mean divided by four is appropriate in concrete with cracks in the 0.01 inch to 0.02 inch (10 to 20 mils) range. Values based on the mean divided by three can be used when detailed inspection and evaluation of the anchors is performed in accordance with Reference 6 and cracks in the concrete in the vicinity of the anchors are not greater than about 0.01 inch (10 mils) in width. Anchors in concrete with cracks greater than about 0.02 inch (20 mils) should be considered outliers, and a separate evaluation will be required. Other evaluation procedures can be used but the user should carefully review the assumptions in those procedures and obtain approval from reviewing authorities. Engineers using an evaluation procedure to verify anchorage adequacy should also consider all limitations or restrictions of the procedures being used and not mixed or substitute features of various procedures to rationalize higher strengths. Likewise, reviewers should not mix provisions of various procedures and impose the most severe of each to justify increased conservatism.

One of the major changes in Reference 6 compared with the previous version (Reference 5), was a detailed review of the effects of cracks in concrete in the vicinity of expansion anchors. A concrete crack passing

February 28, 1991

through an expansion anchor or through the potential failure cone of an anchor can weaken the anchor capacity. Based on this review and input from the NRC, it was agreed that for expansion anchors, the mean divided by three capacity values contained sufficient conservatism to cover any influence from cracks less than about 0.01 inches (10 mils) in width. This range of crack widths should also cover potential cracks which may appear as a result of an earthquake in substantially reinforced concrete typical of nuclear power plants. The mean divided by four capacity values are appropriate for anchors near cracks up to about 0.02 inches (20 mils) width. Anchors near cracks greater than about 0.02 inches (20 mils) should be considered outliers due to the lack of data and must be evaluated by other means. It is not the intent of SSRAP that walkdown engineers be required to use a comparator and measure the widths of cracks near all anchorages. Rather, with minimal training, they should have a feel of the range of cracks involved and make observations, exercise judgment, and draw conclusions. The exact location of most cracks near anchors will be concealed by the equipment base so judgment is the only practical way to treat this issue.

When using ACI 349-80, Appendix B, to design new anchorage or modify existing anchorage, the following modification to that document shall be made. When calculating shear capacity of an anchorage using the shear-friction-type formulation recommended in ACI 349-80, the yield strength of the anchor shall not be taken greater than 60,000 psi (rather than the 120,000 psi limit contained in the document).

Similarly to the use of Generic Equipment Ruggedness Spectra (GERS), SSRAP had to judge how large of a factor should exist between the

February 28, 1991

anchorage capacity and the seismic demand. The evaluation capacities determined by the approach of Reference 6 contain quantifiable but small factors of conservatism. When only a small factor of conservatism exists in the evaluation capacities, some additional factor of conservatism should exist between the evaluation capacity and the demand unless the demand has been conservatively defined. Demand which is defined by in-structure spectra computed roughly in accordance with current U.S. Nuclear Regulatory Commission Regulatory Guides and Standard Review Plans are adequately conservative that the Reference 6 evaluation capacities may be compared directly to the demand. In other words, no additional factor of conservatism is necessary. However, if realistic (approximately median centered) in-structure spectra such as those suggested herein for use with the earthquake experience data are used to specify the demand, then an additional factor of conservatism is necessary to cover some of the variability in demand. Demand specified by realistic (median centered) in-structure spectra should be multiplied by a factor of conservatism of 1.25 before being compared with Reference 6 anchorage evaluation capacities. A 1.25 factor of conservatism is considered adequate because at least another 20% margin exists in the Reference 6 anchorage evaluation capacities.

For most equipment, such as all electrical equipment and valves on piping, it is judged appropriate to use 5% damped spectra to define the seismic demand. However, in the case of simple lightly loaded, typically welded instrument racks and more massive equipment such as engine and motor generators, air compressors, pumps, and chillers, 5% damping may not be justified for anchorage evaluation. Most such equipment is essentially

February 28, 1991

rigid (fundamental frequency greater than approximately 20 Hz) so that damping is nearly irrelevant. In these cases, 5% damped spectra may be used. In the extremely rare case where such equipment is not essentially rigid (such as some instrument racks and a few vertical pump motor housings and supports), SSRAP recommends the use of 3% damped spectra only for anchorage evaluation. The 5% damped spectra should continue to be used to demonstrate equipment ruggedness. Where 5% damped in-structure spectra exist, standard techniques such as those in Appendix A of Reference 4 may be used to estimate a 3% damped in-structure spectra over the entire frequency range. Where 1.5 times the 5% damped horizontal ground response spectrum has been used to estimate the realistic (median centered) 5% damped in-structure spectrum for frequencies above about 8 Hz and elevations less than about 40 feet above grade, an approximate 3% damped in-structure spectrum can be obtained by scaling the 5% damped in-structure spectrum as follows:

- 1) Scale Factor = 1.3 at 8 Hz
- 2) Scale Factor = 1.0 at 20 Hz
- 3) Linear interpolation on log-log scale for intermediate frequencies.

The stiffness of engineered anchorage is of particular concern for many electrical cabinets which tend to be tall, slender and can be subjected to large overturning moments. There is also a concern with field modifications to anchorage. Flexibility of the base anchorage can be caused by the bending of anchorage components or cabinet base sheet metal allowing excessive cabinet movement, reducing its natural frequency and possibly increasing its dynamic response. Cabinet base flexibility

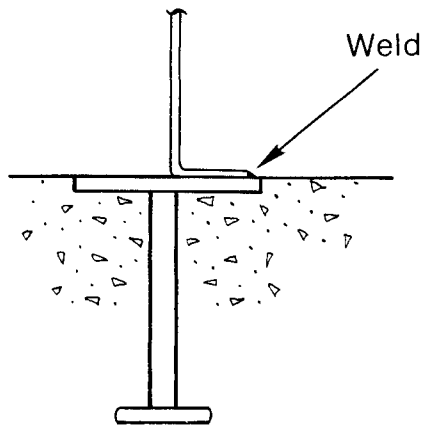


February 28, 1991

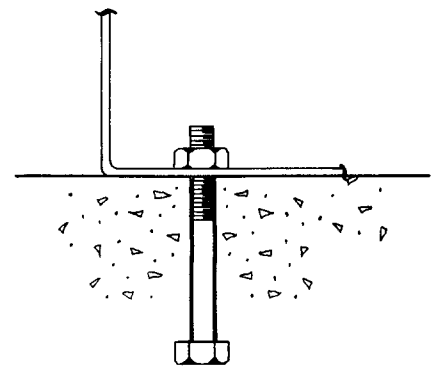
can also lead to high stresses in anchorage components and failure of the anchorage or cabinet base metal. Excessive eccentricities in the load path between the cabinet and the anchor is a major cause of base anchorage flexibility.

Examples of welds and fasteners which contribute to cabinet flexibility are shown in Figures 7-1a and 7-1b. Figures 7-1c and 7-1d show preferred configurations in which base metal bending and prying action are reduced. Figure 7-1e illustrates a field-modification detail that might experience excessive shear, bending and prying action and may induce bending into the base frame. There are many other examples that could be illustrated. The undesirable condition in Figure 7-1a can easily be corrected by properly welding the outside edge of the cabinet base to the embedded metal. Similarly, the undesirable bending of sheet metal in Figure 7-1b can often be corrected by adding a properly designed thick steel plate washer, probably square or rectangular, under the nut to resist the bending caused by uplift tension in the cabinet side wall.

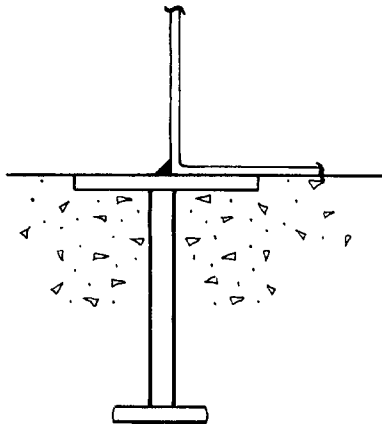
SSRAP is concerned about the situations that arise from significant eccentricities and bending of flat members in base anchorage details. It is emphasized that the action of loads along all three axes on these potentially flawed designs must be considered when evaluating the adequacy of equipment anchorage. Note that for the anchorage shown in Figure 7-1d or in Figure 7.1b with a strengthening washer resisting uplift tension in the cabinet, the tension in the anchor bolt will be greater than the tension uplift in the cabinet due to the prying action or eccentricity in the connection. A free-body diagram of the base configuration with appropriate assumptions will easily indicate the proper tension demand on



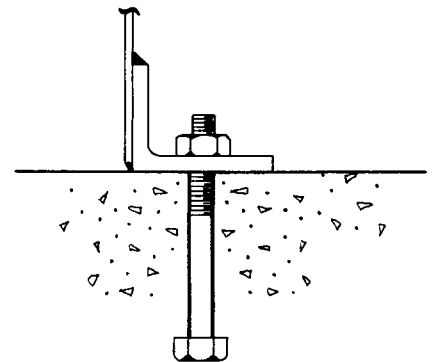
**A Undesirable Flexible Welded Anchorage**  
Uplift causes sheet metal frame to bend.



**B Undesirable Flexible Bolted Anchor:**  
Uplift causes sheet metal to bend.



**C Desirable Stiff Welded Anchorage**  
Loads pass through sheet metal wall.



**D Desirable Stiff Bolted Anchorage**  
Structural angle base provides adequate stiffness.

**E Undesirable Flexible Base Anchorage**  
Plate can bend from uplift loads and base frame might bend from shear loads.

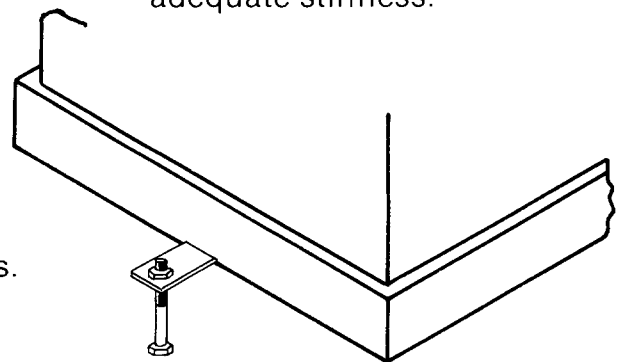


Figure 7.1 Examples of Stiff and Excessively Flexible Anchorage Connections

February 28, 1991

the embedded bolt. Similarly, if the weld in Figure 7-1c is actually near the edge of the plate rather than at the center as shown, bending will be present in the plate and the tensile load on the embedded headed stud will be greater than the cabinet tension load.

SSRAP is of the opinion that the engineers doing the walkdown spend their time evaluating how the anchorage will really perform rather than completing lengthy forms and being more concerned about documentation. Prior to the walkdown, SSRAP envisions all critical equipment will be listed and for each equipment type and size, the number of bolts or length and size of welds needed for strength will be tabulated using a source such as Reference 6. A uniform seismic input may be used for most equipment for simplicity. When the equipment is visited during the walkdown, the engineers can use the tabulation and immediately tell if the quantity of base anchorage strength is adequate. The walkdown engineers can then evaluate the eccentricities and stiffness issues that will significantly influence anchorage performance and pass most items by qualitative evaluation. Documentation should be brief, so engineers can do engineering, consisting of several lines on a sheet of paper of similar equipment items, including equipment identification and brief notation of anchorage size. If eccentricities or stiffness issues are present that cannot be passed on the spot, then a sketch should be made on a separate sheet of paper for later evaluation. Design and regulatory procedures should be established to allow simple anchorage modifications to be made to improve questionable or unacceptable anchorage. SSRAP would rather see simple field modifications made instead of expensive, lengthy calculations being performed to attempt to justify marginal conditions.

February 28, 1991

The walkdown engineers should pay careful attention to many items. They will need to verify from drawings, plant records and other means the details of embedded items in concrete and the types of bolts used. They will need to have confidence in the quality of expansion bolt installation in the plant by reviewing plant records and previous test inspection programs. They need to verify that short expansion anchors were not used and that anchors do not connect only to grout pads or other nonstructural elements. Since many raised equipment pads are present in nuclear power plants, careful attention must be given to edge distance limitations and bonding of equipment pads to structure if the consequences of failure are significant. Expansion anchors and embedded bolts can be utilized at full capacities in tension zones of concrete provided cracks in the concrete are evaluated as outlined in Reference 6. The tightness of expansion anchors shall be verified by applying a wrench to confirm that the anchor will not turn loosely in the hole (there is no need to verify the original installation torque nor to reapply any specified torque). Expansion anchors are generally not acceptable for anchoring vibratory equipment such as pumps and air compressors. If expansion anchors are found to exist in the anchorage of this equipment, they should be evaluated by the SRT considering their tightness, the presence of a large margin and accepted only when the load on the expansion anchors is essentially shear. When welds are used at cabinet bases, the SRT must visually observe the welds to ensure that sheet metal burn through or other defects are not present.

Occasionally, electrical cabinets or small items of equipment are mounted on concrete block masonry walls. In such cases, the wall capacity

February 28, 1991

for forces perpendicular to the wall must first be established. Then, anchorage capacity can be addressed as an outlier. Note that Reference 6 does not address anchorage to concrete block masonry.

SSRAP wishes to emphasize that the evaluation of anchorage must be done with great care if proper answers are to be obtained. The stiffness issues raised above must be considered, as they frequently increase the demand on the anchorage. SSRAP is concerned that there may be a tendency for SRT members to use a computer code or charts which have simple input such as bolt and weld sizes and locations and ignores all of the eccentricities in the load path which tends to increase anchor demand. Other situations have been observed by SSRAP members where the evaluating engineer simply evaluated the weld capacity to embedded metal while the bolt capacity to the member being welded or the embedded stud was actually more critical. Thus, in determining the anchorage capacity, every transfer of force from one member to the next must be evaluated. In some anchorage details, as many as three separate connections in the anchorage load path must be evaluated as the seismic force is transferred from the equipment frame or cabinet to the concrete of the supporting structure.

The SRT must also evaluate the effects of gaps between the equipment and supporting structure which can cause increased stresses in the bolts due to bending of the bolt. Examples of this condition are equipment bolted through metal gratings, equipment with narrow curbs or pads of grout installed beneath a base plate or frame and equipment supported on bolts with double nuts at the equipment frame. In these conditions, the SRT must accurately determine existing conditions, draw free-body diagrams to evaluate bending stresses in the bolt and use an appropriate method to

February 28, 1991

combine the basic bolt tension and shear loads with bending stresses caused by the gap.

When the walkdown engineers sign the documentation sheet, they must be professionally and personally satisfied that the anchorage was properly engineered and is adequate to meet the specified criteria and the various potential concerns summarized in this report.

Sampling considerations for equipment anchorage are discussed in Section 9.

8. BASE ISOLATION SYSTEMS

Base isolation systems exist on many items of mechanical equipment to isolate vibrations within the equipment from their supporting structure. Base isolators are particularly vulnerable to failure when subjected to seismic forces, and earthquake experience is full of examples of failed vibration isolators which allowed excessive movement of equipment and loss of function. SSRAP is particularly concerned about the potential performance of base isolators unless very careful seismic design attention has been taken.

Vibration isolators were traditionally designed to isolate equipment vibration and little attention was given to their potential seismic performance. The dramatic failure of most isolators in the area of strong ground shaking of the San Fernando, California, earthquake of 1971 focused attention on this vulnerability. It was not until the mid-1970s that engineers and isolator manufacturers conscientiously addressed this issue and began to routinely consider suitable details for isolated equipment in seismic exposures. Vibration isolators, consisting primarily of one or several springs, fail when the springs cannot resist lateral loads. Many isolators are manufactured of cast iron which shatters when subjected to actual earthquakes. Rubber and elastomer products in isolators can fail when bonding adhesives or the material itself fails. Other isolators have steel sections surrounding the spring element which at first appears stout. However detailed review reveals that critical stresses must be resisted by minimal fillet or tack welds and bending stresses are forced to be resisted by flat bearing plates. Isolator failure allows excessive movements which can rupture utility or piping runs. SSRAP is of the

February 28, 1991

opinion that base isolated equipment in older nuclear plants should be considered suspect and a potential failure until shown adequate or retrofit work is performed.

SSRAP recommends that only two approaches to equipment with vibration isolators be considered acceptable for seismic exposure in nuclear power plants. First, isolator systems of any type can be accepted if a complete set of bumpers is present to prevent excessive lateral movement in all directions. The bumpers should not only prevent any excessive lateral movement and torsion but a positive method of resisting uplift must be provided other than springs, rubber or adhesives in tension. If the bumpers do not have elastomeric pads to prevent hard impact, the effect of that impact on the equipment and particularly any relays should be evaluated. Secondly, a set of isolators which were specially designed for seismic applications (not cast iron, unbraced springs, weak elastomers, etc.) may be accepted provided suitable check calculations verify all possible load combinations and eccentricities within the isolator itself, including possible impact loads.

If the isolator system is judged unacceptable, retrofit work should be performed. There are three basic approaches to isolator retrofit. First is installing bumpers to prevent excessive movement. Steel sections can be installed adjacent to the base frame with elastomeric pads to prevent hard impact. If uplift must also be resisted, the bumper design should also provide uplift restraint. The second solution is replacing the existing isolators with new isolators which are properly designed for seismic forces. Third, if isolation is determined unnecessary, the equipment could be rigidly anchored to its support structure.



9. SAMPLING CONSIDERATIONS FOR EQUIPMENT ANCHORAGE

The Seismic Review Team (SRT) must establish an inspection procedure and sampling criteria for equipment anchorage. There will be many pieces of equipment to inspect during the walkdown, and the SRT must have a definite plan of action for equipment anchorage evaluation during their walkdown.

Equipment anchorage will most likely be one of three types: expansion bolts into concrete, cast-in-place bolts embedded in concrete, and welds to steel members which are embedded into concrete with some kind of anchorage. The SRT must be prepared prior to the walkdown to make on-the-spot judgments of anchorage adequacy or inadequacy or the need for detailed calculational effort. This requires prior determination for the plant of what constitutes acceptable anchorage for each basic type of equipment and a review of available construction documents for the plant to determine what was supposed to have been installed for equipment anchorage.

The EPRI/URS report (Reference 6), which serves as the basic guidance for anchorage evaluation for the walkdown, gives some guidance for inspecting expansion anchors but not for inspecting welds or cast-in-place bolts. The walkdown is not intended to be a quality control substitute for the plant but only a verification that anchorage installed under some form of a quality control program is sufficiently rugged for potential seismic forces. Therefore, the anchorage evaluation program developed by the SRT must be of sufficient detail to give the SRT a comfortable feeling that they understand the approach used and the consistency used in equipment anchorage when the plant was constructed and

February 28, 1991

that the anchorage is sufficiently rugged for potential seismic forces. The exact procedures utilized will depend on the data available from construction records and the findings during the plant walkdown.

The SRT and the engineering staff providing backup support should first determine what information is available from the construction documents. For all various equipment types, they should determine what anchorage was supposed to be installed, bolt sizes, types of expansion anchors, weld sizes, embed details, etc. If available construction records do not indicate anchorage details, then that should be noted as more detailed field inspection, and evaluation will be required. Details of equipment parts raised above the slab level should also be recorded. Due to the volume of material that must be evaluated and collected, copies of appropriate details and drawings should be assembled so easy reference to the construction details are available for future reference.

It is impossible for SSRAP to give specific rigid guidance to the SRT as to the detailed review and sampling quantities of anchorages that should be undertaken during a plant walkdown. There will be so many variables for each plant that the exact sampling procedures and degree of inspection and review will vary considerably for each plant. SSRAP does not envision any statistical studies be undertaken to determine sampling quantities but that they use their judgment relative to the degree of inspection required. The following paragraphs will outline SSRAP's conception of the inspection effort that should be undertaken: SSRAP expects that the anchorage of each item of equipment will be visually inspected to provide an understanding of the type of anchorage system used. For pumps, compressors, generators, etc., the anchorage is fully

February 28, 1991

visible and easy to review, document and evaluate. For electrical equipment, inspection is more difficult as equipment cabinets must be opened to see and inspect bolts. Despite the difficulty, each item of equipment must be reviewed within the general guidelines that follow:

Anchorage details should be reviewed not only for general seismic adequacy but also for conformance with the construction documents. The review for conformance with construction documents is not to verify quality control procedures during construction but to gain confidence in drawings so inaccessible anchorages on electrically hot cabinets and similar items can be eventually assumed without detailed inspection.

The anchorage of each piece of equipment shall be reviewed. The SRT shall determine if expansion anchors, welds or cast-in-place bolts were provided for anchorage. They shall verify the number and size of anchorages and review for the types of items (size, spacing, edge distance, sound concrete, embedment depth, etc.). Each item shall be inspected, although banks of repetitive electrical equipment may be reviewed without verifying each anchor, provided a reasonable number of cabinets in the bank are opened and anchorage is adequate and consistent with the construction documents. If construction documents are lacking, then most cabinets in the bank should be opened until the SRT knows what to expect and finds it when they open each successive cabinet. SSRAP is in general agreement with the recommendations of the EPRI/URS report (Reference 6) on the items to be inspected. SSRAP believes that the SRT must thoroughly review that document and thoroughly understand its implications, but SSRAP believes that some relaxation in sampling may be taken in verifying the presence of every anchor. Furthermore, welds to

February 28, 1991

embedded steel items and cast-in-place bolts should be inspected and documented to the same general level of thoroughness as described for expansion anchors. If the construction documents indicate certain details which are consistently found, the SRT should be allowed the ability of reducing the amount of inspection. However, if anchorage details, embedment lengths, anchor tightness, etc., show considerable variability from the construction documents, then virtually every anchor should probably be inspected.

SSRAP recognizes that there are several difficult issues involved in inspecting anchorage. One is certainly the embedment depth of expansion anchors, cast-in-place bolts or embedded anchors that may be present. Another is the requirement of the EPRI/URS report to inspect the tightness of all bolts (or a sampling based on two alternative approaches) even when they are in the front of cabinets with rear access only. SSRAP does note that the random statistical sampling procedure of the EPRI/URS report (Reference 6) should be used with judgment as it is based on a uniform population whereas the bolts being sampled for tightness may be of variable size, type and use and installed by different contractors. SSRAP agrees that sampling is appropriate to inspect tightness but is of the opinion that at least 25% of all bolts in large groups of anchorages containing a few hundred bolts be inspected with the sample size approaching 100% when the total number of bolts in a group is less than about 40. The SRT should be aware that an inspection of tightness is not required in the EPRI/URS report if the anchorage contains 50% more anchors than required for a capacity of mean divided by four. The anchors in the front of electrical cabinets with rear access are the most difficult to

February 28, 1991

inspect, but they were also the most difficult to install so inspection of a reasonable number of these bolts is essential. This may require inspection when selected equipment is deenergized or when the plant is shut down. The embedment depth of anchors, if construction records are not available, may entail a significant effort by technicians supporting the SRT. Ultrasonic methods can be used to verify embedment depth or several anchors can be physically removed. Whatever the method of verification, it is not meant to be an extensive verification unless there appears to be inconsistency or poor correlation with the construction documents.

SSRAP is aware that deficiencies with anchorages may result from raised concrete parts or grout placed beneath base plates. An expansion anchor may extend through a grout pad and barely penetrate the concrete slab, making it virtually useless in resisting seismic loads. The SRT must be on the watch for raised pads and grout beneath base plates and make a realistic assessment of their adequacy in the event of an earthquake of design proportions.

When concerns or deficiencies of anchorages are found, inspection sampling should be increased as appropriate until the SRT is satisfied that the scope of any systematic deficiency is defined. Deficient anchorages should be corrected unless the balance of the anchors are sufficient to provide adequate anchorage for the equipment.

SSRAP does not wish to stipulate an exact number of anchors to inspect in detail nor a specific procedure for review. Each plant will probably present a unique situation relative to the detail of construction documents and the anchorage correlation found, and the SRT should be given

February 28, 1991

the latitude to determine exactly the sampling quantity they select for the various aspects of anchorage inspection. The SRT must sign-off for their inspection, so the inspection should be thorough enough that the SRT engineers feel professionally satisfied that the anchorage of all items of equipment is adequate to resist the specified earthquake motions. The process depends on the SRT being fully satisfied that the anchorage of all items of equipment is adequate to resist the seismic motion prescribed for the plant.

10. ELECTRICAL POWER EQUIPMENT

The following four classes of electrical power equipment are considered: Motor Control Centers, Low-Voltage Switchgear, Medium-Voltage Switchgear and Transformers. SSRAP is concerned that many MCCs and instrument cabinets have frequencies substantially below 8 Hz. In addition, test data has shown some equipment in a broad range of electrical equipment categories, such as switchgear and transformers, to have natural frequencies significantly less than 8 Hz when subjected to test spectra comparable to the reference spectra. This data indicates that the SRT must be convinced that the fundamental frequency of the equipment is not significantly below 8 Hz. If the fundamental frequency is below about 8 Hz, the floor response spectra must be compared to 1.5 times the bounding spectra (see Table 3-2).

The additional caveats for the first three classes are similar; but for clarity, the three have been separately discussed.

A. MOTOR CONTROL CENTERS

Motor control centers contain motor starters (contactors) and disconnect switches. They also may have over-current relays to protect the system from overheating. In addition, some units will contain small transformers and distribution panels for lighting and 120V utility service. Motor control centers of the 600 volt class are included in the data base.

Based on a review of the data base and anticipated variations in conditions, SSRAP is of the opinion that Motor Control Centers are sufficiently rugged to survive a seismic event generating

February 28, 1991

ground motion within the Bounding Spectrum and remain operational thereafter provided the following conditions exist in the nuclear facility:

- The unit is properly anchored with stiff engineered anchorage. Both the strength and stiffness of the anchorage and its component parts must be considered. Stiffness of the anchorage can be evaluated by engineering judgment based on the cabinet construction and the location and type of anchorage, giving special attention to the potential flexibility between the tiedown anchorage and the walls of the cabinet. SSRAP is concerned with the potential flexibility associated with bending of a sheet metal flange between the anchor and the cabinet wall.

The intent of this recommendation is to prevent excessive movement of the cabinet and to assure that under earthquake excitations the natural frequency of the installed cabinet will not be in resonance with both the frequency content of the earthquake and the fundamental frequency of the structure, thereby allowing comparison of the ground response spectra with the Bounding Spectrum. Anchorage shall be evaluated in accordance with the guidelines outlined in Section 7.

- Adjacent cabinets and multi-bay cabinet assemblies, which contain relays for which chatter is not acceptable, and are close enough to impact, shall be bolted together.



February 28, 1991

- Equipment and their enclosures (but not conduit) mounted externally to cabinets and supported by them should be estimated to have a total weight of less than about one hundred pounds on any cabinet. SSRAP is concerned that the center of gravity of the cabinet will be raised too high, the total weight of the cabinets will be too large or large eccentric weights will introduce excessive torsion. Items attached to the cabinets should be rigidly anchored to avoid impacting.
- For purposes of anchorage checking only, the effective weight of any attached conduit and equipment should be included in the cabinet weight.
- Relays and contactors for which chatter is not acceptable shall be evaluated in accordance with the guidance given in Section 5.
- The general configuration of the cabinets should be similar to cabinets conforming to NEMA Standards. This requirement is imposed to preclude unusual designs not covered in the data base.
- Cutouts in the lower half of cabinet side sheathing are less than about 6 inches wide and 12 inches high.
- An assessment of the fundamental frequency of the cabinet should be made. Many motor control centers have a fundamental frequency below about 8 Hz. For cabinets which have a fundamental frequency below about 8 Hz the floor response spectrum must be compared to 1.5 times the Bounding Spectrum.

B. LOW-VOLTAGE SWITCHGEAR

Low-voltage switchgear consists of low voltage, that is, 600V or less, distribution busses, circuit breakers, fuses, associated control relays, and disconnect switches. Low-voltage switchgear of the 600V class is included in the data base.

Based on a review of the data base and anticipated variations in conditions, SSRAP is of the opinion that Low-Voltage Switchgear are sufficiently rugged to survive a seismic event generating ground motion within the Bounding Spectrum and remain operational thereafter provided the following conditions exist in the nuclear facility:

- The unit is properly anchored with stiff engineered anchorage. Both the strength and stiffness of the anchorage and its component parts must be considered. Stiffness of the anchorage can be evaluated by engineering judgment based on the cabinet construction and the location and type of anchorage, giving special attention to the potential flexibility between the tiedown anchorage and the walls of the cabinet. SSRAP is concerned with the potential flexibility associated with bending of a sheet metal flange between the anchor and the cabinet wall.

The intent of this recommendation is to prevent excessive movement of the cabinet and to assure that under earthquake excitations the natural frequency of the installed cabinet will not be in resonance with both the frequency content of the earthquake and the fundamental

February 28, 1991

frequency of the structure, thereby allowing comparison of the ground response spectra with the Bounding Spectrum. Anchorage shall be evaluated in accordance with the guidelines outlined in Section 7.

- The SRT shall confirm that potential relative side-to-side motion between the draw-out type circuit breaker and the cabinet is limited such that the secondary contacts are not disconnected. Stab (bayonet) type primary or secondary contacts are sufficient to prevent this problem. Flat type bus connections also limit motion perpendicular to the connection.
- Adjacent cabinets and multi-bay cabinet assemblies, which contain relays for which chatter is not acceptable, and are close enough to impact, shall be bolted together.
- Equipment and their enclosures (but not conduit) mounted externally to cabinets and supported by them should be estimated to have a total weight of less than about one hundred pounds on any cabinet. SSRAP is concerned that the center of gravity of the cabinet will be raised too high, the total weight of the cabinets will be too large or large eccentric weights will introduce excessive torsion. Items attached to the cabinets should be rigidly anchored to avoid impacting.
- For purposes of anchorage checking only, the effective weight of any attached conduit and equipment should be included in the cabinet weight.

February 28, 1991

- Relays and contactors for which chatter is not acceptable shall be evaluated in accordance with the guidance given in Section 5.
- The general configuration of the cabinets should be similar to those specified in ANSI C37.20 Standards. This requirement is imposed to preclude unusual designs not covered in the data base.
- Cutouts in the lower half of cabinet side sheathing should be less than 30% of the width of the side panel. The height of the cutout shall be less than 60% of the width of the panel. This also applies to side panels between multi-bay cabinets. Cutout restrictions do not include the bus transfer compartment if the remaining part of the enclosure conforms with the cutout limitations.

C. MEDIUM-VOLTAGE SWITCHGEAR

Medium-voltage switchgear consists primarily of circuit breakers and associated relays (such as over-current relays or ground fault protection relays), interlocks, and other devices to provide protection to the equipment that it services. Medium-voltage switchgear of 2.4kV and 4.16kV is included in the data base.

Based on a review of the data base and anticipated variations in conditions, SSRAP is of the opinion that Medium-Voltage Switchgear are sufficiently rugged to survive a seismic event generating ground motion within the Bounding Spectrum and remain

February 28, 1991

operational thereafter provided the following conditions exist in the nuclear facility:

- The unit is properly anchored with stiff engineered anchorage. Both the strength and stiffness of the anchorage and its component parts must be considered. Stiffness of the anchorage can be evaluated by engineering judgment based on the cabinet construction and the location and type of anchorage, giving special attention to the potential flexibility between the tiedown anchorage and the walls of the cabinet. SSRAP is concerned with the potential flexibility associated with bending of a sheet metal flange between the anchor and the cabinet wall.

The intent of this recommendation is to prevent excessive movement of the cabinet and to assure that under earthquake excitations the natural frequency of the installed cabinet will not be in resonance with both the frequency content of the earthquake and the fundamental frequency of the structure, thereby allowing comparison of the ground response spectra with the Bounding Spectrum. Anchorage shall be evaluated in accordance with the guidelines outlined in Section 7.

- In some switchgear, the potential transformers and/or control power transformers are mounted on trunnions rather than on slides. If trunnion-mounted transformers are present, the SRT shall confirm that these transformers have limited vertical displacement relative to the cabinet such

February 28, 1991

that the contacts are not damaged or disconnected. Shake table tests have demonstrated that a positive restraint is needed to keep the trunnion pin in its cradle at base motions equivalent to the reference spectrum. This restraint is unnecessary at base motions about one-half the reference spectrum or less.

- Adjacent cabinets and multi-bay cabinet assemblies, which contain relays for which chatter is not acceptable, and are close enough to impact, shall be bolted together.
- Equipment and their enclosures (but not conduit) mounted externally to cabinets and supported by them should be estimated to have a total weight of less than about one hundred pounds on any cabinet. SSRAP is concerned that the center of gravity of the cabinet will be raised too high, the total weight of the cabinets will be too large or large eccentric weights will introduce excessive torsion. Items attached to the cabinets should be rigidly anchored to avoid impacting.
- For purposes of anchorage checking only, the effective weight of any attached conduit and equipment should be included in the cabinet weight.
- Relays and contactors for which chatter is not acceptable shall be evaluated in accordance with the guidance given in Section 5.
- The general configuration of the cabinets should be similar to those specified in ANSI C37.20 Standards. This

February 28, 1991

requirement is imposed to preclude unusual designs not covered in the data base.

- Cutouts in the lower half of cabinet side sheathing should be less than 30% of the width of the side panel. The height of the cutout shall be less than 60% of the width of the panel. This also applies to side panels between multi-bay cabinets. Cutout restrictions do not include the bus transfer compartment if the remaining part of the enclosure conforms with the cutout limitations.

D. TRANSFORMERS

Low voltage transformers convert distribution voltage (4.16kV or less) to low voltage (480V). Distribution transformers convert low voltage (480V) to 240V or 120V. Units may contain protective relays.

Floor-mounted liquid- and air-cooled unit substation transformers and floor- or wall-mounted distribution transformers are considered.

Based on a review of the data base and anticipated variations in conditions, SSRAP is of the opinion that unit substation and distribution transformers are sufficiently rugged to survive a seismic event generating ground motion with the Bounding Spectrum and remain operational thereafter provided the following conditions exist in the nuclear facility:

- The unit is properly anchored. Anchorage shall be evaluated in accordance with guidelines outlined in Section 7.

February 28, 1991

- For floor-mounted dry and oil-type units, the transformer coils shall be positively restrained within their cabinet so that relative sliding and rocking motions between the transformer coil and their cabinet is kept to an acceptable level. SSRAP is concerned that excessive relative motions may damage the wiring yoke or that the coils may come in contact with their cabinet so that there is a short circuit or that electrical insulation is damaged. Installation procedures for some transformers recommend that bolts used to anchor the coils during shipping be removed. If the unit is factory sealed or constructed so that removing shipping anchors is precluded, it can be assumed that the vibration environment during shipping is greater than that expected for the earthquakes considered here, and no internal inspection is necessary. This caveat applies to these transformers. Large transformers of 750 kVA or larger shall also have the top of the coils braced by a structural frame or shall be evaluated for adequate restraint.
- For 750 kVA transformers and larger, there shall be at least a 2-inch gap between the energized component and the upper portion of the transformer cabinet. And that the connection between the high voltage leads and the first anchor point can accommodate at least a 3-inch relative displacement. If these conditions are not met, the SRT shall verify from a lateral analysis that there is sufficient gap and/or provision for relative displacement. This caveat is in



February 28, 1991

addition to the above caveat requiring top bracing or verification analysis for the lateral structural support of the core/coil.

- The base assembly of floor-mounted units is properly braced or stiffened such that lateral forces in any direction do not rely on weak-way bending of sheet metal or thin webs of structural steel shapes. If such unbraced or unstiffened steel webs exist in the nuclear plant, they shall be investigated and justified by the walkdown engineer by other means for adequacy of strength and stiffness.
- The transformer contained in wall-mounted units is to have engineered anchorage and is to be anchored to its enclosure near to the enclosure surface which supports the enclosure.
- Cabinets which contain relays for which chatter is not acceptable and that are capable of impacting should be bolted together.
- Relays for which chatter is not acceptable shall be evaluated in accordance with the guidance given in Section 5.

11. BATTERY CHARGERS AND STATIC INVERTERS

Battery chargers are assemblies of electronic components which convert AC input to DC output. Static inverters are physically similar but convert DC input to AC output. The cabinets of battery chargers and static inverters are sheet metal with numerous ventilation screens for air flow. These units in nuclear power plants are normally floor-mounted cabinets with a base assembly to raise the bottom of the cabinet above the floor. Smaller wall-mounted chargers and inverters are included in the data base.

Based on a review of the data base and anticipated variations in conditions, SSRAP is of the opinion that battery chargers and static inverters are sufficiently rugged to survive a seismic event generating ground motion within the Bounding Spectra and remain operational thereafter provided the following conditions exist in the nuclear facility:

- The battery charger or static inverter is a solid state type.
- For the floor-mounted units, the transformer, which is the heaviest component of this equipment, is positively anchored and mounted near the base of the cabinet. If not mounted near the base, then the load path should be evaluated.
- The base assembly of floor-mounted units is properly braced or stiffened such that lateral forces in any direction do not rely on weak-way bending of sheet metal or thin webs of structural steel shapes. If such unbraced or stiffened steel webs exist in the nuclear plant, they shall be investigated and justified by the walkdown engineer by other means for adequacy of strength and stiffness.

February 28, 1991

- The unit is properly anchored. Anchorage shall be evaluated in accordance with guidelines outlined in Section 7.
- If the battery charger or static inverter is a wall-mounted unit, anchorage shall be verified to be adequate, and the transformer supports and bracing shall be visually reviewed for a proper load path to the rear cabinet wall.
- Relays for which chatter is not acceptable shall be evaluated in accordance with the guidance given in Section 5.

When using Generic Equipment Ruggedness Spectra (GERS) for battery chargers or static inverters, in addition to complying with the caveats, inclusion rules and similarity requirements of Reference 19 plus those above, the following conditions shall be verified to exist in the nuclear facility:

- The unit has power controls utilizing silicon-controlled rectifiers (SCR).
- The load path from the transformer to the cabinet anchorage should be evaluated for all units. SSRAP understands that early shake table testing resulted in design changes which strengthened cabinet construction due to poor performance of weak cabinets.

12. STATION BATTERIES ON RACKS

This class of equipment includes both lead-acid storage batteries and their supporting structure (racks). The batteries are part of the uninterruptable power system (UPS), which consists of solid-state inverter (typically), a battery charger, a set of lead-acid batteries and an automatic transfer switch. One of its function is to supply the critical load in the event of loss of offsite power. This is done by the inverter, which without switching, obtains power from the standby batteries. The batteries are required to supply power to the inverter until the emergency generators come on line or offsite AC power is restored.

Subject to the limitations set forth below, SSRAP is of the opinion that batteries meet the criteria for the Bounding Spectrum.

- The plates of the cells are lead-calcium, flat-plate or of the Manchex design.
- Each individual battery weighs less than 450 pounds.
- There are close-fitting, crush-resistant spacers between the cells, which must fill about two-thirds of the vertical space between the cells. The end and side rails are close fitting against the cells (with shims, if needed).
- The mounting rack must be anchored, and the anchorage must be evaluated in accordance with the guidelines outlined in Section 7.
- The batteries are restrained by side and end rails.
- The racks shall have longitudinal cross bracing unless engineering judgment or analysis shows that such bracing is not needed. Racks constructed of wood shall be evaluated.

February 28, 1991

- SSRAP is aware of the concern with the aging of batteries. In particular some models may be susceptible to structural and or metallurgical changes with time that may result in either structural failure or reduced capacity after vibration. Testing of artificially aged batteries may result in overstating these concerns.

Based on the experience data base and some limited test data, SSRAP is of the opinion that for batteries that are less than 10 years old and have been maintained properly there is no seismic concern due to aging. For batteries that are more than 10 years old some models may be degraded after exposure to an earthquake. For batteries over 10 years old the aging issue needs further study.

13. CONTROL PANELS AND INSTRUMENTATION CABINETS

Control panels and instrumentation cabinets generally consist of a steel frame supporting sheet metal panels on to which control and instrumentation components are bolted on steel frame and sheet metal cabinets into which electronic components are attached (often on slide-out drawers). These include a large variety of electrical panels but exclude instrument racks which are described in Section 14.

Based on a review of the data base, which reported this class has performed well, with the exception of a few broken indicator light filaments and occasional spurious signals, SSRAP is of the opinion that control panels and instrumentation cabinets are sufficiently rugged to survive a seismic event generating ground motion within the Bounding Spectrum and remain operational thereafter provided the following conditions exist in the nuclear facility. Due to a large variation in construction, a walkdown by competent engineers must be performed to evaluate the adequacy of this class of equipment including the following considerations.

- Computers and programmable controllers must be evaluated separately.
- Strip chart recorders must be evaluated separately. SSRAP is concerned with long, narrow recorders which are cantilevered off the panel without additional structural support.
- The unit is properly anchored. Anchorage shall be evaluated in accordance with guidelines outlined in Section 7.
- The steel frame and sheet metal shall be evaluated in the walkdown for adequacy. Adequacy will be based on engineering judgment.

February 28, 1991

- Panels or cabinets which contain necessary relays and that are capable of impacting should be bolted together.
- Drawers or equipment on slides shall be restrained from falling out.
- Relays for which chatter is not acceptable shall be evaluated in accordance with the guidance given in Section 5.
- There shall be sufficient slack and flexibility in connections, such as electrical cable, to the control panel and instrumentation cabinet.

14. INSTRUMENT RACKS

Instrument racks are steel-braced frames used to mount instruments and controls such as transmitters, pressure switches, electro-pneumatic transducers, and gauges. Components are either attached directly to the steel members or to steel panels which are welded or fastened to the rack. Except for a few cases of impact from falling objects, the data base contained no instances of damage to the racks nor to the attached wiring.

Based on a review of the data base, SSRAP is of the opinion that instrument racks are sufficiently rugged to survive a seismic event generating ground motion within the Bounding Spectrum and remain operational thereafter provided the following conditions exist in the nuclear facility. Due to a large variation in construction, a walkdown by competent engineers must be performed to evaluate the adequacy of this class of equipment including the following considerations.

- Computers and programmable controllers must be evaluated separately.
- The unit is properly anchored. Anchorage shall be evaluated in accordance with guidelines outlined in Section 7.
- The steel frame and sheet metal racks shall be evaluated in the walkdown for adequacy. Adequacy will be based on engineering judgment.
- Racks which contain relays for which chatter is not acceptable and that are capable of impacting should be bolted together.



February 28, 1991

- Relays for which chatter is not acceptable shall be evaluated in accordance with guidelines outlined in Section 5.
- There shall be sufficient slack and flexibility in connections, such as electrical cable, to the instrument rack.
- For slender unbraced instrument racks, an assessment of the fundamental frequency should be made. For racks which have a fundamental frequency below about 8 Hz, the floor response spectrum must be compared to 1.5 times the Bounding Spectrum.

February 28, 1991

15. DISTRIBUTION PANELS

Distribution panels contain assemblies of circuit breakers or fusible switches mounted in vertical steel cabinets. The cabinets may be floor or wall mounted. The general configuration of the cabinet must be similar to those specified in NEMA Standards.

Based on a review of the data base, SSRAP is of the opinion that distribution panels are sufficiently rugged to survive a seismic event generating ground motion within the Bounding Spectrum and remain operational thereafter provided the following conditions exist in the nuclear facility.

- The unit is properly anchored. Anchorage should be evaluated in accordance with guidelines outlined in Section 7.
- The distribution panel contains circuit breakers and switches. If other equipment is contained within the panel, it must be evaluated on a case-by-case basis.
- All door latches or screwdriver-operated door fasteners must be secured.
- Panels which contain relays for which chatter is not acceptable and that are capable of impacting should be bolted together.
- Relays for which chatter is not acceptable shall be evaluated in accordance with the guidance given in Section 5.

16. TEMPERATURE SENSORS

Temperature sensors are either thermocouples or resistance temperature detectors (RTDs).

Based on review of the data base, SSRAP is of the opinion that temperature sensors are sufficiently rugged and meet the criteria for the Bounding Spectrum provided the following conditions exist in the nuclear facility.

- There is sufficient slack in the attached wiring.
- Detrimental differential displacement between the mounting of the connection head and the mounting of the temperature sensor cannot occur.
- The associated electronics is all solid state (no vacuum tubes).

17. ENGINE AND MOTOR GENERATORS

Engine and motor generators are relatively stiff and very rugged devices due to their inherent design and operating requirements. Electric motors used in this class of equipment are also included. Subject to the limitations set forth below, the equipment meets the criteria for the Bounding Spectrum.

Engine generators are used for emergency AC power in the event of loss of offsite power. They typically have capacity of up to a few megawatts. SSRAP is of the opinion that the data base is adequate to include reciprocating piston engines (e.g., diesel) of all sizes. Due to the limited data base, turbine engines are not included. The peripheral systems (e.g., pumps and filters) are included only if they are mounted on the engine generator or its skid\*.

Motor generators are a source of uninterruptable power for AC to DC or DC to AC conversion, power fluctuation control, or frequency conversion. Typically motor generators in power plants have capacities of a few hundred horsepower. The data base is sufficient to cover all sizes.

For engine and motor generators it is the opinion of SSRAP that all such units are very rugged and need no further evaluation except as noted in the following caveats:

- The unit is properly anchored. Expansion anchors are generally not acceptable. See Section 7 for further discussion.
- Any vibration isolation system must be evaluated (see Section 8).

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\*Control panels, fuel oil tanks, etc., not on the generator or skid are not included and must be separately evaluated.

February 28, 1991

- The main driver and driven components must be connected by a rigid support or skid. If not, the potential for differential displacement, which may bind shafts or lead to excessive bearing wear, must be evaluated.
- Relays for which chatter is not acceptable on the engine or motor generator must be separately evaluated in accordance with the guidance given in Section 5 with the exception of relays on reciprocating engines that routinely see high vibration due to operation.
- Sufficient slack and flexibility must be present in cooling, fuel and electrical lines attached to the units.

18. AIR COMPRESSORS

Air compressors are relatively stiff and very rugged devices due to their inherent design and operating requirements. Motors used in this class of equipment are also included. Subject to the limitations set forth below, the equipment meets the criteria for the Bounding Spectrum.

Free-standing air compressors provide compressed air (e.g., for pneumatic control) and include centrifugal and reciprocating piston compressors and drive motor. Peripheral equipment is included if mounted directly on the air compressor.

For air compressors, it is the opinion of SSRAP that all such units are very rugged and need no further evaluation except as noted in the following caveats:

- The unit is properly anchored. Expansion anchors are generally not acceptable. See Section 7 for further discussion.
- Any isolation system must be evaluated (see Section 8).
- Relays for which chatter is not acceptable must be separately evaluated in accordance with the guidance given in Section 5 with the exception of relays on air compressors that routinely see high vibration due to operation.
- Sufficient slack and flexibility must be present in cooling, air and electrical lines attached to the compressor.

19. PUMPS

Pumps are relatively stiff and very rugged devices due to their inherent design and operating requirements. Motors used in this class of equipment are also included. Subject to the limitations set forth below, the equipment meets the criteria for the Bounding Spectrum.

A. HORIZONTAL PUMPS

Horizontal pumps include rotary impeller and positive displacement pumps. They may be driven by electric motors, reciprocating piston engines, or steam turbines. Peripheral systems are included if they are mounted directly on the pump. The data base is sufficiently broad that horizontal pumps of all capacities are included.

For horizontal pumps, the opinion of SSRAP is that all such units are very rugged and needs no further evaluation except as noted in the following caveats:

- The unit is properly anchored. Expansion anchors are generally not acceptable. See Section 7 for further discussion.
- Any vibration isolation system must be evaluated (see Section 8).
- The driver and pump must be connected by a rigid base or skid. If not, the potential for differential displacement must be evaluated.
- Thrust restraint of the shaft in both axial directions should exist. From discussions with U.S. pump manufacturers SSRAP understands that pumps have such axial thrust restraint so that explicit verification is not necessary. However, any indication to the contrary should be investigated.

February 28, 1991

- Relays for which chatter is not acceptable must be separately evaluated in accordance with the guidance given in Section 5.
- Sufficient slack and flexibility must be present in cooling, fuel, and electrical lines.
- Brief consideration should be given to identify situations where horizontal pumps may be affected by gross pipe motion, differential displacement, and excessive nozzle loads. SSRAP notes that this is an issue associated with excessive force on pump nozzles, which could potentially break the pump nozzle, cause pump case distortion sufficient to cause binding, or fail anchorage.

SSRAP notes that these excessive forces are uncommon and need only be considered if there is a long section of unsupported pipe or a heavy valve attached to the pipe near the pump. During the walkdown an experienced engineer can assess if further evaluation is required beyond the walkdown.

#### B. VERTICAL PUMPS

Vertical pumps include an electric motor drive attached to a base flange with a centrifugal or a deep well pump below the flange. Peripheral equipment attached to the motor or pump is included. The data base is sufficiently broad that vertical pumps of all capacities are included. SSRAP feels that vertical pumps, above the flange are very rigid and need no further analysis except as noted below.



February 28, 1991

SSRAP notes that the variety of vertical pump configurations and shaft lengths below the flange, and the relative small number of data base points in several categories, preclude the use of the data base to screen all vertical pumps. Vertical turbine pumps, i.e., deep well submerged pumps with cantilevered shafts up to 20 feet in length and with bottom bearing support of the shaft to the casing are well enough represented to meet the bounding criteria below the flange as well. SSRAP recommends either individual analysis or use of another method as a means of evaluating other vertical pumps below the flange. The chief concerns would be damage to bearings due to excessive loads, damage to the impeller due to excessive displacement, and damage due to interfloor displacement on multi-floor supported pumps. As discussed in Section 2, there is evidence of increased wear and maintenance required on vertical pumps after earthquakes.

The caveats for vertical pumps are:

- The unit is properly anchored. Expansion anchors are generally not acceptable. See Section 7 for further discussion.
- Shafts on vertical pumps with unsupported lengths in excess of 20 ft. must be evaluated separately. The impeller drive shaft must be supported within the casing.
- Brief consideration should be given to avoid situations where vertical pumps may be affected by gross pipe motion, differential displacement, and nozzle loads (see discussion for horizontal pumps).

February 28, 1991

- Relays for which chatter is not acceptable shall be evaluated in accordance with the guidance given in Section 5.
- Sufficient slack and flexibility must be present in cooling and electrical lines.

20. VALVES

Valves of many different types present on piping in nuclear power plants are covered in this section. Included are air-operated diaphragm valves, piston-operated valves, spring-operated pressure relief valves and motor-operated valves. Not included in the data base in sufficient quantities and not covered in this section are liquid-operated piston valves such as hydraulic piston-operated valves.

Air-operated diaphragm valves consist of a valve operated by a rod actuated by air pressure against a diaphragm attached to the rod. The actuator is supported by the valve body through a cantilevered yoke. Piston-operated valves or spring-operated pressure relief valves contain air or liquid in a cylinder or chamber which actuates the valve with control provided by a spring. Motor-operated valves consist of an electric motor and gear box cantilevered from the valve body by a yoke and interconnected by a drive shaft. The motor and gear box serve as an actuator to operate the valve.

Based on a review of the data base and anticipated variations in conditions, SSRAP is of the opinion that valves are sufficiently rugged to survive a seismic event generating ground motion within the Bounding Spectrum and remain operational thereafter provided the following conditions exist in the nuclear facility:

- The valve body is not of cast iron.
- The valve yoke construction is not of cast iron in motor-operated valves, piston-operated valves and spring-operated pressure relief valves.
- The valve is mounted on a pipe of 1-inch diameter or greater.

February 28, 1991

- For air-operated diaphragm valves, piston-operated valves which are lightweight similar to air-operated diaphragm valves and spring-operated pressure relief valves, the distance from the centerline of the pipe to the top of the operator or cylinder shall not exceed the distance indicated in Figure 20-1 corresponding to the diameter of the pipe.
- For motor-operated valves and piston-operated valves, which are of substantial weight, the distance from the centerline of the pipe to the top of the operator or cylinder and the weight of the operator shall not exceed the values indicated in Figure 20-2 corresponding to the diameter of the pipe.
- The actuator and yoke is supported by the pipe and neither is independently braced to the structure or supported by the structure unless the pipe is also braced immediately adjacent to the valve to a common structure.
- Sufficient slack and flexibility is provided in the tubing, conduits or piping which supplies the air or power needed to operate the valve.

SSRAP recognizes that Figure 20-2 for the motor-operated valves and substantial piston-operated valves may not cover all combinations of operator weight and eccentricity from the pipe centerline due to limits in the data base. Therefore, SSRAP is of the opinion that some extrapolation of the values in Figure 20-2 may be done provided the engineer making the extrapolation uses sound engineering judgment. For example, for a given pipe diameter, the values of operator weight and distance to the top of

February 28, 1991

the operator from centerline of pipe may be varied provided their product, a measure of the cantilever moment applied to the pipe, does not exceed the value calculated from Figure 20-2. SSRAP recommends that the distance to the top of the operator not be increased by the procedure by more than about 30%. Likewise, if the ground motion spectra for the site is below the SSRAP Bounding Spectrum in the entire frequency range possible for the piping and valve network, the operator weight or distance to the top of the operator can be increased by the ratio of the spectra. SSRAP recommends that either of these values not be increased by more than about 30% by this procedure.

SSRAP also wishes to point out that the operator weights given in Figure 20-2 are from the data base and may have been estimated slightly low from available catalogs. Thus, if an actual operator is slightly heavier than the value in Figure 20-2, the engineer evaluating the valve can use some engineering judgment in assigning similarity.

SSRAP also believes that the evaluating engineer can extrapolate the operator length values in Figure 20-1 using the weight and length limits of Figure 20-2 provided the yoke of the air-operated diaphragm valve is not of cast iron. Again, any extrapolation of this type should not exceed about 30% beyond the limits of Figure 20-1.

For air-operated, liquid-operated and motor-operated valves not complying with the above limitations, the seismic ruggedness may be demonstrated by static tests. In these tests, a static force equal to three times the approximate operator weight shall be applied approximately at the center of gravity of the operator non-concurrently in each of the three orthogonal principal axes of the yoke. Such tests should include

February 28, 1991

demonstration of operability following the application of the static load. The limitations other than those related to the distance of the top of the operator to the centerline of the pipe, given above, shall remain in effect. Similarly, static tests can be performed on a mock-up test stand provided the valve details are very similar to those in the plant. If there are numerous valves, a rational test program can be developed to envelope the valve configurations in the plant. Alternately, an analytical evaluation can be made.

If the valve body is of cast iron, SSRAP is of the opinion that the valve can remain provided stress analysis of the valve and associated piping reveals very low stresses due to the piping loads. It may be necessary to add braces to the piping near the valve to obtain these low stresses.

When using GERS for air-operated diaphragm valves (Reference 36), note that the GERS are to be compared with in-structure spectra for the pipe at the valve location, as previously discussed (Section 4). When using GERS for motor operators for motor-operated valves, note that the GERS covers only the operator and that the valve, yolk and the effect of the valve on the pipe must be separately evaluated.

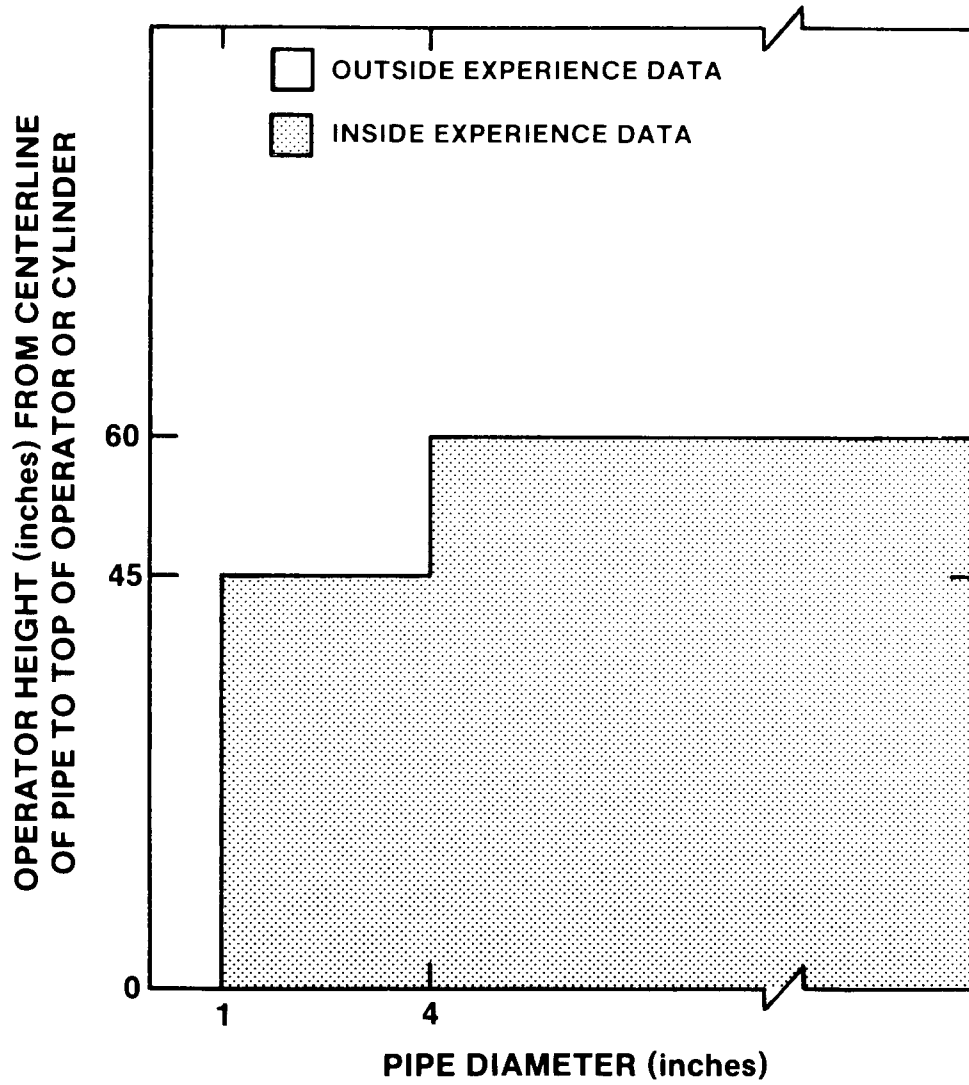
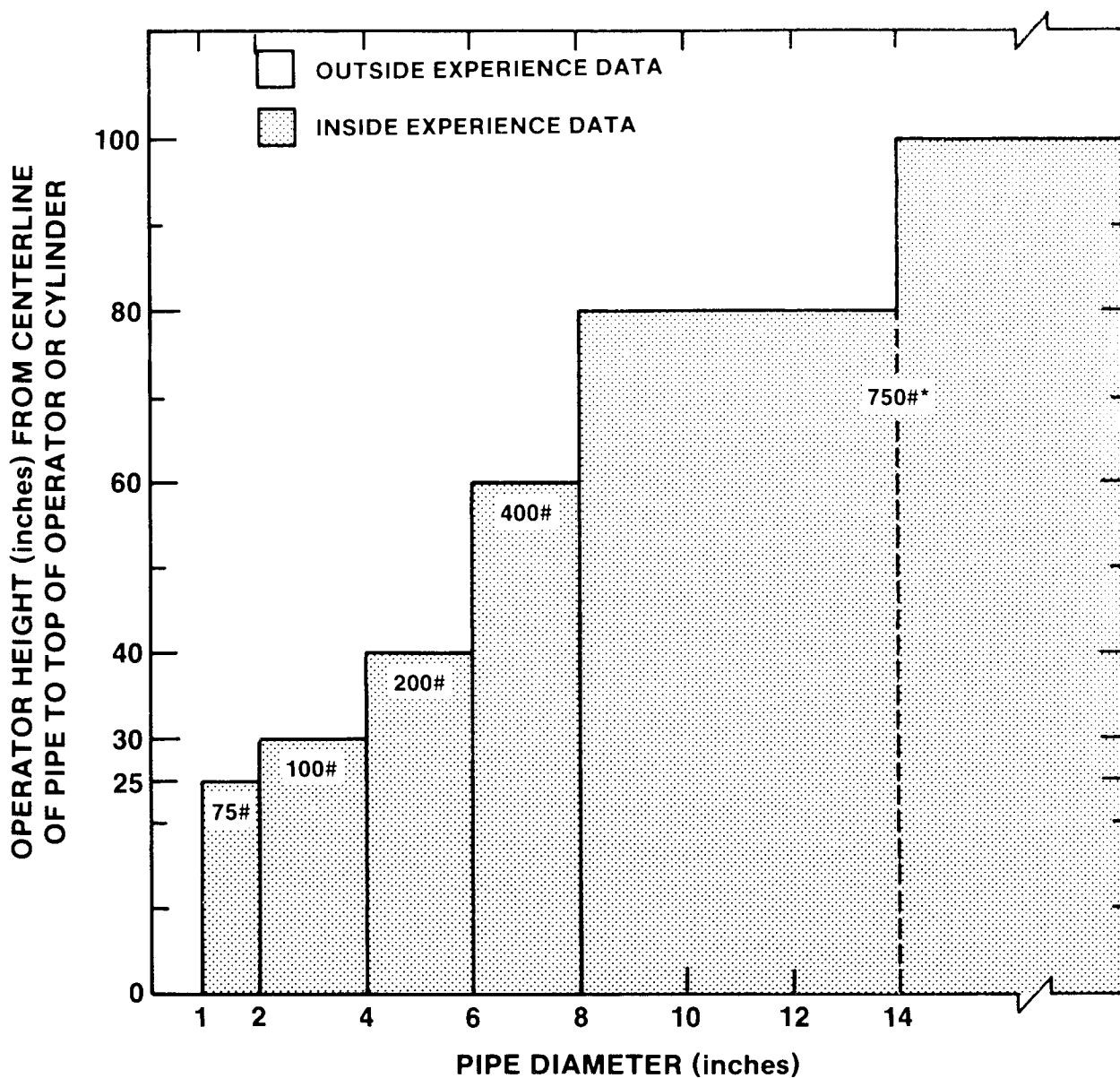


Figure 20-1 LIMITS OF EXPERIENCE DATA FOR AIR-OPERATED DIAPHRAGM VALVES, SPRING-OPERATED PRESSURE RELIEF VALVES AND PISTON-OPERATED VALVES OF LIGHT-WEIGHT CONSTRUCTION



\*APPROXIMATE MAXIMUM OPERATOR WEIGHT

Figure 20-2 LIMITS OF EXPERIENCE DATA FOR MOTOR-OPERATED VALVES AND SUBSTANTIAL PISTON-OPERATED VALVES



21. FANS AND AIR HANDLERS

Fans, air handlers, and associated equipment are relatively rugged devices and subject to the limitations set forth below, meet the criteria for the Bounding Spectrum.

A. FANS

This category includes free-standing and direct mounted fans, blowers, exhausters of the axial and centrifugal type. The axial fans include propeller, tube axial, and vane axial types. The electric drive motors are included. Fans of all sizes are included. Plant unique, special configuration fans shall be subject to plant unique reviews.

It is the opinion of SSRAP that these fans need no further evaluation except review per the following caveats:

- The unit is properly anchored. Anchorage shall be evaluated in accordance with guidelines outlined in Section 7.
- Any vibration isolation system must be evaluated (see Section 8).
- The drive motor and fan must be attached in a way sufficient to limit differential displacement. In cases where the attachment is not on a common base or is flexible, the system must be evaluated.
- In the case of axial fans with long shafts between motor and fan, it must be verified that the shaft is supported at the fan as well as at the motor.
- Sufficient slack and flexibility must be present in attached electrical lines.

February 28, 1991

- The walkdown team must be cognizant of the possibility of excessive duct distortion during an earthquake that may bind or misalign the fan. This need only be considered in cases of long unsupported ducts near the fan or relatively stiff ducts subjected to significant relative support motion.

B. AIR HANDLERS

Air handlers are sheet metal enclosures with, typically, fans, heat exchangers, filters, coils, and dampers. All size of air handlers are included.

It is the opinion of SSRAP that air handlers need no further evaluation except review per the following caveats:

- Anchorage of the enclosure and heavy internal equipment must be evaluated.
- Vibration isolation systems may be present externally or internally. They must be evaluated by the procedures of Section 8.
- Sufficient slack and flexibility must be present in attached electrical or fluid lines.
- Relays for which chatter is not acceptable shall be separately evaluated in accordance with the guidance given in Section 5.

22. CHILLERS

Chillers are the primary component of chilled water centralized HVAC systems. Their purpose is to chill water or refrigerant. Primary components of a chiller include an evaporator, a condenser, a compressor, and a control panel. The evaporator and condenser are usually two cylindrical tanks stacked in parallel and frequently mounted one above the other.

Based on a review of the data base and anticipated variations in conditions, SSRAP is of the opinion that chillers are sufficiently rugged to survive a seismic event generating ground motion within the Bounding Spectrum and remain operational thereafter, provided the following conditions exist in the nuclear facility:

- The evaporator and condenser tanks are reasonably braced between themselves for lateral forces parallel to the axis of the tanks without relying on weak-way bending of steel plate or webs of structural steel shapes. If weak-way steel plate bending must be relied on to brace the upper tank, then the adequacy of the steel components shall be justified by the walkdown engineer by other means for adequate strength and stiffness.
- The unit is properly anchored. Anchorage shall be evaluated in accordance with guidelines outlined in Section 7.
- If the unit is mounted on vibration isolators, the adequacy of the vibration isolators for seismic loads shall be evaluated in accordance with Section 8.

February 28, 1991

- Relays for which chatter is not acceptable shall be evaluated in accordance with the guidance given in Section 5.

APPENDIX ACOMMENTARY ON SEISMIC MOTION BOUND CRITERIAA.1 DEVELOPMENT OF HORIZONTAL SPECTRA BOUNDS

SSRAP's conclusions relied heavily on the earthquake data base from earthquakes of magnitude 6.0 and greater and facilities for which the estimated mean peak ground acceleration (average of two horizontal components) was equal to or greater than about 0.4g as listed in Table 2.1 of Reference 22. This data base consisted primarily of data from the Sylmar Converter Station and the Rinaldi Receiving Station subjected to the 1971 San Fernando earthquake, the El Centro Steam Plant subjected to the 1979 Imperial Valley earthquake, the Pleasant Valley Pumping plant and oil field facilities northeast of Coalinga and near the epicenter of the 1983 Coalinga earthquake, and facilities near Llolleo and San Pedro subjected to the 1985 Chile earthquake. Based upon a review of ground motion estimates made for these sites by SQUG (References 17 and 19), SSRAP has judged the following ground motion records to be representative of the ground motion at these data base sites:

Data Base Site	Estimated Ground Motion Record	Average Horizontal Ground Acceleration (G)
Sylmar Converter Station	Pacoima Dam Record Scaled to 0.5g	0.5
El Centro Steam Plant	Station 5165, El Centro Differential Array	0.42
Coalinga	Pleasant Valley Pumping Plant Free-Field Record	0.5
Chile	Llolleo Record	0.55

February 28, 1991

The average of the two horizontal response spectra from each of these four records as obtained from References 17 and 19 are shown in Figure A.1. It is SSRAP's understanding that these average spectra are generally considered to be either a reasonable or a conservative representation (underestimation) of the horizontal free-field ground motion at the data base sites. SSRAP concurs with this judgment and has used these average spectra on this basis.

It was SSRAP's judgment that a Reference Spectrum which provides a reasonable description of the ground motion level to which the earthquake experience data demonstrate seismic ruggedness could be obtained by averaging and smoothing these four representative response spectra. A significant number of data base equipment in each of the equipment classes was subjected to ground motion as high as that represented by the Reference Spectrum. The resultant Reference Spectrum is also shown in Figure A.1. The generic Bounding Spectrum shown in Figure 3.1 and Table 3.1 was then obtained by dividing this Reference Spectrum by 1.5. The basis for this 1.5 factor is described in the remainder of this subsection.

It should be noted that the average data base site spectra in Figure A.1 are considered to represent free-field spectra and do not directly relate to the seismic input to the data base equipment. The data base equipment would have seen input which might have been either greater or smaller than the free-field spectra would indicate. The following factors were considered:

1. Foundation Size Effects. This effect relates to the averaging of ground motion over the horizontal extent of the foundation of

February 28, 1991

structures such that seismic motion on the foundation of large structures is likely to be significantly less than that of the free-field. Due to this effect alone, the data base equipment would see smaller seismic input than is indicated by the free-field spectra. However, this effect is related to foundation size, and SSRAP notes that the foundation sizes associated with the data base sites are generally less than for most nuclear plant structures which might contain similar equipment. Therefore, one would generally expect at least as much beneficial size effects for nuclear plants as might have occurred in the data base plants. As a result, SSRAP has concluded that this effect may be ignored in the data base so long as it is also ignored in the nuclear plants for which the data base is being used.

2. Embedment Effects. Foundation embedment is also expected to reduce the foundation motion below that of the free-field. This effect alone might also result in the data base equipment seeing lesser seismic input than is indicated by the free-field spectra. However, nearly all of the data base equipment was mounted in structures with shallow foundations. With the exception of the limited data gathered at the Pleasant Valley Pump Station, this effect was judged to be small. Even if the Pleasant Valley Pump Station were excluded, the conclusions by SSRAP would not be affected. Therefore, SSRAP tended to ignore the potential reduction in equipment response in the data base due to the benefit of embedment effects.

February 28, 1991

3. Structural Amplification Effects. As one progresses up the height of structures, input to equipment will increase due to structural amplification. Due to this effect, equipment is likely to have seen input motion greater than that of the free-field ground. One would expect some amplification over ground spectra at the data base sites. SSRAP judged that the use of free-field ground spectra in lieu of unavailable floor spectra for the data base sites introduced some conservatism. There was no way to remove this conservatism without performing extensive dynamic evaluations of the data base plants.

Because floor spectra were not available in the data base plants and because realistic floor spectra are often not available in the nuclear plants, SSRAP emphasized the comparison of data base free-field spectra with free-field ground spectra for the nuclear plants. However, it was recognized that some structural amplification of floor spectra over free-field spectra might occur even at low elevation (generally less than about 40 feet above grade) in these nuclear plants and that this amplification might exceed that in the data base plants. For this reason, the data base spectra were divided by a factor of 1.5 to obtain a Bounding Spectrum for comparison with free-field horizontal ground spectra at the nuclear plants. This 1.5 factor was to account for the possibility that floor spectra within about 40 feet above grade in the nuclear power plant might be amplified over the ground spectra more than occurred in the data base plants.

Thus, the resultant Bounding Spectrum is directly applicable for comparison with ground spectra. When compared to floor spectra, this



February 28, 1991

Bounding Spectrum may be increased by a factor of 1.5 to bring it back up to the Reference Spectrum of Figure A.1.

Considerable useful data was also collected from data base sites when the estimated ground response spectra were considerably less than the four data base spectra on the Reference Spectrum shown in Figure A.1. In most cases, this data was simply used as confirmatory data in support of conclusions which could be reached from data for sites on which the mean peak acceleration was estimated to exceed about 0.4g. However, in the case of motor-operated valves with large eccentric operator length to pipe diameter ratios, most of the experience data came from the Valley Steam Plant in San Fernando and the Las Ventanas Power Plant and Copper Refinery in Chile, which had somewhat lesser ground motion. In this case of primary reliance on data from the Valley Steam Plant or the Las Ventanas Power Plant in Chile, the eccentric valve masses were factored downward by a 0.6 factor to account for the lesser ground motion at the site from which this data was obtained.

#### A.2 FLOOR SPECTRA VERSUS GROUND SPECTRA

Often floor spectra for nuclear power plants are very conservatively computed. In such cases, an amplification greater than 1.5 may be found even at elevations below 40 feet above grade. However, when more median-centered analyses are performed that use reasonable damping levels for the structure and account for embedment and wave-scattering effects, these high amplifications are not observed with most earthquake ground motion records. The Seismic Safety Margin Research Program (SSMRP) (References 31 and 32) has demonstrated the large conservatism which exists in

February 28, 1991

traditionally computed floor spectra versus median floor spectra. Furthermore, floor spectra measured less than 40 feet above the grade on moderately stiff portions of the Pleasant Valley Pump Station, the Humboldt Bay Nuclear Power Plant (Reference 33), and the Fukushima Nuclear Power Plant do not show amplifications over the ground spectra of more than 1.5 for frequencies above about 6 Hz. In fact, on floors corresponding to near grade level, the floor spectra are less than or about equal to the ground spectra at frequencies above about 6 Hz. Thus, it is SSRAP's judgment that amplifications greater than a factor of 1.5 are unlikely in stiff structures at elevations less than 40 feet above grade, except possibly at the fundamental frequency of the building where higher amplifications might occur when such a frequency is less than about 6 Hz. Thus, for equipment with fundamental frequencies greater than about 8 Hz in their as-anchored condition, it was judged that floor spectral amplifications within 40 feet of grade would be less than 1.5 when reasonably computed using more median-centered approaches.

It was judged by SSRAP that the use of very conservative floor spectra should be avoided when assessing the seismic ruggedness of floor-mounted equipment. It was also the opinion of SSRAP that many of the operating plants may only have these very conservatively computed floor spectra available. To avoid the burden of having to compute more realistic floor spectra, SSRAP decided to anchor its conclusions to ground spectra at the nuclear plant sites in those cases where this was judged to be reasonable.

Thus, for the case of equipment with fundamental frequencies greater than about 8 Hz mounted less than 40 feet above grade, SSRAP's conclusions

February 28, 1991

are based upon comparing the bounding spectra with nuclear power plant ground spectra. Only for the case of equipment mounted more than 40 feet above grade or equipment with as-anchored frequencies less than about 8 Hz is it necessary to use floor spectra.

It was further decided that an 8 Hz frequency requirement was unnecessary in some cases. Many valves in the data base plants were mounted on flexible piping and thus had as-mounted frequencies less than 8 Hz. Thus, floor spectral amplification certainly occurred in the data base valves without failures. Valves in nuclear plants will tend to be mounted on stiffer piping systems than those in the data base, and thus spectral amplifications will be less severe for the nuclear plant valves than for the data base valves. Therefore, the 8 Hz requirement was judged to be unnecessary for valves. It was judged highly unlikely that the fundamental frequency of the housing of properly anchored pumps would be less than 8 Hz. Therefore, it was judged to be unnecessary to establish an 8 Hz cutoff for pumps.

The above recommendation that the seismic bounding spectra can be compared with the design horizontal ground response spectra for equipment mounted less than about 40 feet above grade is based upon the following judgments concerning how structures respond in earthquakes. For embedded structures on soil sites, one would expect deamplification of horizontal ground motion through a moderately stiff structure between the foundation level and grade level. Thus, one would not expect the horizontal motion within the structure at grade level to exceed the horizontal free-field

February 28, 1991

ground motion. For embedded structures on rock sites, one would not expect much deamplification of horizontal ground motion with depth. On the other hand, if the structure is laterally supported by the surrounding rock, one would expect this surrounding rock to prevent amplification of motion within the structure. Thus, one would expect horizontal motion within the structure at and below grade to nearly correspond to the free-field horizontal ground motions because of this lateral support provided by the surrounding rock. Next, with moderately stiff structures, as found in nuclear power plants, one would not expect amplification of motions by a factor greater than about 1.5 within a 40 feet elevation change. Thus, amplification of the horizontal free-field ground spectra by factors greater than 1.5 are considered to be generally unlikely for elevations less than 40 feet above grade.

There are exceptions to these expectations. Some examples are:

1. Sometimes the exterior side walls of an embedded structure are surrounded by crushable foam insulation so as to isolate the structure from lateral support by the surrounding rock or soil.
2. Often the internal structure within the containment building is not laterally tied to the external containment wall so that the internal structure is not laterally supported by the surrounding rock or soil.

For rock or very stiff soil sites where one does not expect substantial deamplification of horizontal motion with depth, one should consider grade for each structure to be the highest elevation at which that structure is laterally supported by the surrounding rock or soil. For the case of external side walls surrounded by crushable foam

February 28, 1991

insulation, this elevation would correspond to the bottom of the crushable foam insulation. For the case of internal structures not laterally tied to external walls, grade should be considered to be the base of the internal structure. For softer soil sites where one does expect substantial deamplification with depth, the top of the ground surface should be considered to represent grade, even for the above two exceptions. In other words, judgment must be exercised when interpreting the "effective" grade elevation, and in some cases this elevation should be considered to be lower than the top of the ground surrounding the building.

Similarly, unique conditions could exist where amplification greater than about 1.5 would be expected to occur within 40 feet above grade. SSRAP is unable to come up with any realistic example from nuclear power plant structures where greater amplifications would be expected. Even so, the provision of allowing comparison of the seismic bounds to the design horizontal ground response spectra for equipment mounted less than 40 feet above grade should be applied with judgment.

The above discussion does assume that the ground motion will have frequency content similar to that represented by the four data base spectra and the Reference Spectrum in Figure A.1, or by either the U.S. NRC Reg. Guide 1.60 Spectrum (Reference 23) or the NUREG/CR-0098 Spectrum (Reference 24). For all of those records, 90% of the power comes from frequencies below about 7 Hz (see Reference 34). Many lower magnitude (less than magnitude 6.0) records associated with short epicentral ranges show significant power coming from frequencies in excess of 8 Hz, particularly those recorded in the eastern U.S. In such cases, one might

February 28, 1991

obtain amplifications greater than about 1.5 at frequencies above about 8 Hz even at low elevations in stiff structures. However, SSRAP notes that high frequency ground motions documented to date do not have much damage potential due to low spectral displacement, low energy content and short duration. Further, the equipment of concern does not appear to have a significant sensitivity to high frequencies (other than possibly relay chatter). Thus, the issue of high frequency amplitudes through buildings is only a concern for the potential failure of brittle materials such as ceramics and for potential chatter. It is SSRAP's firm opinion that the issue of potential amplifications greater than 1.5 above about 8 Hz for high frequency input is of no consequence for the classes of equipment considered in this document except possibly for relay chatter. The SSRAP recommendations for the resolution to the questions of the vulnerability of relays to chatter due to higher frequency input and the amplification of high frequency input are discussed in Section 5. For functionality after the earthquake and structural integrity of these classes of equipment, SSRAP considers its ruggedness recommendations to be particularly conservative for high frequency earthquake inputs so long as the Bounding Spectrum is not exceeded.

### A.3 VERTICAL COMPONENT OF MOTION

SSRAP believes that the vertical component will not be more significant relative to the horizontal components for nuclear plants than it was for the data base plants. Therefore, it was decided that seismic bounds could be defined purely in terms of horizontal motion levels.

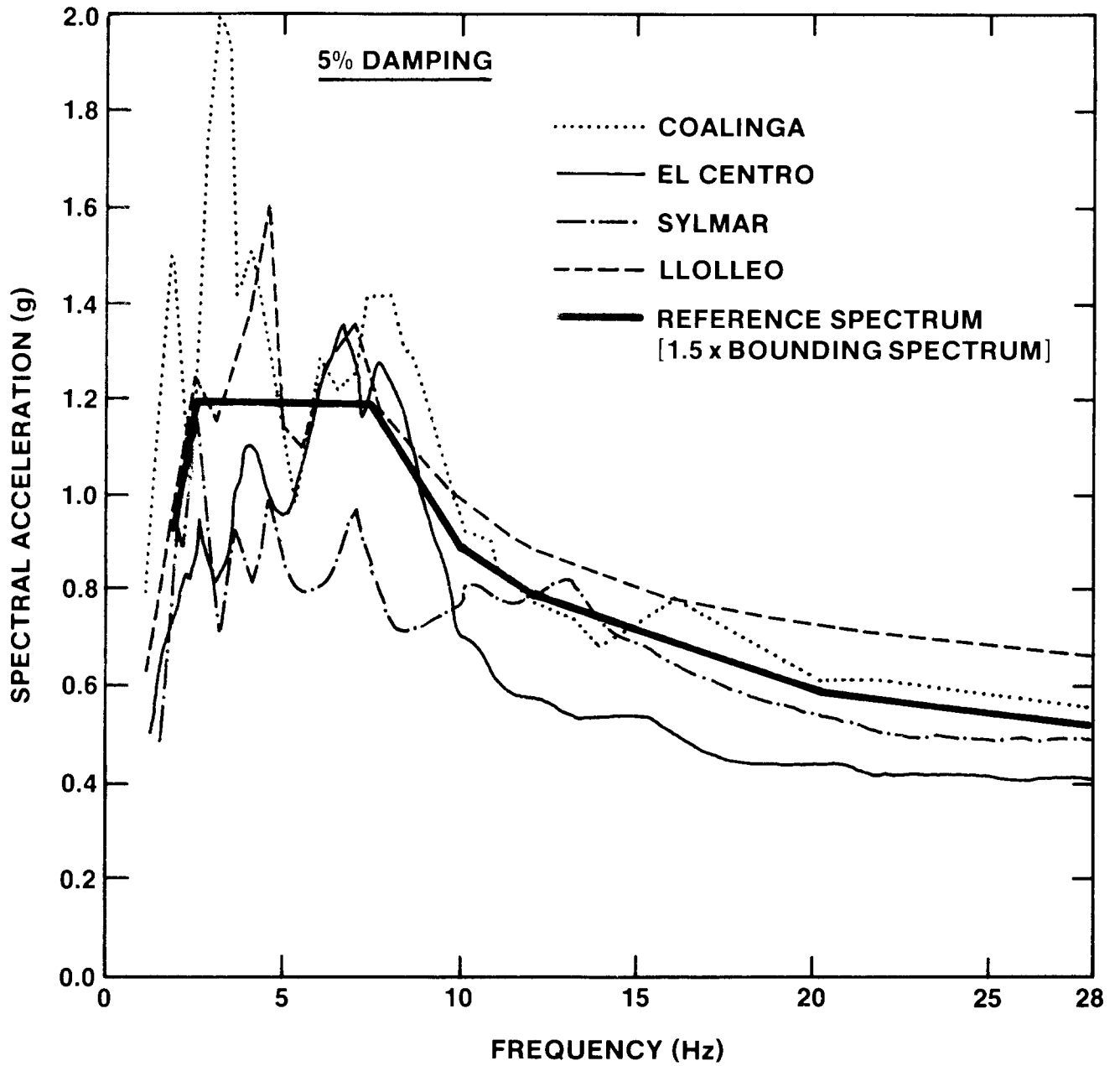


Figure A-1 HORIZONTAL RESPONSE SPECTRA

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**PART II**

**REVIEW PROCEDURE TO ASSESS**

**SEISMIC RUGGEDNESS OF**

**CANTILEVER BRACKET CABLE TRAY SUPPORTS**

**SENIOR SEISMIC REVIEW AND ADVISORY PANEL (SSRAP)**

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## 1.0 INTRODUCTION

The potential performance of cable tray systems and their supports have been the subject of considerable concern and attention in recent years within the nuclear industry. This has resulted in extensive and sophisticated analytical studies, considerable modifications to cable tray systems of added bracing and stronger supports and connections at substantial economic impact. However, these actions are completely contrary to actual experience of cable tray systems and supports when subjected to ground motions in moderate earthquakes. The experience data base of cable tray systems in actual earthquakes has shown excellent performance with only isolated instances of significant damage. Shake table tests to study cable tray systems, supports and defects found in existing plants have confirmed the actual earthquake experience data and demonstrated that usual configurations will perform well in ground motion levels expected at most nuclear installations. The seismic ruggedness of cable tray systems has been well demonstrated experimentally and in actual earthquakes.

In December 1980, the U.S. Nuclear Regulatory Commission (NRC) designated "Seismic Qualification of Equipment in Operating Plants" as Unresolved Safety Issue (USI) A-46. "The objective of USI A-46 is to develop alternative seismic qualification methods and acceptance criteria that can be used to assess the capability of mechanical and electrical equipment in operating nuclear power plants to perform the

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intended safety functions" (Reference 10). A group of affected utilities formed the Seismic Qualification Utility Group (SQUG) to work with the NRC in developing a program methodology to enable resolution of the A-46 issue. To assist in developing a program methodology, SQUG and the NRC jointly selected a five-member Senior Seismic Review and Advisory Panel (SSRAP) in June 1983 to make an independent assessment of whether certain classes of equipment in operating nuclear power plants in the U.S. have demonstrated sufficient seismic ruggedness in past earthquakes so as to render an explicit seismic qualification unnecessary. SSRAP operates as an independent review body with all of its findings submitted concurrently to both SQUG and the NRC.

In the mid 1980s, SQUG and the NRC agreed to add cable trays and conduit systems to the scope of the A-46 program. SSRAP reviewed data and preliminary recommendations for cantilever bracket cable trays prepared by SQUG through its consultant, EQE Incorporated, in the fall of 1986 (Reference 2). After detailed review of the data, SSRAP presented its conclusions in the initial draft of this report dated March 20, 1987. Revisions were issued on August 4, 1987, and October 3, 1988, addressing comments from the NRC and SQUG and including procedures for floor-mounted cantilever bracket cable tray supports. This revision reflects further changes for compatibility with refinements in other A-46 documents.

The purpose of this report is to outline a methodology that can be used to review the seismic ruggedness of cable tray systems and their supports in existing nuclear power plants. SSRAP has used the earthquake experience data base, shake table test results and their professional judgment in establishing this review procedure. In using this approach, it must be kept in mind that the purpose of cable trays and their supports are to support cables, and protect the cables from damage in an earthquake so the cables will remain functional. Damage to the cable trays and their supports is permissible and might happen within this methodology. The intent is that cable functionality is maintained and that cable tray or support damage does not jeopardize other nearby equipment. SSRAP considers minor buckling and distortion of cable trays, buckling or failure of diagonal support braces, distortion of brackets, flexural yielding of clip angles and supports, etc., as permissible.

There are numerous types of cable tray supports and details that can be found in any plant. This report is limited to cable trays supported by cantilever bracket-type supports. These cantilever bracket supports can be attached to a wall or to a vertical member supported from overhead structure or from floor-to-ceiling in many different configurations. Cantilever bracket cable tray supports attached only to the floor are included and are discussed separately in Appendix A due to special issues relative to the analytical procedures for such supports. This report does not cover other types of cable tray

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supports. The methodology has been extended to other types of cable tray supports and conduit supports which are discussed in Reference 9. SSRAP has reviewed Reference 9 extensively and has agreed with the procedures contained within that report.

## 2.0 EARTHQUAKE EXPERIENCE DATA BASE

Cable tray systems have been subjected to actual earthquakes on many occasions. Reference (1) discusses this subject in detail for cable trays with cantilever bracket-type supports. Reference (1) includes documentation of cantilever bracket-supported cable tray and conduit performance in the following earthquakes: San Fernando 1971, Point Mugu 1973, Humboldt Bay 1975 and 1980, Imperial Valley 1979, Morgan Hill 1984, Central Chile 1985, Mexico 1985 and Adak Island, Alaska 1986.

A review of this data base illustrates that cable trays and their support brackets are occasionally subject to minor damage such as minor buckling of members, etc., but that these systems perform very well in protecting the cables from damage in an earthquake. One isolated failure was the collapse of a cable tray run supported by slender posts cantilevering up from the ground at the United Technologies Chemical Plant in the 1984 Morgan Hill earthquake. These cantilever posts did not appear to be adequate for gravity loads based on simple analysis, and SSRAP has covered this type of support based on its judgment and

material prepared in Reference (8). Other forms of distress include a tray that partially slid off a cantilever bracket at the Sicartsa Steel Mill in the 1985 Mexican earthquake. Reportedly, there was no restraining clip or bolt to prevent the cable tray from sliding laterally on the support bracket. Other cases of minor buckling or distress to cantilever brackets or the cable trays themselves are noted, but no damage to the cables is reported.

In summary, the earthquake experience data is favorable and indicates that most cantilever bracket-type cable tray systems are inherently rugged for seismic exposure.

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### 3.0 SHAKE TABLE EXPERIENCE DATA BASE

A large number of shake table tests have been conducted in recent years by ANCO, Bechtel and URS/J.A. Blume and Associates on cable tray and conduit systems (References 11 and 12). These tests have confirmed that cable tray and conduit raceways and their support systems are rugged under seismic ground motion. Testing in the 1 to 3 g ZPA range usually resulted in no damage or inconsequential damage such as minor tray or support distress. When damage did occur, it was generally after several high level seismic events, and associated with some identifiable configuration or effect, as discussed below.

The dominant phenomena associated with cable tray response is high damping resulting from cable motion, and support joint plastic action. Such systems are highly energy-absorbing and withstand, without collapse, input motions many times as great as the motion which would cause them to just exceed the elastic limit of the support components. These systems possess very high equivalent viscous damping, in the range of 10% to 50%, largely due to cable motion within the trays and plastic joint action. Damping is dependent on the amount of cabling present, input motion amplitude, the extent the cables are tied to the tray or restrained from relative motion, etc.



For the earthquake levels discussed herein (free-field ground motion within the SSRAP bounding spectrum of Reference 2), this excellent seismic performance of cable tray systems has been found to be essentially independent of manufacturing and assembly details such as splice location, strut spot welds, tray hold-down clips, tray design, strut clip design, and bolt torque variations. To prevent possible significant tray motion relative to the support, there must be some form of clip holding the tray to the cantilever support (two per support, one on each side of the tray). At higher levels of input than anticipated by the ground spectrum of Reference 2, light gage or improperly designed clips have failed and allowed tray motion relative to the supports. While it has not been generally observed during shake table testing, static tests of light metal strut hardware suggest that there can be considerable variation in strength depending on manufacturing and assembly method. Under-torquing of channel nuts, use of channel nuts with rounded teeth or which are insufficiently hardened, and the presence of excessive galvanization on the strut can lead to significantly lower joint capacity by a factor of two to three. Some channel nuts are manufactured without any teeth, and these connections presumably are much weaker under high repeated loads. Another case noted in shake table tests involved a rigid fabricated "boot" which supported cold-formed channel struts for cable tray support. The rigid boot would not deform under bolt torquing, and the resulting gap caused a weak connection which catastrophically failed in a shake table test. Furthermore, there are two situations that can

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significantly reduce the beneficial damping present in cable trays by a ratio of about 2. These are the use of a mastic-type fire retardant, which has the effect of causing the cables to stick together, and the use of excessive cable ties at extremely close spacing. While it appears that these issues will not be a problem at the seismic levels of concern here, the walkdown engineers would be well advised to keep these issues in mind during their investigation. If many of these factors appear to be present in a given configuration, a special evaluation may be in order.

#### 4.0 INCLUSION RULES FOR SEISMIC RUGGEDNESS EVALUATION

Based on a review of the experience data base and test data, SSRAP recommends that cable trays with cantilever bracket-type supports comply with the following inclusion rules or caveats to be evaluated for seismic ruggedness by the SSRAP criteria:

- The cable trays may be installed at any elevation within a nuclear power station located at a site with a free field ground motion spectrum not exceeding the Seismic Motion Bounding Spectrum contained in Reference (2).
- The cable trays shall have a span between supports not exceeding 10 feet.
- Cable trays should not be filled with cables above the top of the side rail of the cable tray. If any cables are located above the top of the side rails other than an isolated cable or two in the center of the tray, the cables must be restrained by straps or other devices to keep them on the tray during ground shaking.

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- When cable trays have vertical drops more than about 20 feet and flapping of the cables during an earthquake might cause pinching or cutting or impacts with sensitive equipment, the cables shall be restrained by straps or other devices to keep them in the tray during ground shaking.
  - There shall not be a noticeable excessive sag of the cable trays between supports.
  - There must be some form of restraint on each side of the cable tray to prevent sliding on its supporting member.
  - If excessive corrosion of cable trays or supports is observed, the effects of that corrosion on potential seismic performance shall be evaluated separately.
  - The cable trays are mounted such that their sway in an earthquake will not impact cabinets containing relays or other equipment where an impact could cause serious consequences. For guidance, SSRAP recommends for screening potential impacts that a clearance of 2 inches for relatively rigid systems and 6 inches for relatively flexible systems would normally be adequate to prevent impacts subject to the judgment of the walkdown engineers.

- There are no gross defects or large cracks in the concrete to which the cable tray supports are attached. If such gross defects or large cracks are found to be present, their influence on the seismic performance of the cable tray system shall be evaluated separately. Expansion anchors and embedded bolts can be utilized in tension zones of concrete utilizing capacities given in Reference 5.
  
- The cable tray is hung from above or supported off a structural wall. Cable trays supported solely from a post cantilevering up from the floor or ground are covered by this procedure but the limited analytical review shall be in accordance with Appendix A.
  
- Channel nuts used with light metal framing channel systems must have some form of teeth or ridges formed or stamped into the nut where it bears on the lip of the framing channel. This requirement can be verified by review of construction records or by a limited visual sampling of a few connections.

- Strut systems supported by "boots" or similar rigid devices should be specially evaluated. Rigid "boots", especially plant specific custom designs, see (Figure 1), may allow gaps between the vertical strut and support "boot" which greatly reduces the capacity of the bolts connecting the strut to the "boot" for vertical gravity loads. Sometimes this detail can be easily improved by adding a through bolt pin.
  
- Cable trays crossing from one structure to another should be checked for sufficient flexibility and modified as needed. The cable tray system must be able to accommodate the relative motion between the separate structures.
  
- Transverse braces near sensitive equipment should be evaluated to ensure they either will not fail, or that if they fail and fall, they will not cause damage to the sensitive equipment below.
  
- Beam clamps, if used, should not be oriented such that gravity loads are resisted in shear so as to lead to potential sliding of the beam clamp.

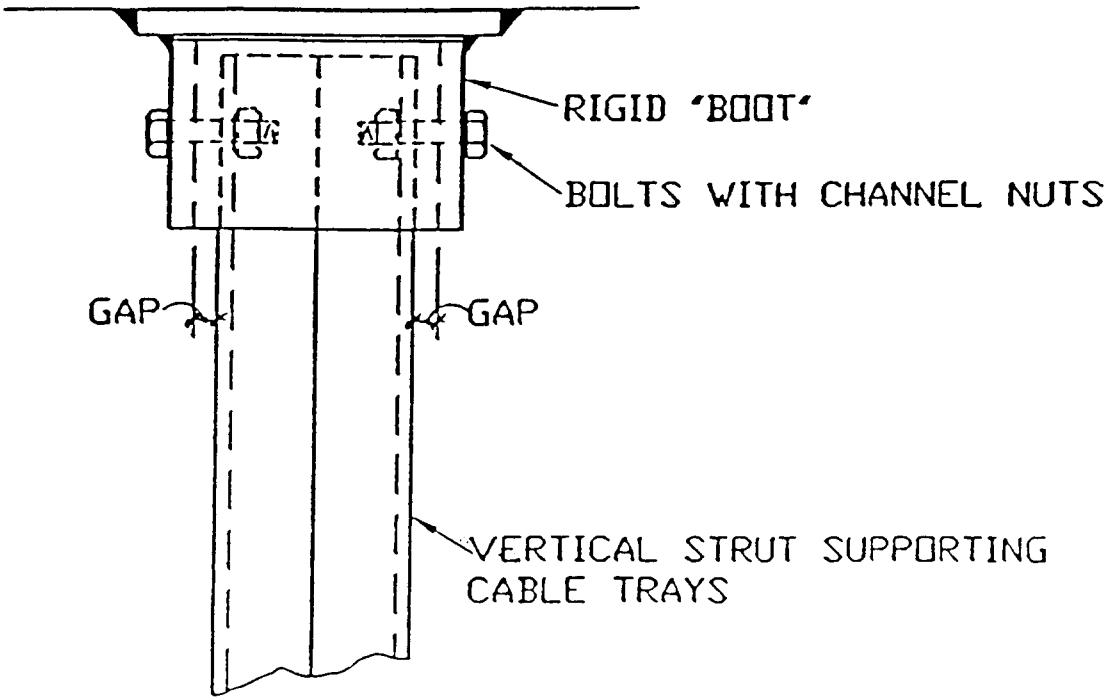


Figure 1. Detail of rigid "Boot" support for vertical strut supporting cable trays that failed completely in shake table tests and should not be permitted in nuclear plants. This non-typical custom-designed boot was so rigid that bolt tightening would not allow closure of the gaps shown.

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## 5.0 SEISMIC WALKDOWN PROCEDURES

During the plant walkdown, the Seismic Review Team (SRT) shall review cable tray systems and configurations for general seismic ruggedness. They shall, in particular, look for those items mentioned in the inclusion rules for seismic ruggedness evaluation for general compliance. They shall be alert for unusual or unique conditions which might not be covered within the experience and test data bases, and which might not exhibit the desired seismic performance.

SSRAP envisions that the detailed walkdown will be conducted by at least two knowledgeable engineers under the general direction of the SRT. Initially, the SRT would brief the cable tray engineers about what is expected, and the level of detail anticipated during the walkdown. The engineers would then spend about one week each walking through the plant tracing the various cable tray runs and noting the different conditions. They should review the cable trays and their supports for general compliance with the inclusion rules for seismic ruggedness evaluation, although complete inspection is not expected and a limited sampling of details of similar support types will be sufficient. In addition, the engineers shall select cable tray supports for the limited analytical review. Upon completion of their walkdown, the engineers shall spend at least three to four hours walking through the plant with members of the SRT to inform the SRT of

their findings, and gain general agreement on the cable tray supports selected for the limited analytical review.

The walkdown engineers should constantly be looking for unusual or nontypical conditions which may affect the seismic ruggedness of the cable tray systems. They should look for connection details like the rigid steel "boot" connection previously described for vertical supports that failed in shaking table tests and similar unusual connections. Although the longitudinal seismic response of cable tray systems has not caused failures in actual earthquakes, the walkdown engineers should look for "hard spots" which might draw excessive loads in an earthquake. For example, a lengthy cable tray run with long, flexible supports may have one or several short, rigid supports from a lower portion of the structure. If such a condition is found, the engineers should use their professional judgment to assess the condition and evaluate qualitatively if the support or supports might actually fail. SSRAP would not be concerned with the failure of a single support as the cable tray and cables should easily span to adjacent supports without damage to the cables. However, if the failed support might fall on sensitive equipment below and cause significant damage, then there would be cause for concern. SSRAP encourages the walkdown engineers to exercise such judgment and share their judgments with the SRT members for general concurrence.

SSRAP is aware of a concern of aging of cable ties made of plastic-type materials which are frequently used to restrain cables within the cable trays. If restraining straps are required on vertical drops or when trays are filled above the top of their side rails and those restraining straps are of a plastic-type material, then the walkdown engineers should make a brief qualitative evaluation by physically pulling or tugging on a few of the straps or enclosed cables to insure that the straps have not become brittle. If the straps break or easily fail under this simple test, then their effectiveness in an earthquake is obviously questionable and replacement should be provided in those areas where they are needed.

As part of the cable tray walkdown, the walkdown engineers should select a sampling of cable tray supports for limited analytical review. SSRAP envisions that the walkdown engineers would select about ten to twenty cable tray support systems which cover the general type of supports found within the plant. This sample size should be increased if many different cable tray supports are present in a single plant. The cases selected should include the different basic configurations of tray supports and include the fuller trays or heavier weights on the support system that are found in the plant. If cables fill the trays above the top of the side rail, the sampling for limited analytical review should bracket all these conditions of possible overload. In plants with very full cable trays, this could increase

the sample size higher than ten to twenty supports. The walkdown engineers should watch for heavy weights such as pipes, conduits, fire protection, etc., which may have been added on to the original cable tray supports since the original installation. Some of these conditions would be logical selections for limited analytical review. They should also look for missing or loose bolts or clips, corrosion, poor workmanship and flaking galvanizing which might affect channel nut strength. If these conditions are found, they should be evaluated or corrected if appropriate. Undersized welds or welds of poor quality visually, particularly at the support's anchor connection, provide obvious candidates for limited analytical review. Supports at the top of long vertical drops which may support more than normal loads are also candidates for selection. The exact number of supports selected for analytical review will vary depending on the diversity of support systems and conditions within the plant.

## 6.0 LIMITED ANALYTICAL REVIEW

A limited analytical review shall be performed on those cable tray supports selected by the SRT and the walkdown engineers as representative of conditions within the plant with the lowest estimated seismic margin. The intent of this limited analytical review is not to simulate potential seismic performance or stresses, but to correlate, approximately, conditions within the plant analytically with conditions that performed well in the experience data base.

It is important for the analyst to understand the philosophy behind this limited analytical review. As previously discussed within this report, cable trays and supports have performed extremely well in past earthquakes and shaking table tests with few exceptions. The trays and their supports typically act as pendulums and wiggle and sway but do not fail. Ductile inelastic performance such as yielding of clip angle supports or steel vertical support members is completely acceptable as it allows the cable tray to deform and move without brittle or premature failure. The high damping inherent in cable tray systems reduces the dynamic motions resulting from the inelastic performance and maintains integrity.

The limited analytical review is to be performed using static analysis and realistic capacity criteria for the strength of members. Realistic capacity analysis is defined as equivalent to Part 2 - Plastic Design of the AISC Specification for Steel Design (Reference 3). For cold-formed steel members, use stresses of 1.7 times the AISI Specification for those members (Reference 4). In calculating the realistic capacity, the bending of clip angles and eccentricities in clip angles should generally be ignored, and ductile yielding of hanging members and braces is not of concern and should not be considered as the realistic capacity.

For expansion anchors, use the Mean divided by 3 or 4 as appropriate from the URS Seismic Anchorage Guidelines as published by EPRI (Reference 5). All aspects of Reference 5 must be followed, including spacing of anchorages, embedment depths, inspection requirements, etc. The one relaxation is that expansion bolt tightness need not be checked by a wrench for overhead bolts resisting gravity load tension. When using Reference 5 capacities, SSRAP would recommend that the more conservative values (i.e., Mean divided by 4 for expansion anchors) be used for initial evaluation recognizing that cracks may be present in the concrete near the support being considered or other supports within the plant represented by this support. The walkdown engineers should observe any large noticeable cracks from the floor using a bright flashlight which might create an outlier for cable tray supports. If

it becomes necessary to use the less conservative capacity values of Reference 5 (i.e. Mean divided by 3 for expansion anchors which recognizes cracks not larger than 10 mills, 0.01 inch in the concrete) to pass the limited analytical review, then the walkdown engineers may have to return to the plant and utilize ladders as needed to satisfy themselves that the concrete does not contain significant cracks within the vicinity of cable tray supports represented by sample. In evaluating such a condition for overall ruggedness of a cable tray system, the SRT must use their judgment, recognizing that a single large crack near one cable tray support might allow that single support to fail in an earthquake, but not endanger the entire system of cables being supported.

Many cable tray supports are built with various configurations of cold-formed steel channel struts with inturned lips at the open portion of the channel. These systems are typically proprietary products known as Unistrut, Superstrut, Power Strut, B-Line, etc. Connections to these channel struts is with the use of channel nuts that have been formed or stamped in a way that prevents slipping along the lips of the channel after tightening. Design values for bolts connected with these channel nuts are based on manufacturer's recommendations using a minimum factor of safety of 3 as recommended in Reference 6. Due to a lack of access to actual test data for these bolts with channel nuts, SSRAP recommends using the normal design value as the realistic capacity. SSRAP is aware that many factors affect the strength of these nuts, including

the actual torque on the bolts, the configuration of the teeth or ridges on the nut that bear against the channel and the actual case hardness of these teeth, and the amount of galvanizing on the channel strut. SSRAP is not advocating any detailed inspection of these items since it is aware that tests have been performed on these various material or installation "defects" showing that the factor of safety of 3 is sufficient to encompass the lower strength values represented by these "defects" to the extent they are usually encountered.

Floor-mounted cantilever bracket cable tray supports perform similar to cantilever bracket cable tray supports hung from overhead except for concerns of buckling of the vertical post and the fact that the effect of gravity is not always beneficial. When floor-mounted cantilever bracket supports deflect laterally, gravity load effects will cause additional moment at the base due to P- $\Delta$  effects. Furthermore, inelastic deformations of clip angles or slip of expansion bolts providing base fixity can increase P- $\Delta$  or instability effects and must be considered. In addition, since gravity loads are not beneficial, the longitudinal effects and motion cannot be dismissed based on the experience data base. The limited analytical review for floor mounted cantilever bracket cable tray supports has been modified to reflect these concerns and is contained in Appendix A.



For each selected cantilever bracket cable tray support attached overhead or to a wall, SSRAP envisions the following analytical checks:

1. Check the cable tray support and its connections for the actual dead load (without any load factors) against normal gravity load design values. This check shall include all eccentricities of the actual load except that the bending of clip angles shall be ignored. This check shall include both the support system as well as the bracket which directly supports the cable tray.
2. For vertical cantilevers from an overhead support, check the basic vertical support and its connections for 3.0 times the actual dead load considered as a gravity load along the axis of the vertical support. In other words, ignore the moment that each support bracket would impose on the vertical support. Use realistic member and connection capacities as discussed previously (Part 2 - AISC Plastic Design, Reference 5 for expansion bolts, channel nuts with a factor of safety of 3, etc.).
3. For vertical cantilevers from an overhead support which, when subjected to horizontal lateral forces, will exhibit ductile flexible behavior, no lateral load analytical check is to be performed. Likewise, cantilever brackets bolted directly to a structural wall do not require a lateral load analytical check.

4. For vertical cantilevers from an overhead support which, when subjected to horizontal lateral forces, will exhibit potentially brittle-type behavior as in partially welded details or will behave in a very rigid fashion, check the cable tray support for the actual dead load (without any factors) acting in conjunction with 2.0g as a lateral horizontal static force. In this check, include the gravity load moment that each support bracket imposes on the vertical support. Use realistic member and connection capacities as discussed previously (Part 2 - AISC Plastic Design, Reference 5 for expansion bolts, channel nuts with a factor of safety of 3.0, etc.) For welded connections, the connection shall be considered acceptable, even if it cannot resist the calculated load, if the weld is stronger than the member and develops the member's full strength.

For members welded to a plate or assembly which is attached to concrete with expansion anchors, the expansion anchors shall be considered acceptable, even if they cannot resist the horizontal load imposed, if the expansion anchors are stronger than the plastic flexural strength of the member supported. For a braced rigid support system with a diagonal brace, perform the check as described and determine which element controls the capacity. If the diagonal brace or its connections control the capacity, then check the main vertical member only for the capacity of the diagonal brace. If the connection is a partial weld, verify the

weld capacity at the maximum possible force in the weld (up to loads of  $1.0 \times DL + 2.0g$  horizontal) considering maximum and minimum realistic diagonal brace loads. This latter situation may seem confusing, but SSRAP is concerned that diagonal braces may induce high downward forces in the vertical support which may induce failure. Examples 3 and 4 in the following pages should clarify the approach to be used in these cases.

The  $2.0g$  lateral horizontal static force is intended to be used for correlation with the earthquake experience data base at sites with a free field SSE equal to the SSRAP Bounding Spectra given in Reference 2. For sites with a lower SSE, the  $2.0g$  can be reduced proportionally by the ratio of the spectral accelerations of the site SSE to the spectral accelerations of the SSRAP Bounding Spectra. If realistic floor spectra are available for the plant, it is preferable to use a horizontal static force equal to 2.5 times the zero period acceleration (ZPA) of the point of attachment of the cable tray supports.

In performing these analytical checks, many simplifying assumptions are to be made which would not normally be permitted in the nuclear power industry. The bending of clip angles is to be analytically ignored. The bending or yielding of steel members in flexure or flexure and tension is considered not to be a failure mode. In calculating the tension load in an embedded bolt due to moment, the tension load may be

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calculated as the moment divided by the distance between the bolts or center of bolt groups. It must be remembered that the purpose of a cable tray is to support the cables and protect them during the earthquake. Yielding or damage to the cable tray does not imply damage or loss of function to the cables, thus, damage is acceptable to the cable tray itself provided it does not jeopardize the cable functionally.

The philosophy behind this limited analytical review is completely different from conventional structural analysis. There are two types of actions involved in vertically-hung cable tray support systems. The first is the vertical gravity load pulling down on the vertical support system. The second is those factors causing the cable tray support to sway laterally, specifically, lateral forces due to earthquake and eccentricities of the gravity load from a single vertical support. Provided the potential failure mechanisms for lateral loads are ductile or yielding, such as clip angle bending, steel yielding or slip in light metal bolts with channel nuts, the effect of these sway-producing effects does not need to be considered in the analysis. In other words, if some flexural yielding, or channel nut bolt slip allows the cable tray support to swing somewhat freely like a pendulum, it is not necessary to calculate nor justify lateral force effects by analysis.

However, if the failure mode is potentially brittle, such as a nominal weld of the vertical support to a heavy plate anchored overhead, then SSRAP feels that the lateral load analytical check must be performed as the pendulum motion which has demonstrated such superior seismic motion may not be present without a brittle failure of the weld. If the weld in question is stronger than the member it supports, then the condition is satisfactory since the high seismic loads will tend to yield the member in a ductile manner rather than fail the weld.

SSRAP has particular concerns with some configurations of cantilever supports that are braced with short, strong diagonal members. Under lateral loads, such a short diagonal can impose high vertical loads on the primary support of the vertical member raising concerns about the adequacy of the connection of that member to the structure above. For this condition, lateral load analytical check must be performed. However, if the diagonal member controls the capacity at less than 1.0 times dead load plus 2.0 g horizontal lateral load, then the vertical member's supports need not be checked for more than the diagonal brace will cause to be exerted on the vertical member. Buckling of a diagonal brace is acceptable under this procedure and should not be considered a failure. Some judgment by the analyst performing the analysis will be needed in this case for compatibility with the intent of the check.

It must be kept in mind that this limited analytical review is not intended to simulate potential seismic performance or stresses, but to correlate approximately conditions within the plant analytically with conditions that performed well in the experience data base. The rationale for the checks is as follows: The 1.0 times gravity load check is intended to insure that the cable trays have not been overloaded to a point where the supports no longer are adequate to resist the basic gravity dead load. The 3.0 times dead load without eccentricity check is a simple check to insure that the basic connectors have a large dead load margin. The experience data base supports pass this check and verification of a large dead load margin provides assurance that if an isolated support should fail for some unforeseen situation, that a progressive support failure mechanism is unlikely. For ductile mechanisms, no lateral load check is required consistent with the experience data base and shake table test experience. For brittle or braced conditions, the 2.0g lateral check corresponds to the majority of the experience data base for ground motions up to the SSRAP boundary spectra. In fact, many cable trays in the experience data base saw significantly higher levels of shaking. For plants with lower SSEs, the 2.0g can be scaled down by ratio of the spectra. In addition, when floor response is available and realistically calculated, the 2.0g value can be replaced with 2.5 times the ZPA at the point of attachment of the cable tray support. This option is considered conservative and obviously need not be used if the other approaches lead to a lower equivalent force.

Since the analytical check is intended only to show conformance with the experience data base, the calculations should be kept simple and direct using normal industrial (non-nuclear) practice. To give guidance, SSRAP has provided calculations for two sample supports in Appendix B.

SSRAP also does not intend that the cable tray supports hung from above or attached to a wall be checked for longitudinal lateral forces, i.e., lateral forces parallel to the long run of the cables. There are numerous cases of this condition in the experience data base without damage or distress to the cables (Reference 7), and SSRAP does not believe that analytical checks are needed for this condition. The experience data base justifies this situation, and ductile pendulum action will be sufficient for good performance. For cable trays supported by floor mounted vertical posts, see Appendix A.

Despite the lack of analytical check for longitudinal cable tray effects in an earthquake, SSRAP does expect the walkdown engineers to use their judgment in looking for potential conditions of concern. For example, a long run of cable trays may be hung with long flexible supports except for a single short, stiff hanger from a lower support point barely above the cable tray. Longitudinal seismic forces may fail this short, stiff hanger, but the cable tray should be able to span to the adjacent supports, even partially as a catenary, and protect the cables from damage. SSRAP would not be concerned about

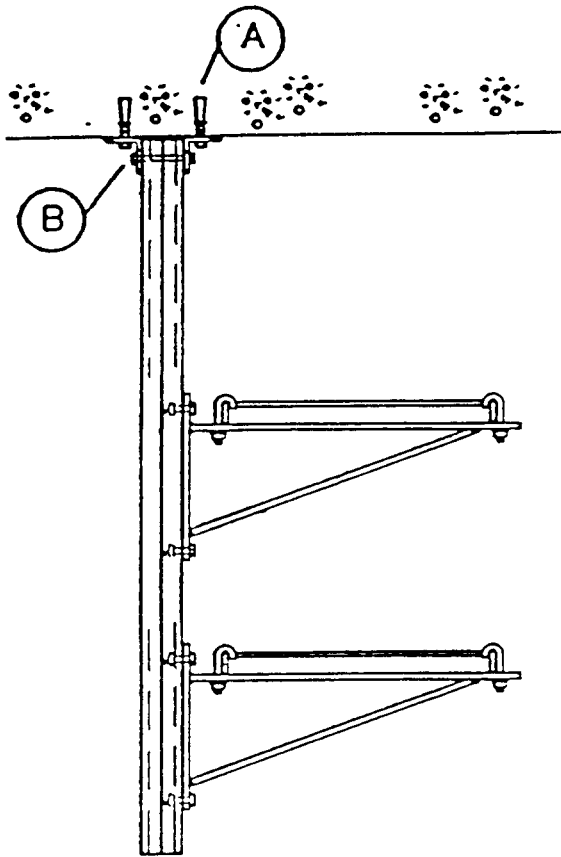
such a condition provided the failed support could not fall on sensitive equipment below. Similar conditions might be encountered where a cable tray passes through an unreinforced block wall. SSRAP expects the walkdown engineers to use considerable professional judgment in assessing these situations as they are encountered, and raise issues only if the consequences seem to indicate harm to the cables themselves or to adjacent sensitive equipment. SSRAP believes the methodology and approach is consistent with shake table test results, the earthquake experience data and the professional judgment of the SSRAP. The limited analytical method correlates well with many cases of actual cable trays in the earthquake experience data that have performed well in past earthquakes.

If one or several of the cable tray supports selected at a plant fail to pass the limited analytical check, then more extensive analysis or tests of those and similar cable trays in the plant should be performed by more traditional analysis, and strengthening measures may be appropriate.

Examples 1 to 7 follow, giving an illustration of the analytical checks that SSRAP envisions with the use of these guidelines. The first digit of the check notations in the narrative of the Example is keyed numerically to the four numbered paragraphs of analytical checks previously outlined in this section. These examples are not meant to be a complete coverage of cantilever bracket cable tray supports, but only examples to demonstrate application of the analytical checks.



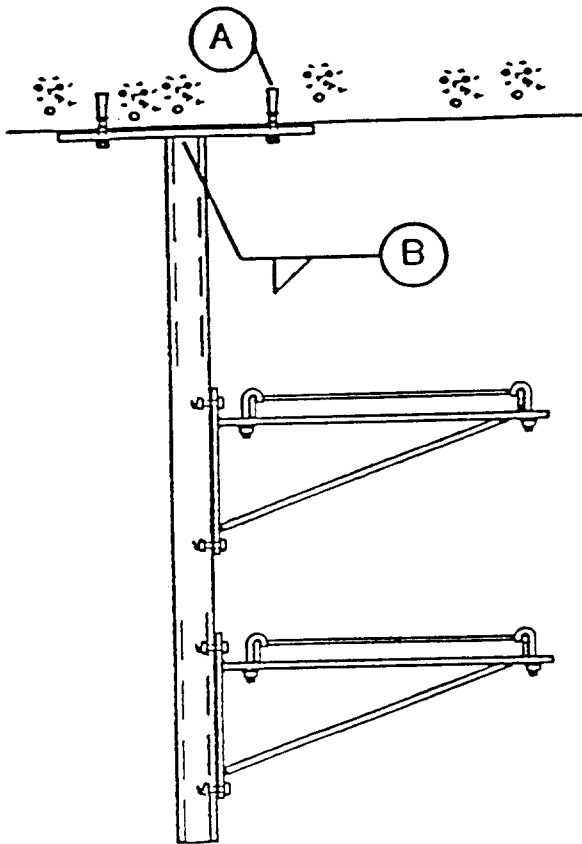
EXAMPLE 1



- 1-1 Check the entire system for  $1.0 \times DL$  (Dead Load) including eccentricity of cable trays from support above at normal design strengths.
- 2-1 For  $3.0 \times DL$ , check expansion anchors (A) for capacity per Ref. 5, ignoring eccentricity of cable trays from support.
- 2-2 For  $3.0 \times DL$ , check bolts (B) for capacity, ignoring eccentricity of cable trays from support.
- 3-1 This condition is inherently ductile, as high lateral loads will cause bending of clip angles and slight slip of the bolts with channel nuts at (B). Therefore, lateral load check need not be calculated.

If checks 1-1, 2-1 and 2-2 are all satisfactory, support is seismically rugged.

EXAMPLE 2



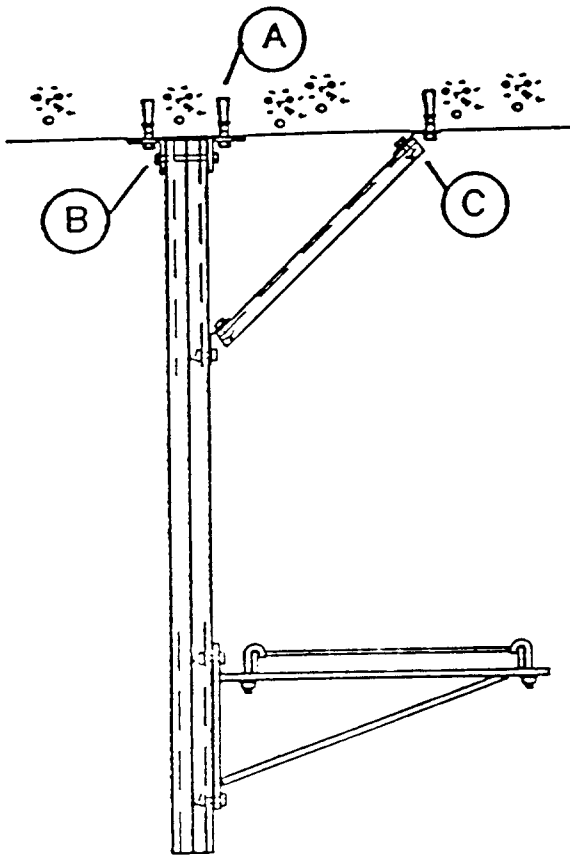
- 1-1 Check the entire system for 1.0xDL including eccentricity of cable trays from support above at normal design strengths.
- 2-1 For 3.0xDL, check expansion anchors (A) for capacity per Ref. 5, ignoring eccentricity of cable trays from support.
- 2-2 For 3.0xDL, check weld (B) for capacity per Part 2 - AISC Specification, ignoring eccentricity of cable trays from support.

4-1 For 1.0xDL + 2.0g horizontal, check weld strength (B) for capacity per Part 2 AISC Specification. If weld is full penetration or stronger than the vertical member, then this check is not necessary.

4-2 For 1.0xDL + 2.0g horizontal, check expansion anchors (A) for capacity per Ref. 5. Moment transmitted need not exceed plastic flexural strength of vertical support member.

If checks in 1-1, 2-1, 2-2, 4-1 and 4-2 all have sufficient capacity or are not necessary, support is seismically rugged.

### EXAMPLE 3



1-1 Check the entire system for  $1.0 \times DL$  including eccentricity of cable trays from support above at normal design strengths.

2-1 For  $3.0 \times DL$ , check expansion anchors (A) for capacity per Ref. 5, ignoring eccentricity of cable trays from support and diagonal brace.

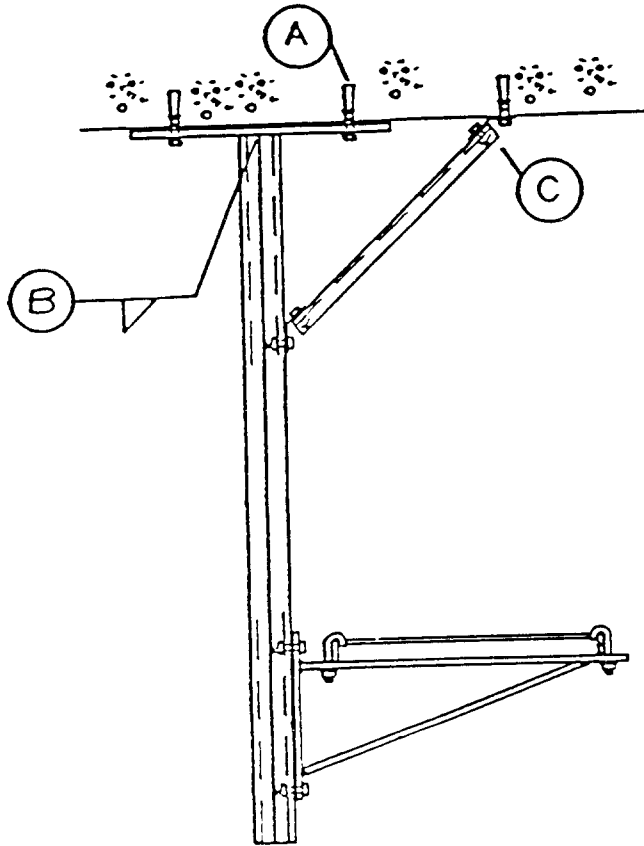
2-2 For  $3.0 \times DL$ , check bolts (B) for capacity, ignoring eccentricity of cable tray from support and diagonal brace.

4-1 For  $1.0 \times DL + 2.0g$  horizontal, check expansion anchors (A) and (C) for capacity per Ref. 5 and bolting at (B) and (C) for capacity. Check diagonal brace for buckling.

4-2 If the diagonal brace or any of its connections do not pass the check in 4-1, limit the diagonal brace to the lowest calculated capacity and check expansion anchors (A) and bolts (B) for loads limited by  $1.0 \times DL +$  that  $\% g$  that causes capacity to be reached in the diagonal brace. If expansion anchors (A) and bolts (B) have sufficient capacity for that load and 1-1, 2-1 and 2-2 checks are satisfactory, support is seismically rugged.

If Checks 1-1, 2-1, 2-2, 4-1 and 4-2 all have sufficient capacity or are not necessary, support is seismically rugged.

EXAMPLE 4



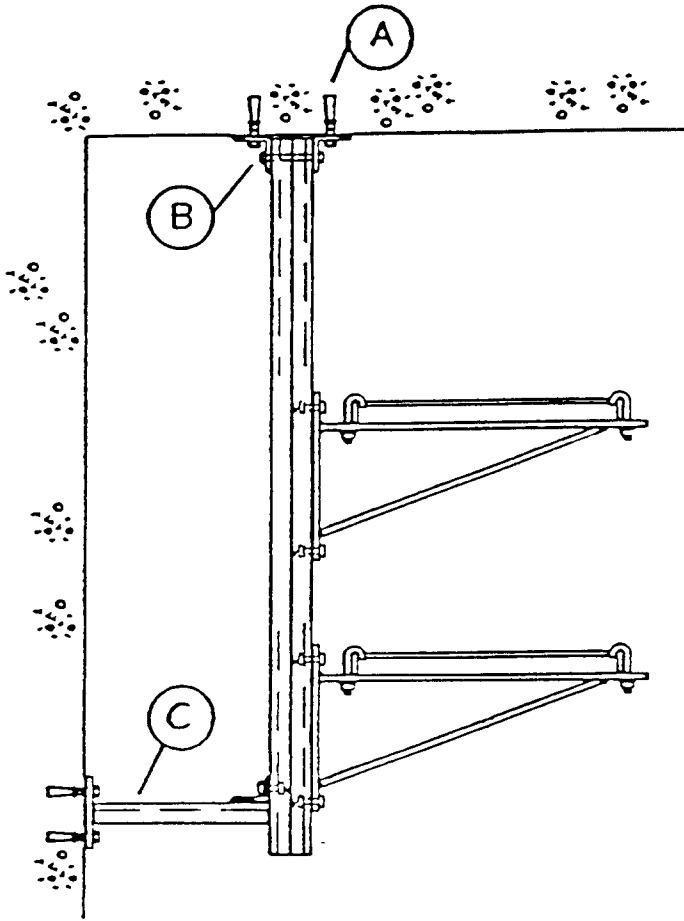
- 1-1 Check the entire system for  $1.0 \times DL$  including eccentricity of cable trays from support above at normal design strengths.
- 2-1 For  $3.0 \times DL$ , check expansion anchors A for capacity per Ref. 5, ignoring eccentricity of cable trays from support.
- 2-2 For  $3.0 \times DL$ , check weld B for capacity per Part 2 - AISC Specification, ignoring eccentricity of cable trays from support.
- 4-1 For  $1.0 \times DL + 2.0g$  horizontal check expansion anchors A and C for capacity per Ref. 5, bolts C at end of diagonal strut for capacity per Part 2 - AISC Specification. Check diagonal brace for buckling.

EXAMPLE 4 (continued)

4-2 If the diagonal brace or any of its connections do not pass the check in 4-1, then determine the maximum possible loads on expansion anchors (A) and weld (B), considering both highest and lowest probable loads in the diagonal brace with the remainder of the load to reach  $1.0 \times DL + 2.0g$  horizontal taken in bending of the vertical cantilever ignoring the cantilever brace. For determining the highest and lowest probable brace loads if controlled by channel nuts, assume lowest load corresponds to the manufacturer's design value times 1.5 for the channel nut to account for possible defects in manufacture and installation, and highest load corresponds to the manufacturer's design value times 3.0 for the channel nut. If expansion anchor (A) and weld (B) have sufficient capacity, support is seismically rugged. If weld is full penetration or fully develops member, weld is considered adequate. Moment transferred to expansion anchor (A) need not exceed plastic flexural strength of vertical support.

If Checks 1-1, 2-1, 2-2, 4-1 and 4-2 all have sufficient capacity or are not necessary, support is seismically rugged.

EXAMPLE 5



1-1 Check the entire system for 1.0xDL including eccentricity of cable trays from support above at normal design strengths.

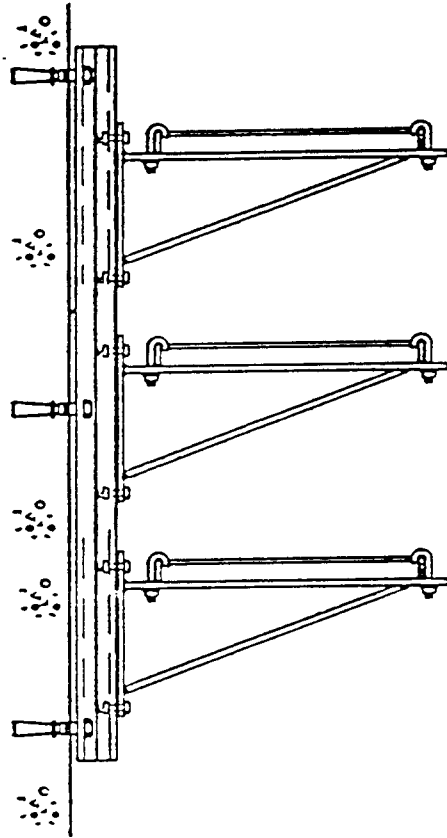
2-1 For 3.0xDL, check expansion anchors (A) for capacity per Ref. 5, ignoring eccentricity of cable trays from support.

2-2 For 3.0xDL, check bolts (B) for capacity, ignoring eccentricity of cable trays from support.

3-1 Since any failure of strut (C) will result in ductile condition similar to Example 1, lateral load is not needed by inspection.

If checks 1-1, 2-1 and 2-2 are all satisfactory, support is seismically rugged.

EXAMPLE 6

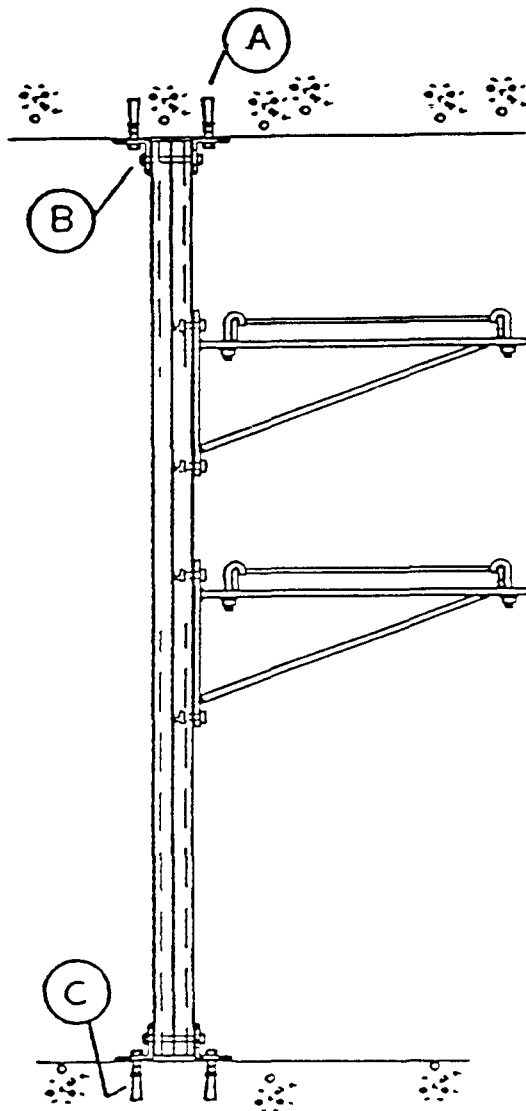


1-1 Check the entire system of  $1.0 \times DL$  (Dead Load) including eccentricity of cable trays from support at normal design strengths.

3-1 A lateral load check is not necessary as this support system is ductile and extremely stable for lateral loads.

If check 1-1 is satisfactory, support is seismically rugged.

EXAMPLE 7



- 1-1 Check the entire system for  $1.0 \times DL$  (Dead Load) including eccentricity of cable trays from support at normal design strengths.
  
- 2-1 For  $3.0 \times DL$ , assuming all gravity load is resisted at top, check expansion anchors (A) for capacity per Ref. 5 and bolts (B) for capacity, ignoring eccentricity of cable trays from vertical support. If these connections can resist entire load and check 1-1 is satisfactory, check is completed and support is seismically rugged.
  
- 2-2 If the top connection can resist only a portion of the  $3.0 \times DL$  loads, check the vertical strut in compression (including buckling considerations) for remainder of load not able to be resisted at top connection. Verify that connections at base details have capacity to resist compression load assumed in strut.



EXAMPLE 7 (continued)

3-1 System is inherently ductile for lateral loads so a lateral load check is not necessary unless check 2-2 is used.

4-1 If check 2-2 was used indicating that the top connections cannot resist  $3.0 \times DL$ , then the top and bottom connectors of the strut (expansion anchors, channel nuts, welds, etc.) shall be checked for  $1.0 \times DL + 2.0g$  horizontal. The vertical strut need not be checked.

If check 1-1, 2-1 or 2-2 and 4-1 are satisfactory, support is seismically rugged.

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Prepared for and in collaboration with Bechtel Power Corporation, Los Angeles, Power Division, Santa Monica, CA.

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**APPENDIX A**

**SPECIAL CONSIDERATIONS FOR  
FLOOR MOUNTED CANTILEVER BRACKET  
CABLE TRAY**



## APPENDIX A

This Appendix addresses cantilever bracket cable tray supports which are floor mounted. Floor mounted cantilever supports, subjected to seismic motion, will act in the same manner as cantilever supports mounted overhead with the exception that the effect of gravity on the floor mounted support will cause additional moment at the base when significant lateral deflections occur. Furthermore, if inelastic action occurs at the base or in the base connection due to clip angle bending or member yielding or buckling, concerns about stability must be carefully addressed. Due to these special concerns, SSRAP has located information on floor mounted cantilever bracket cable trays in this Appendix so the additional concerns to verify seismic ruggedness can be clearly outlined.

SSRAP has developed this criteria based on the experience data base and SSRAP's judgment. There are limited cases of floor mounted cable tray supports in the data base. However, SSRAP is of the opinion that, provided stability issues are not present, floor mounted cable tray supports are inherently rugged for seismic exposure. SSRAP has adapted portions of Reference (8) directly into this Appendix.

All portions of the report to which this Appendix is attached apply to floor mounted cantilever bracket cable trays. This includes the

general discussion, the inclusion rules, the seismic walkdown procedures and the general concept of the limited analytical review. However, there are additional requirements and a somewhat different philosophy when executing the limited analytical review. The examples of the limited analytical review contained in the main report do not apply to floor mounted supports and the examples given in this Appendix should be followed instead.

The limited analytical review is similar to the condition of wall or overhead mounted supports. The basic philosophy behind this methodology is that floor mounted cantilever supports will act in the same manner as cantilever supports mounted overhead with the exception that the floor mounted supports must not become unstable because of the formation of a plastic hinge or buckling or exhibit excessive base rotation due to moments and forces caused by the lateral seismic loads and the eccentricities of the cable tray loads. Furthermore, analytical checks must be included for seismic loads longitudinal to the cable tray run.

Two analytical checks are required. They are a dead load check that meets normal code design requirements and a dead load plus lateral load check that meets realistic member and connection capacities. The details of these checks are discussed later. It should be pointed out, however, that unlike the overhead mounted cantilever supports that



behave in a ductile manner, all floor mounted cantilever supports chosen for an analytical review must be checked for dead load plus a lateral horizontal static force to assure that instability is not a concern.

Overhead mounted cantilever supports that behave in a ductile manner will typically act as pendulums under large seismic forces. Ductile performance such as yielding of clip angle supports or steel vertical support members is considered acceptable because the eccentricities which develop as the support sways from side to side are resisted by gravity. This condition is not valid for floor mounted supports. Eccentricities which result as the support sways are not resisted by gravity; instead the P- (moment due to gravity load times horizontal displacement) effects will result in an additional moment at the base of the support. If the support yields and can no longer resist this moment, then the support will not maintain its integrity. Therefore, inelastic performance of floor mounted supports is not acceptable if it causes instability. However, local yielding of components is acceptable if it does not lead to instability of the support system.

The procedure for cantilever supports mounted overhead requires a check of the vertical support and its base connection for three times dead load concentrically applied to the vertical member. This is not judged to be a meaningful analytical check for floor mounted cantilever

supports. This check would not provide meaningful information on the margin of the anchorage or of the post since its capacity is greatly influenced by the eccentricity of the loads.

For each cable tray support selected by the SRT for the limited analytical review, the following analytical checks should be performed:

1. Check the cable tray support and its connections for the actual dead load (without any load factors) against normal gravity load design values. This check should include the support system as well as the bracket which directly supports the cable tray and should include all eccentricities of the actual load.
2. For vertical cantilever cable tray supports attached at the floor, check for the actual dead load (without any factors) acting in conjunction with a 2.0 g lateral horizontal static force as defined below. In this check, include the gravity load moment that each support bracket imposes on the vertical support. This check shall be used to verify the adequacy of the support column and its base connections (i.e. welds, bolts, and channel nuts). Use realistic member and connection capacities as discussed below. Yielding of clip angles or steel vertical members is not acceptable if it contributes to instability.

The 2.0 g lateral horizontal static force may be reduced for sites with a free field SSE less than the SSRAP Bounding Spectra as described in the body of the report. However, the lateral horizontal force need not be applied concurrently in both orthogonal directions. When applying the horizontal force longitudinally or parallel to the cable tray run, torsion in the vertical support post may be ignored. Furthermore, if stiff braces or other provisions have been made at occasional vertical posts to provide bracing for the cable tray system longitudinally, then it shall be demonstrated that the occasional brace can resist its tributary mass for the lateral horizontal static force with or without the reserve capacity of the other vertical posts. For this occasional stiff horizontal support, torsion from the cable tray being eccentric from the brace or braces should be included in the analysis.

Cable tray supports may have arms that are orthogonal to each other as shown in Figure A-1. All mass attached to the support should be considered in the analysis for the direction being evaluated, including the tributary mass from cable trays parallel to the direction under consideration. The torsional moments for horizontal forces caused by the eccentricity of the cable trays parallel to the direction under consideration may be neglected. SSRAP intends the analytical procedures only to demonstrate

conformance with the data base, not to represent actual stresses that might occur in an earthquake. Torsion is neglected here even for stability calculations because SSRAP feels that torsion tends to be resisted by the cable trays and overstated analytically and that there is sufficient conservatism in the recommended horizontal load. The gravity load moments on the vertical post shall be considered as bi-axial bending on the vertical post and the base connections.

Concrete expansion anchors in tension can experience a small slip when loaded near their capacity. This slip can result in an additional moment on the support due to P- $\Delta$  effects caused by the rotation of the support at the base. Rotation can also be caused by the bending of clip angles at the base of the support and slip of channel nuts. For many support types, this additional moment will be negligible and does not need to be included. The significance of this additional load should, however, be evaluated to determine if it should be included in the analytical check. A slip of 1/8 inch on expansion bolts at the base should be considered. A slip of 1/16 inch in channel nuts at the base should also be considered. If the combined P- $\Delta$  effects are less than about 5% of the total moment, they can be ignored.

Unlike supports mounted on the ceiling, expansion anchor bolts on floor mounted supports must be checked with a wrench for tightness as specified in Reference (5). Design values for bolts connected with channel nuts on cold-formed steel channel struts are based on the manufacturer's recommendations using a minimum factor of safety of 3. Alternatively, test data for specific connection types may be used in lieu of the above capacity requirements. Capacities based on test data should have safety factors consistent with those recommended in the applicable codes specified above.

For the vertical cantilever support with a diagonal brace, perform the check as described above, check the support column and its base connections along with the connections of the diagonal brace. The diagonal brace should also be checked for buckling. If the diagonal brace or any of its connections do not pass this check, then determine the maximum possible loads on the column base and anchorage. This is determined by considering both the highest and lowest probable loads in the diagonal brace (e.g. tension capacity and buckling capacity of the brace) with the remainder of the load to reach  $1.0 \times DL +$  horizontal seismic force taken in bending of the vertical cantilever ignoring the diagonal brace. For determining the highest and lowest probable brace loads when controlled by channel nuts, assume the lowest load corresponds to the manufacturer's design value times 1.5 for the channel nut to account for possible defects in manufacture and

---

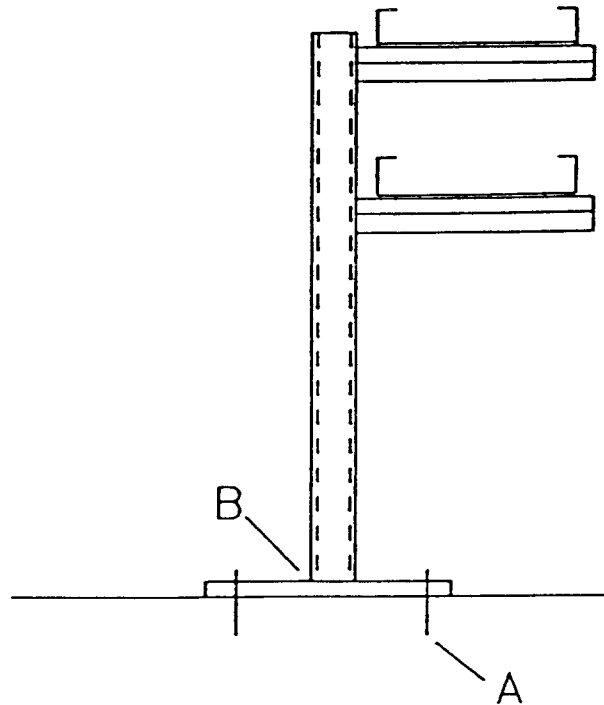
installation, and highest load corresponds to the manufacturer's design value times 3.0 for the channel nut. If the column base and anchorage have sufficient capacity, the support is seismically rugged. If the limited analytical review determines that the diagonal brace may buckle, then the consequences of the buckled brace on stability shall be addressed.

With regard to the lateral horizontal static force check, SSRAP envisions this check only to correlate with the experience data base and the judgment of SSRAP relative to a reasonable means to verify ruggedness. SSRAP does not recommend that lateral forces be applied in both horizontal directions concurrently since this check is not intended to simulate actual forces but only to verify ruggedness.

SSRAP recommends that torsion be neglected when considering horizontal forces longitudinally or parallel to the direction of the cable tray. This is because SSRAP believes that restraining clips and the tray itself will yield slightly before such torsional forces are realistically transferred to the vertical post. SSRAP also recommends that the horizontal component of bending in the cantilever bracket itself due to horizontal forces parallel to the cable tray run (longitudinally) be ignored.

The following examples A-1 through A-4 illustrate the analytical checks required for floor mounted cantilever bracket cable tray supports. The examples in the main body of the report should not be followed for floor mounted supports or supports supported solely from a beam below the cable trays:

EXAMPLE A-1

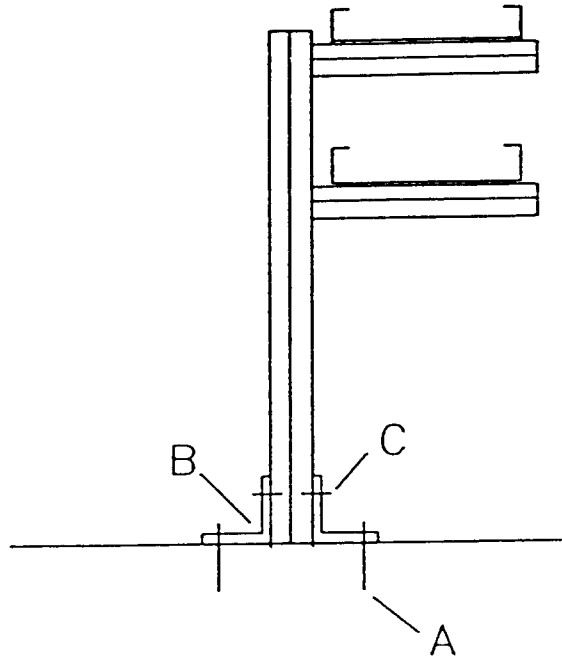


- 1-1 Check the entire system for  $1.0 \times DL$  (dead load), including eccentricity of cable trays, against normal design strength allowables.
  
- 2-1 For  $1.0 \times DL + 2.0g$  horizontal, check expansion anchors (A) for capacity per Reference 5. Perform check non-concurrently for both orthogonal directions (2).
  
- 2-2 For  $1.0 \times DL + 2.0g$  horizontal, check weld strength (B) and the vertical post for capacity per Part 2 AISC Specification (1). Perform check non-concurrently for both orthogonal directions (2).

(See Page A-16 for footnotes.)

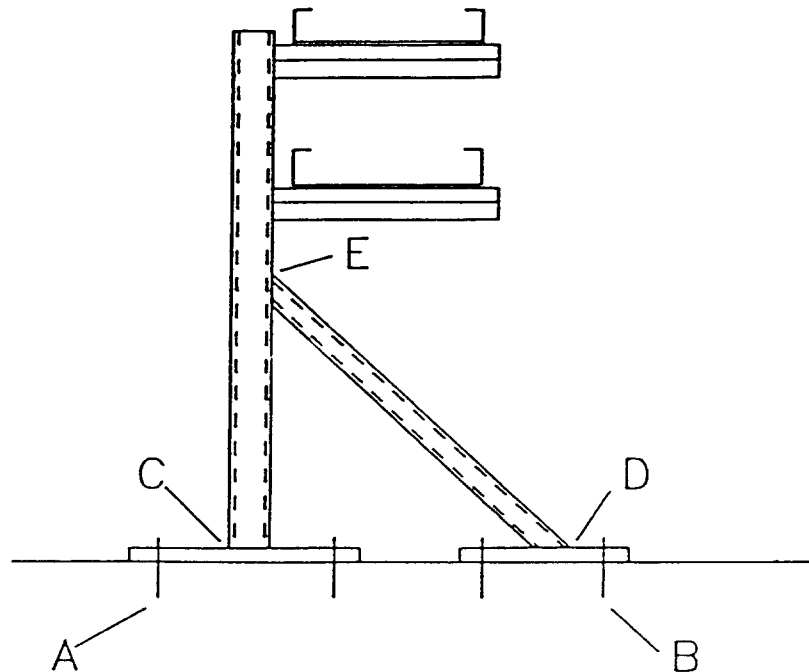


**EXAMPLE A-2**



- 1-1 Check the entire system for  $1.0 \times DL$ , including eccentricity of cable trays, against normal design strength allowables.
  
- 2-1 For  $1.0 \times DL + 2.0g$  horizontal, check expansion anchors (A) for capacity for Reference 5. Perform check non-concurrently for both orthogonal directions <sup>(2)</sup>.
  
- 2-2 For  $1.0 \times DL + 2.0g$  horizontal, check channel nuts and bolts (C) per manufacturer's recommendations using a minimum factor of safety of 3. Also check clip angles (B) and the vertical post for capacity per Part 2 AISC Specification. Local yielding of clip angles is allowed only when it does not lead to instability of the support <sup>(1)</sup>. Perform check non-concurrently for both orthogonal directions <sup>(2)</sup>.

EXAMPLE A-3

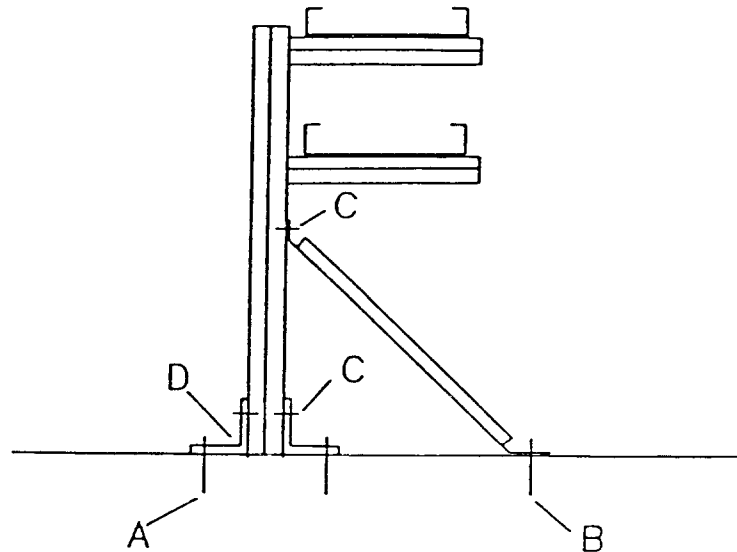


- 1-1 Check the entire system for  $1.0 \times DL$ , including eccentricity of cable trays, against normal design strength allowables.
- 2-1 For  $1.0 \times DL + 2.0g$  horizontal, check expansion anchors (A) and (B) for capacity per Reference 5. Perform this check non-concurrently for both orthogonal directions.
- 2-2 For  $1.0 \times DL + 2.0g$  horizontal, check weld strength (C), (D) and (E) (where applicable) and the vertical post for capacity per Part 2 AISC Specification. Perform this check non-concurrently for both orthogonal directions.
- 2-3 For  $1.0 \times DL + 2.0g$  horizontal, check diagonal brace for buckling.

**EXAMPLE A-3 (Continued)**

- 2-4 If the diagonal brace or any of its connections do not pass this check, then determine the maximum possible loads on the column base (C) and anchorage (A). This is determined by considering both the highest and lowest probable loads in the diagonal brace (e.g. tension capacity and buckling capacity of the brace) with the remainder of the load to reach  $1.0 \times DL +$  horizontal seismic force taken in bending of the vertical cantilever ignoring the diagonal brace. If the column base and anchorage have sufficient capacity, the support is seismically rugged.

EXAMPLE A-4



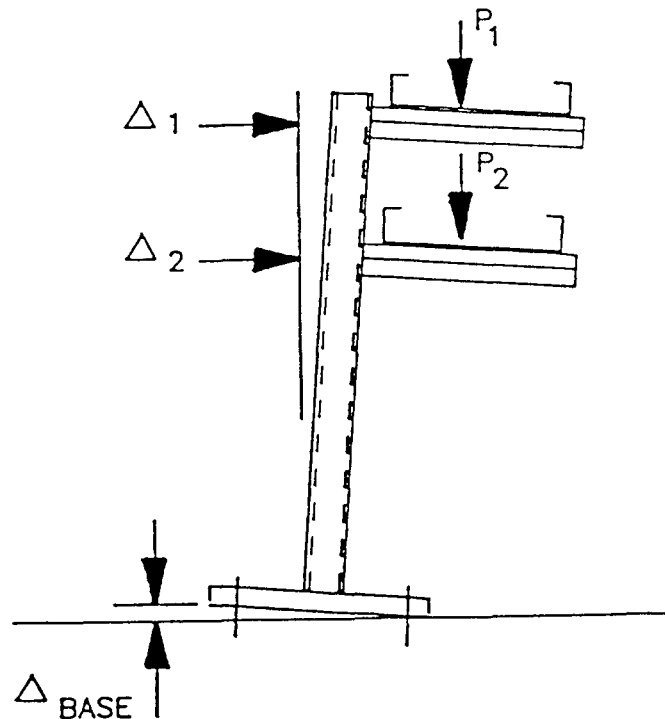
- 1-1 Check the entire system for  $1.0 \times DL$ , including eccentricity of cable trays, against normal design strength allowables.
- 2-1 For  $1.0 \times DL + 2.0g$  horizontal, check expansion anchors (A) and (B) for capacity per Reference 5. Perform this check non-concurrently for both orthogonal directions.
- 2-2 For  $1.0 \times DL + 2.0g$  horizontal, check channel nuts and bolts (C) per manufacturer's recommendations using a minimum factor of safety of 3. Also check slip angles (D) and the vertical post for capacity per Part 2 AISC Specification. Local yielding of clip angles is allowed only when it does not lead to instability of the support. Perform this check non-concurrently for both orthogonal directions. Note that, as drawn, this support is unstable for longitudinal forces as it will pivot about bolts (C).
- 2-3 For  $1.0 \times DL + 2.0g$  horizontal, check diagonal brace for buckling.

**EXAMPLE A-4 (Continued)**

- 2-4 If the diagonal brace or any of its connections do not pass this check, then determine the maximum possible loads on the column base (C) and (D), and anchorage (A). This is determined by considering both the highest and lowest probable loads in the diagonal brace (e.g. tension capacity and buckling capacity of the brace) with the remainder of the load to reach  $1.0 \times DL +$  horizontal seismic force taken in bending of the vertical cantilever ignoring the diagonal brace. For determining the highest and lowest probable brace loads when controlled by channel nuts, assume the lowest load corresponds to the manufacturer's design value times 1.5 for the channel nut to account for possible defects in manufacture and installation, and the highest load corresponds to the manufacturer's design value times 3.0 for the channel nut. If the column base and anchorage have sufficient capacity, the support is seismically rugged.

FOOTNOTES FOR EXAMPLES A-1 THROUGH A-4

1. When performing the lateral load check, the P- $\Delta$  effects caused by an initial slip of the expansion anchors in tension of at least 1/8 inch should be considered. If clip angles or channel nuts attach the post to the base, then slip of those elements should be considered, using 1/16 inch slip of the channel nut and bending of the clip angle as a minimum. The additional load from these P- $\Delta$  effects may be negligible for many support types and can be neglected when the total P- $\Delta$  moment is less than about 5 percent of the total base moment.



2. The horizontal load imposed on floor mounted supports can create torsional moments on the post and its base support which can be ignored in this analytical check.

## **APPENDIX B**

### **SAMPLE CALCULATIONS**

---



SSRAP CABLE TRAYS

EXAMPLE CALCULATION #1

(SIMILAR TO SSRAP REPORT EXAMPLE 1)

GIVEN:

$W_1 = 400 \#$

DOUBLE CHANNEL STRUT:

SECTION P1001

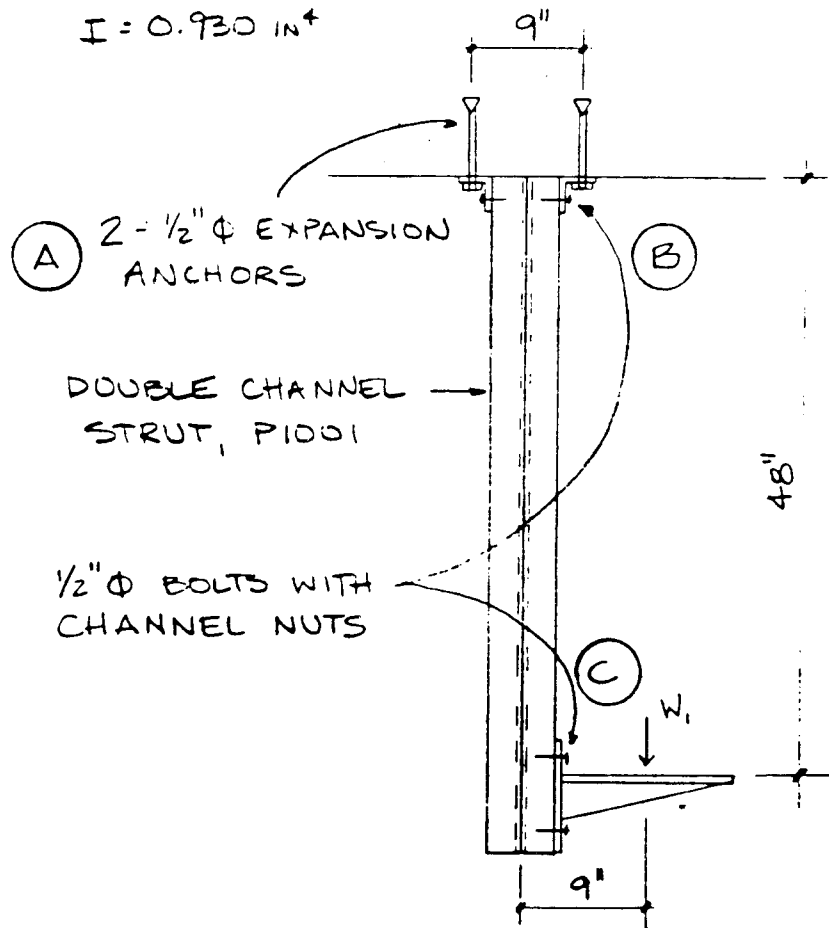
UNISTRUT OR SIMILAR



$A = 1.11 \text{ IN}^2$

$S = 0.572 \text{ IN}^3$

$I = 0.930 \text{ IN}^4$



**CHECK 1-1** 1.0 x DL ONLY, INCLUDING ECCENTRICITIES

AT TOP CONNECTION:

$$\text{MOMENT} = M_T = .400^{\#} \times 9'' = 3600^{\# \cdot \text{IN}}$$

$$\text{RESULTING } T = 400^{\#}$$

AT (A)  $\frac{1}{2}'' \phi$  EXPANSION ANCHORS

FROM E.P.R.I. REPORT "SEISMIC VERIFICATION OF NUCLEAR PLANT EQUIPMENT ANCHORAGE", ASSUMING  $f'_c > 4000 \text{ psi}$ , USING MEAN/4 VALUES, KNOCK DOWN FACTOR = 1.0 (CAN USE MANUFACTURER'S

$$\text{ALLOWABLE } T = 1700^{\#}$$

$$\text{ALLOWABLE } V = 1800^{\#}$$

RECOMMENDED STRENGTH FOR THIS CHECK)

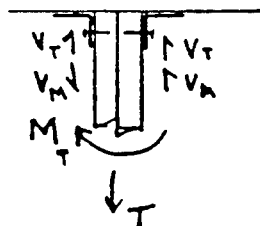
LOAD IN BOLTS:

$$\begin{aligned} T/\text{ANCHOR} &= \frac{WT}{2} + \frac{M_T}{9''} \\ &= \frac{400^{\#}}{2} + \frac{3600^{\# \cdot \text{IN}}}{9''} = 600^{\#} / \text{BOLT} \end{aligned}$$

$$V/\text{ANCHOR} = 0$$

$$\frac{600^{\#}}{1700^{\#}} = 0.35 < 1.0 \quad \underline{\underline{\text{OK}}}$$

AT (B)  $\frac{1}{2}'' \phi$  BOLTS WITH CHANNEL NUTS IN CLIP ANGLES



FROM UNISTRUT CATALOG, BOLTS WITH CHANNEL NUTS (WITH SAFETY FACTOR = 3)  
ALLOWABLE  $V = 1500^{\#}$   
ALLOWABLE  $T = 2000^{\#}$

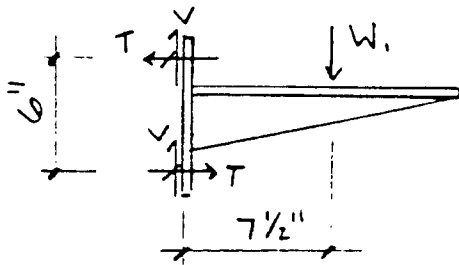
CHECK 1-1, AT (B), CONTINUED

$$V_{/BOLT} = V_T + V_M = \frac{T}{2} + \frac{M_T}{3"} = \frac{400^\#}{2} + \frac{3600^\# \cdot \text{in}}{3"} \\ = 1400^\#$$

$$T_{/BOLT} = 0$$

$$\frac{1400^\#}{1500^\#} = 0.93 < 1.0 \quad \underline{\underline{OK}}$$

AT (C) 1/2"  $\phi$  BOLTS WITH CHANNEL NUTS AT BRACKETS



$$T_{/BOLT} = \frac{400^\# \times 7.5"}{6"} = 500^\#$$

$$V_{/BOLT} = \frac{400^\#}{2} = 200^\#$$

$$\frac{200^\#}{1500^\#} + \frac{500^\#}{2000^\#} = 0.38 < 1.0$$

OK

CHECK 2-1 3.0 x DL, IGNORING ECCENTRICITIES

AT (A) 1/2"  $\phi$  EXPANSION ANCHORS

$$T_{/ANCHOR} = 3.0 \times \frac{400^\#}{2 \text{ ANCHORS}} = 600^\# < 1800^\#$$

OK

**CHECK 2-2** 3.0 x DL, IGNORING  
ECCENTRICITIES

AT (B) 2 - 1/2"  $\phi$  BOLTS WITH CHANNEL NUTS

$$V/BOLT = \frac{3.0 \times 400^\#}{2 \text{ BOLTS}} = 600^\#$$

$$T/BOLT = 0$$

$$\frac{600^\#}{1500^\#} = 0.4 < 1.0 \quad \underline{\underline{OK}}$$

**CHECK 3-1**

THIS SYSTEM IS INHERENTLY DUCTILE,  
AS HIGH LATERAL LOADS WILL CAUSE BENDING  
OF THE CLIP ANGLES AND SLIGHT SLIP OF THE  
BOLTS WITH CHANNEL NUTS AT (B). THEREFORE,  
LATERAL LOAD CHECK NEED NOT BE CALCULATED.

CHECKS 1-1, 2-1 AND 2-2 ARE ALL  
SATISFACTORY, AND THE SUPPORT IS  
SEISMICALLY RUGGED.

SSRAP CABLE TRAYS

EXAMPLE CALCULATION #2

(SIMILAR TO SSRAP REPORT EXAMPLE 2)

GIVEN:

$W_1 = 200\#$

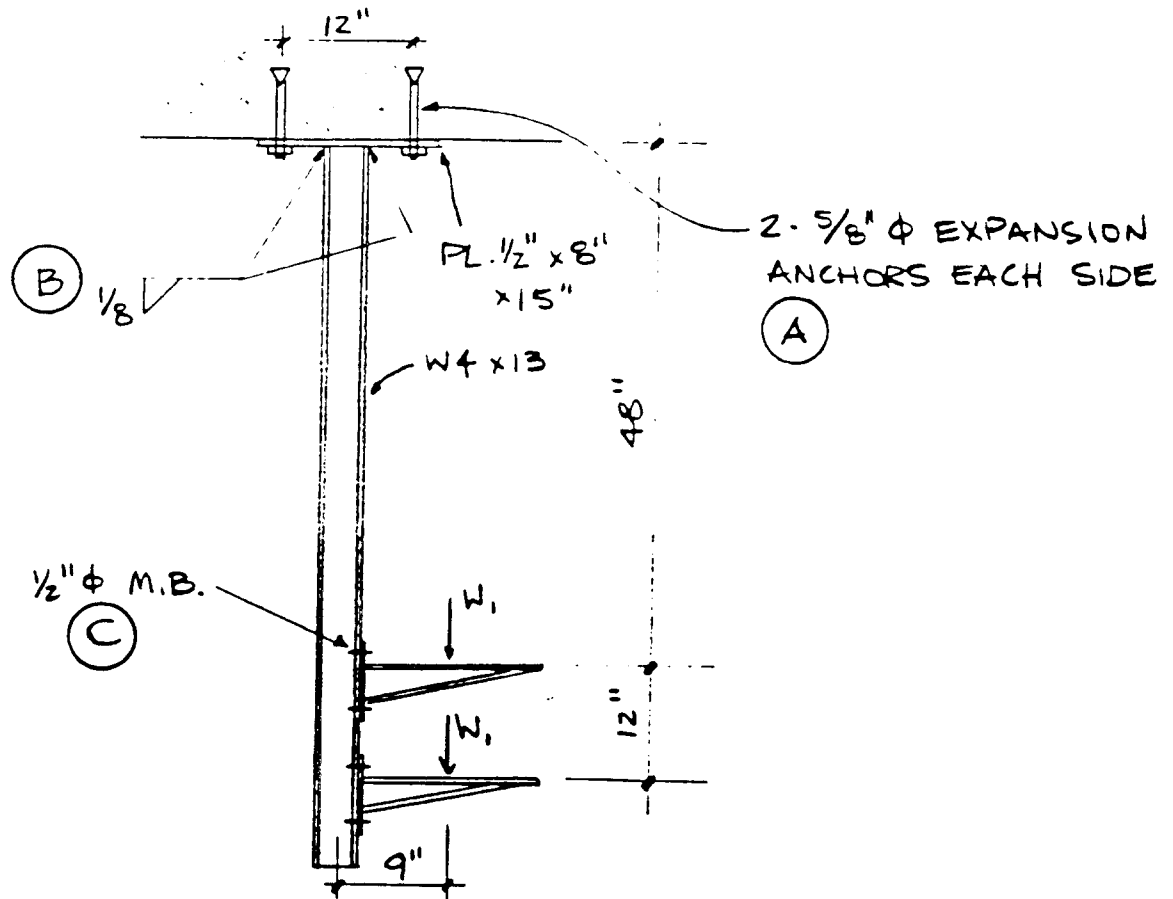
VERTICAL STRUT: W4 x 13

$A = 3.83 \text{ in}^2$

$S = 5.46 \text{ in}^3$

$I = 11.3 \text{ in}^4$

ASSUMED  $\frac{1}{8}$ " FILLET WELDS



N.T.S.

**CHECK 1-1** 1.0 x DL ONLY,  
INCLUDING ECCENTRICITIES

AT TOP CONNECTION

$$T = 2 \times 200^{\#} = 400^{\#}$$

$$\text{MOMENT} = M_T = 2 \times 200^{\#} \times 9'' = 3600^{\# \cdot \text{IN}}$$

AT (A) 2 - 5/8"  $\phi$  EXPANSION ANCHORS  
AT EACH END OF 1/2" PLATE

FROM E.P.R.I. REPORT, "SEISMIC VERIFICATION  
OF NUCLEAR PLANT EQUIPMENT ANCHORAGE";  
ASSUMING EXPANSION ANCHORS, USING MEAN/4 VALUES,  
KNOCK DOWN FACTOR = 1.0,  $f_c' > 4000$  psi.

$$\text{ALLOWABLE } T = 2400 \text{ psi}$$

$$\text{ALLOWABLE } V = 2900 \text{ psi}$$

LOAD:

$$T/\text{ANCHOR} = \frac{T}{4} + \frac{M_T}{2 \times 12''}$$

$$= \frac{400^{\#}}{4} + \frac{3600^{\# \cdot \text{IN}}}{2 \times 12''} = 250^{\#}$$

$$V/\text{ANCHOR} = 0$$

$$\frac{250^{\#}}{2400^{\#}} < 1.0 \quad \underline{\underline{\text{OK}}}$$

AT (B) ASSUMED 1/8" FILLET WELDS  
AT EACH FLANGE

$$\text{WELD AREA}/\text{FLANGE} = 4'' \times 0.707 \times 0.125 \text{ IN}^2 = 0.35 \text{ IN}^2$$

$$\text{CAPACITY}/\text{WELD} = 0.35 \text{ IN}^2 \times 20,000 \text{ psi} = 7000^{\#}$$

$$\text{LOAD: } T/\text{WELD} = \frac{M_T}{4.125''} = \frac{3600^{\# \cdot \text{IN}}}{4.125''} = 873^{\#} < 7000^{\#}$$

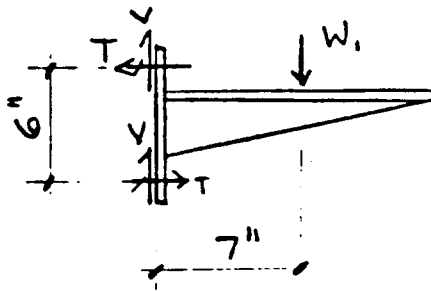
OK

CHECK 1-1

CONTINUED

PAGE 3  
OF 5

AT (C)  $\frac{1}{2}$ "  $\phi$  MACHINE BOLTS / BRACKET



FROM A.I.S.C.,

$$\text{ALLOWABLE } T = 0.196 \text{ in}^2 \times 20,000 \text{ psi} \\ = 3930 \#$$

$$\text{ALLOWABLE } V = 0.196 \text{ in}^2 \times 10,000 \text{ psi} \\ = 1960 \#$$

$$T / \text{BOLT} = \frac{200 \# \times 7''}{6''} = 233 \#$$

$$V / \text{BOLT} = \frac{200 \#}{2} = 100 \#$$

$$\frac{100 \#}{1960 \#} + \frac{233 \#}{3930 \#} = 0.11 < 1.0 \quad \underline{\underline{\text{OK}}}$$

CHECK 2-1

3.0 x DL, IGNORING ECCENTRICITIES

AT (A)  $\frac{5}{8}$ "  $\phi$  EXPANSION ANCHORS

$$T / \text{ANCHOR} = \frac{3.0 \times 2 \times 200 \#}{4 \text{ ANCHORS}} = 300 \#$$

$$V / \text{ANCHOR} = 0$$

$$\frac{300 \#}{2400 \#} = 0.13 < 1.0 \quad \underline{\underline{\text{OK}}}$$

CHECK 2-2

3.0 x DL, IGNORING  
ECCENTRICITIES

PAGE 4  
OF 5

AT (B)  $\frac{1}{8}$ " FILLET WELDS AT EACH FLANGE

$$\begin{aligned}\text{WELD AREA/FLANGE} &= 4" \times 0.707 \times 0.125" \\ &= 0.35 \text{ in}^2\end{aligned}$$

$$\text{TOTAL ALLOWABLE T} = 2 \times 0.35 \text{ in}^2 \times 1.7 \times 20,000 \text{ psi}$$

$$T = 24,000 \#$$

$$\text{LOAD! } T_{\text{ACTUAL}} = 3.0 \times 2 \times 200 \# = 1200 \#$$

$$\frac{1200 \#}{24,000 \#} = 0.05 < 1.0 \quad \underline{\underline{\text{OK}}}$$

CHECK 4-1

1.0 x DL + 2.0g HORIZONTAL

AT (B)  $\frac{1}{8}$ " WELDS

$$\begin{aligned}\text{ACTUAL } T / \begin{matrix} \text{FLANGE} \\ \text{WELD} \end{matrix} &= \frac{2 \times 200 \#}{2} + \frac{2 \times 200 \# \times 9"}{4.125"} + \frac{2.0 \times 200 \# (48" + 60)}{4.125"} \\ &= 11,545 \#\end{aligned}$$

$$\text{ACTUAL } V / \begin{matrix} \text{FLANGE} \\ \text{WELD} \end{matrix} = \frac{2.0 \times 200 \#}{2 \text{ WELDS}} = 400 \#$$

$$V_{\text{TOT/WELD}} = \sqrt{(400)^2 + (11,545)^2} = 11,552 \#$$

$$\text{ALLOWABLE } V / \text{WELD} = 0.35 \text{ in}^2 \times 1.7 \times 20,000 \text{ psi}$$

$$= 11,900 \# > 11,552 \# \quad \underline{\underline{\text{OK}}}$$



**CHECK 4-2** 1.0 x DL + 2.0g HORIZONTAL

AT (A)  $\frac{5}{8}$ "  $\phi$  EXPANSION ANCHORS

$$T/ANCHOR = \frac{2 \times 200^{\#}}{4} + \frac{2 \times 200^{\#} \times 9''}{2 \times 12''} + \frac{2.0 \times 200^{\#} (48'' + 60'')}{2 \times 12''}$$

$$= 2050^{\#}$$

$$V/ANCHOR = \frac{2.0 \times 2 \times 200^{\#}}{4 \text{ BOLTS}} = 200^{\#}$$

$$\text{ALLOWABLE } T = 2400^{\#}$$

$$\text{ALLOWABLE } V = 2900^{\#}$$

BILINEAR FORMULATION:

$$0.7 \frac{2050^{\#}}{2400^{\#}} + \frac{200^{\#}}{2900^{\#}} = 0.67 < 1.0 \quad \underline{\underline{OK}}$$

CHECKS 1-1, 2-1, 2-2, 4-1 AND 4-2 ARE ALL SATISFACTORY, AND THE SUPPORT IS SEISMICALLY RUGGED.



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