9.2 RACEWAY SYSTEMS

9.2.1 CABLE AND CONDUIT RACEWAY *SYSTEMS*[1]

9.2.1.1 Introduction

The purpose of this section is to describe the Cable and Conduit Raceway Review which should be used to screen out from further consideration the cable and conduit raceways which can be shown to be seismically adequate.

The Cable and Conduit Raceway Review consists of: (1) a *facility* walkdown in which the raceways are evaluated against a set of Walkdown Guidelines, and (2) an analytical check of selected worst-case supports using a set of Limited Analytical Review Guidelines. Those portions of the raceway systems which do not pass these screening guidelines are classified as outliers and should be evaluated separately using alternative methods. Some acceptable alternative methods for evaluating certain types of outliers are given. The remainder of this Introduction summarizes the elements of the Cable and Conduit Raceway Review.

Basis for Screening Procedure

The screening procedure contained in this section is based primarily on the use of earthquake experience and shake table test data. With few exceptions, raceway systems have exhibited superior performance in past earthquakes and in shake table tests. This successful performance has occurred despite the fact that most of the raceway systems in the data base had not been designed for earthquakes. This section of the *DOE Seismic Evaluation Procedure* provides guidance for understanding those aspects of raceway construction that provide acceptable performance and those features that might lead to poor performance.

Other more refined or sophisticated seismic qualification techniques may be used to *evaluate* the seismic adequacy of cable and conduit raceway systems; however, these other methods are generally not described in detail in this document. Some acceptable methods, based on standard engineering principles with consistent factors of conservatism, are included herein for evaluating certain types of outliers to the screening procedure.

Seismic Review Guidelines

The seismic review guidelines contained in this section are applicable to steel and aluminum cable tray and conduit support systems at any elevation in a *DOE facility*, provided the *Reference* Spectrum (shown in Section *5.3.1*) envelopes the largest horizontal component of the *5%* damped, *in-structure response spectrum (see Section 5.2) for that elevation.*

Cable and conduit raceway systems are considered seismically adequate if, during and following a *DBE*, the electrical cables being supported by the raceway systems can continue to function and the raceway systems continue to maintain overhead support as defined in this section. Minor damage, such as member buckling or connection yielding, is considered acceptable behavior. The following guidelines are provided in this section:

- Walkdown Guidelines - The purpose of the walkdown guidelines is to *evaluate* that the raceway systems are bounded by the earthquake experience and shake table test data bases. This is done by checking the raceway systems against a set of "Inclusion Rules." Guidelines are also provided to assess "Other Seismic Performance Concerns" which could result in unacceptable damage. Guidance is also provided for selecting worst-case samples of the

[1] Section 8.0 of SQUG GIP (Ref. 1)

raceway support systems in the *facility* for which "Limited Analytical Reviews" should be performed. Finally, the walkdown should be used to *evaluate* that there are no seismic spatial interactions which could adversely affect the performance of the raceway system. Section *9.2.1.2* covers these Walkdown Guidelines.

- Limited Analytical Review Guidelines - The purpose of the Limited Analytical Review is to check that selected worst-case, representative samples of the raceway support systems in the facility are at least as rugged under seismic loadings as those in the earthquake experience and shake table test data bases that performed well. If these samples do not pass this Limited Analytical Review, further evaluations should be conducted and the sample expanded as appropriate. Section *9.2.1.3* covers these Limited Analytical Review Guidelines.

The background for these guidelines is described in Reference *42*. A summary of available experience data from earthquakes and shake table tests can be found in Reference *46*. Additional background on the philosophy behind several aspects of the guidelines are included in Reference *50*. These references should be studied in conjunction with the guidelines in this section before conducting the seismic adequacy review of raceway systems.

Outlier Resolution

An outlier is defined as a raceway hardware feature which does not meet the Inclusion Rules, has significant Other Seismic Performance Concerns, or does not satisfy the Limited Analytical Review Guidelines contained in this section. An outlier may be adequate for seismic loadings, however, additional evaluations should be performed or alternative methods used beyond the scope of the screening evaluation procedure contained in this section. Section *9.2.1.4* describes some of the acceptable methods for evaluating raceway outliers. These additional evaluations and alternative methods should be thoroughly documented to permit independent review.

Seismic Capability Engineers

The screening guidelines for performing *facility* walkdowns and limited analytical reviews should be applied by a Seismic Review Team (SRT) consisting of at least two Seismic Capability Engineers (SCEs) who meet the qualification and training guidelines given in *Chapter 3*. These engineers are expected to exercise engineering judgment based upon the guidelines given in this section and the background and philosophy used to develop these guidelines as described in References *46*, *47*, and *50*. They should understand those aspects of raceway construction that provide acceptable performance and those features that may lead to poor performance.

When resolving outliers, it is especially important that the *SCEs* exercise professional judgment when applying the guidelines contained in this section since these guidelines are generic in nature to cover a wide range of applications. The *SRT* should be satisfied that the specific raceway system under review is adequately supported, based upon an understanding of the background and philosophy used to develop the guidelines in this section.

Scope of Review

The scope of review includes all the cable and conduit raceway systems in the *facility* which support electrical wire for equipment on the *Seismic Equipment List (SEL)*, as developed in *Chapter 4*.

In some older *facilities* it may be difficult to identify which raceways support the power, control, and instrumentation wiring for individual items of equipment. If this detailed information is not available, then all the cable and conduit raceway systems in the *facility* which could carry wiring for equipment *on the SEL* should be reviewed using the guidelines contained in this section.

Organization of Section

The remainder of this section is organized as follows:

- Section *9.2.1.2* contains the Walkdown Guidelines for conducting seismic adequacy reviews of as-installed conduit, cable trays, and their support systems.

- Section *9.2.1.3* contains the Limited Analytical Review Guidelines for checking the seismic adequacy of a bounding sample of the *facility* raceway support systems.

- Section *9.2.1.4* contains a summary of additional evaluations and alternative methods for assessing the seismic adequacy of raceway outliers.

- Section *9.2.1.5* contains guidelines on how to document the results of the Cable and Conduit Raceway Review.

9.2.1.2 Walkdown Guidelines[2]

Guidelines for conducting a seismic adequacy review of as-installed conduit, cable trays, and their support systems are presented in this section. The review has two purposes. The first is to check the raceway systems against certain Inclusion Rules to show the *facility* raceway systems are within the envelope of the earthquake experience and shake table test data bases. Guidelines are also provided to assess Other Seismic Performance Concerns which could result in unacceptable damage.

The second purpose of the review is to select representative, worst-case samples of the raceway supports in the *facility* on which Limited Analytical Reviews will be performed. The samples selected should encompass the diversity of the *facility's* support systems. The guidelines for performing the Limited Analytical Review are covered in Section *9.2.1.3*.

9.2.1.2.1 General Walkdown Procedure[3]

The general walkdown procedure given in this subsection describes a method for performing detailed screening and assessment of conduit and cable tray systems for seismic adequacy. This evaluation relies in part upon engineering judgment which should be exercised during the *facility* walkdown. This engineering judgment should be based on a good understanding of the performance of raceway systems in past earthquakes and in shake table tests.

The individuals on the raceway evaluation walkdown team should meet the requirements for *SCEs* as defined in *Chapter 3*. The walkdown should be conducted by one or more *SRT*, each consisting of at least two SCEs. The *SRT* should have a clear understanding and working knowledge of the screening guidelines presented below and have studied References *46*, *47*, and *50* thoroughly. They should also become familiar with the raceway design and construction practices of the *facility*, as well as with the general *facility* layout, raceway routing, and the design of raceway systems which cross building separations.

It is expected that the SRT will spend from one to two weeks in the *facility*. The duration may vary depending on the number of SRTs, the size of the *facility*, the complexity and accessibility of the *facility* raceway systems, and so forth.

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2 Section 8.2 of SQUG GIP (Ref. 1)
3 Section 8.2.1 of SQUG GIP (Ref. 1)

It is recommended that the SRT take general notes, including rough sketches or photographs, as appropriate, of typical system attributes. More detailed notes should be taken to document decisions and evaluations made in the field. Walkdowns may be conducted on an area-by-area, system-by-system, or run-by-run basis. Time should be set aside on a daily basis for the SRT to review notes and sketches; to collect *facility* drawings or information, if needed; and to check selected supports by preliminary calculations, if warranted. Recommended documentation for the review is discussed in Section *9.2.1.5*.

During the *facility* walkdown, the SRT should (1) *evaluate* that the cable and conduit raceway systems meet the Inclusion Rules given in Section *9.2.1.2.2*; (2) note and evaluate any of the Other Seismic Performance Concerns given in Section *9.2.1.2.3*; (3) select a sample of representative worst-case raceway supports as described in Section *9.2.1.2.4*; and (4) judge whether there are any seismic spatial interactions which could adversely affect the performance of the raceway system as *outlined* in Section *9.2.1.2.5*. The distinction between the first two walkdown objectives is explained below.

The Inclusion Rules identify the important limits of the earthquake experience and shake table test data bases and certain undesirable details which, if violated, could significantly compromise the seismic adequacy of a raceway system.

The SRT should visually inspect the raceway systems within the scope of review to determine whether the general construction practice in the *facility* is in agreement with the Inclusion Rules. The SRT should examine in detail several supports or spans of each different configuration type at a variety of locations in the *facility*. In addition, the SRT should actively seek out problems and be alert for and evaluate any instances of non-compliance with the Inclusion Rules noticed as part of the walkdown.

If it appears that any of the Inclusion Rules are not met, then the SRT should investigate that portion of the raceway system in sufficient detail so that the team is convinced they understand the extent of the identified condition. That portion of the raceway system should then be classified as an outlier and evaluated using the guidelines given in Section *9.2.1.4*.

The Other Seismic Performance Concerns given in Section *9.2.1.2.3* represent less significant or less well-defined conditions which should be evaluated during the *facility* walkdown. They are included in the guidelines of this section as representative of the type of concerns which the SRT should look for and evaluate to determine whether they could significantly compromise the seismic adequacy of the raceway system.

It is not necessary for all of the raceway systems in the *facility* to be inspected in detail for the Other Seismic Performance Concerns. Instead, the SRT should note and evaluate any of these concerns, if and when they are noticed as a part of the walkdown.

If it appears that any of the other Seismic Performance Concerns are not met, then the SRT should exercise their engineering judgment in assessing whether the condition significantly compromises the seismic adequacy of the raceway system. If it appears that the area of concern is not significant, then the SRT should note the condition on the walkdown documentation and provide a written explanation for their conclusion. However, if, in their judgment, the area of concern is significant, then that portion of the raceway system should be classified as an outlier and evaluated in a manner similar to an Inclusion Rule outlier.

In many cases, the *facility* walkdown may be conducted from the floor level. In some cases however, it may be necessary to examine the raceway system more closely if vision from the floor is obstructed. As different support configurations are observed during the *facility* walkdown, the SRT should examine them to familiarize themselves with the construction and details of the raceway system. When any suspect condition is observed which may violate one of the Inclusion Rules or may represent a significant Other Seismic Performance Concern, then a closer examination should be carried out.

In general, the level of effort of the review should be enough to give the SRT confidence in the seismic adequacy of the *facility* raceway systems. Ultimately the SRT is responsible for the seismic evaluations. Their sound engineering judgment is the key to successful execution of these guidelines so that the review is both safety-effective and cost-effective. In this spirit, these guidelines are only guidelines, not requirements; the sound engineering judgment of the SRT is the most important factor, particularly when evaluating the seismic adequacy of outliers.

9.2.1.2.2 Inclusion Rules[4]

The Inclusion Rules in this section identify the important limits of the earthquake experience and shake table test data bases and certain undesirable details which, if violated, could significantly compromise the seismic adequacy of a raceway system. These Inclusion Rules should be evaluated using the general walkdown procedure given in Section *9.2.1.2.1.*

Rule 1 - Cable Tray Span. The length of unsupported cable tray between adjacent supports should not exceed about 10 feet in the direction of the run. When the cable tray extends beyond the last support in a run, it should not cantilever out (overhang) beyond this support more than 1/2 the maximum unsupported span length, i.e., about 5 feet. This span and cantilever overhang were selected because they are supported by earthquake experience data.

Rule 2 - Conduit Span. The length of unsupported conduit in the direction of the run between adjacent supports, or the length of unsupported conduit cantilevered out from the last support in a run should not exceed the spans and overhangs given in the following table. These spans and overhangs were selected because they are supported by earthquake experience data and are consistent with the National Electrical Code (Reference *88*).

Conduit Size (inches)	Approximate Maximum Spans Between Adjacent Supports (feet)	Approximate Maximum Cantilever Overhang (feet)
1/2 and 3/4	10	5
1	12	6
1-1/4 and 1-1/2	14	7
2 and 2-1/2	16	8
3 and larger	20	10

Rule 3 - Raceway Member Tie-downs. For cantilever bracket-supported systems, cable trays and conduit should be secured to their supports so the trays or conduit cannot slide and fall off the supports. Normal industrial friction type hardware, such as the "z-clip" commonly used for cable trays, is a sufficient means of attachment.

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4 Section 8.2.2 of SQUG GIP (Ref. 1)

Systems do not have to be secured to every support, unless the supports are at the maximum spacing described above. For example, consider a 60-foot length of cable tray. If there is a support at each end and the interior supports are at the maximum span of 10 feet described in Rule 1, then the raceway system should be tied down at all seven supports in the 60-foot run. If there are more than seven supports, the trays need to be secured to only about seven of these supports in any 60-foot run, regardless of how many additional supports there actually are in the run.

Rule 4 - Channel Nuts. Channel nuts used with light metal framing systems should have teeth or ridges stamped into the nuts where they bear on the lip of a channel as shown in Figure *9.2.1-1*.

Rule 5 - Rigid Boot Connection. Strut systems supported by "boots" or similar rigid devices, especially *facility*-specific designs, should be evaluated on a case-by-case basis. Shake table tests have shown that a rigid boot overhead connection detail, as shown in Figure *9.2.1-2(a)*, has a significantly-reduced vertical load-carrying capacity in seismic motion. Any gap between the vertical support member and the boot prevents the development of high clamping forces in the connection and thus causes a significantly reduced load-carrying capacity. Cable tray test specimens with this detail have collapsed in shake table tests.

A rigid boot connection with gaps can be upgraded to an acceptable connection by using a through bolt as shown in Figure *9.2.1-2b*). This connection has been shown to be acceptable by shake table tests.

Rule 6 - Beam Clamps. Beam clamps should not be oriented in such a way that gravity loads are resisted only by the clamping or frictional forces developed by the clamps. The earthquake experience data base includes many examples of beam clamps attached to the lower flange of structural steel beams such that the gravity loads are resisted by bearing of the inside top of the clamp on the top of the lower flange of the beam. On the other hand, beam clamps oriented so gravity load is resisted only by the clamping frictional force, as shown in Figure *9.2.1-3*, might loosen and slip off in an earthquake and possibly cause a collapse.

Rule 7 - Cast-Iron Anchor Embedment. Threaded rod-hanger anchor embedments constructed of cast iron should be specially evaluated since there is a potential for a brittle failure mode. *Facility* documentation should be used to determine whether anchor embedments are cast iron. The earthquake experience data base includes examples where heavily-loaded rod hangers threaded into cast-iron inserts failed. The cast-iron anchor detail is shown in Figure *9.2.1-4*. Failure modes included anchor pullout and anchor fracture where rods were only partially threaded into the anchor.

9.2.1.2.3 Other Seismic Performance Concerns[5]

The Other Seismic Performance Concerns in this section represent less significant or less well-defined conditions which should be evaluated during the *facility* walkdown. They are included in the guidelines of this raceway evaluation section as representative of the type of concerns which the SRT should be looking for during the *facility* walkdown. When one of these Other Seismic Performance Concerns is found, the SRT should determine whether the area of concern could significantly compromise the seismic adequacy of the raceway system. These seismic concerns should be evaluated using the general walkdown procedure given in Section *9.2.1.2.1*.

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[5] Section 8.2.3 of SQUG GIP (Ref. 1)

Concern 1 - Anchorage. The SRT should pay close attention to the review of anchorage for the raceway supports. The team should pay particular attention to system anchorage for heavily-loaded supports. When the type of anchorage detail cannot be determined by visual inspection, other methods of determining the anchorage detail may be used, provided the SRT is convinced they understand the actual details. For example, the *facility* design drawings, construction records, or procurement specifications may provide the unknown details. If overhead welds are not visible (for example, they are covered by fire retardant), other similar supports without the coating can be inspected, or as-installed *facility* documentation reviewed to gain understanding of the weld adequacy. Similarly, if the anchorage for large junction boxes is not visible (for example, if the box is flush mounted to a wall), then other boxes that can be readily opened or reviewed may be inspected instead, or *facility* installation specifications may be reviewed to provide the unknown details. Small, lightweight junction boxes need not be specifically anchored if they are not required to act as conduit supports (i.e., they may be included within conduit spans as defined in Rule 2 of Section *9.2.1.2.2*).

Adequacy of other types of anchorage such as plastic inserts or lead shield plugs for cable tray systems are not covered by these guidelines. However, the adequacy of anchorage such as plastic inserts or lead shield plugs on lightly-loaded conduit supports rigidly attached to a wall may be evaluated on a case-specific basis by using manufacturers' information, performing *facility*-specific tests, or performing proof tests. In addition, anchorage adequacy for lightly-loaded conduit supports which are rigidly attached to a wall with less than about 15 pounds dead load may be *evaluated* by giving the conduit a tug by hand.

Concern 2 - Cracks in Concrete. Visible large cracks, significantly spalled concrete, serious honeycomb or other gross defects in the concrete to which the cable tray or conduit supports are attached should be evaluated for their potential effects on anchorage integrity during an earthquake. The walkdown team should include supports of raceways anchored into concrete with gross defects in the sample selected for the Limited Analytical Review (Section *9.2.1.3*).

Concern 3 - Corrosion. Excessive corrosion of cable trays, conduit, supports, or anchorage should be evaluated for its potential effect on structural integrity. Evaluations should consider the alternative of estimating the strength reduction due to corrosion, if appropriate.

Concern 4 - Sag of Conduit and Cable Trays. There should not be a noticeable sag of the conduit or cable tray. As a general guideline, noticeable sags are defined as about 1 inch of deflection in a span with a length of 10 feet. If a noticeable sag is found, its cause should be determined before concluding corrective action is required. For example, the sag may have occurred during construction, have no relation to structural integrity, and thus not require any corrective measures. The walkdown team should include supports of raceways sagging due to heavy loads in the sample selected for the Limited Analytical Review (Section *9.2.1.3*).

Concern 5 - Broken or Missing Components. Broken or missing cable tray and conduit components should be repaired or replaced. Locations where cable is routed near rough, sharp edges such as sheet metal cutouts should be evaluated for their potential to cause insulation damage in an earthquake.

Concern 6 - Restraint of Cables. Any cables above the top of the side rail should be restrained to keep them in the tray during an earthquake. Isolated cables in the center of the tray do not have to be restrained. If cables are not restrained, they should be evaluated to determine if they are a credible earthquake hazard to themselves (through flopping or falling out of the trays and becoming pinched or cut) or whether they are a hazard to nearby *facility* features (for example, by impacting a fragile component).

When cable trays have vertical drops of more than about 20 feet and flapping of the cables during an earthquake might cause pinching or cutting of the cables or impact with nearby fragile equipment, the cables should be restrained to keep them in the tray.

Concern 7 - Aging of Plastic Cable Ties. There is concern that old cable ties which are made of plastic-type materials may not have sufficient strength as a result of aging. Cable ties are frequently used to restrain cables within 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 ensure 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 they should be replaced in those areas where they are needed.

Concern 8 - Hard Spots. Occasional stiff supports in long flexible runs of cable trays or conduit should be evaluated to determine if the seismic movement of the run could cause the stiff support to fail. This concern is mainly associated with longitudinal motion. Cable tray or conduit systems with a long run of supports that are relatively flexible in the longitudinal direction may also contain a support that is relatively stiff as shown in Figure *9.2.1-5*. The stiff support may thus be subjected to considerable load and fail due to loads from earthquake-induced, longitudinal movement of the cable tray or conduit run. Where the stiff support is located around the bend from the long run, the flexibility and ductility of the bend in the tray or conduit will typically prevent failure of the stiff support from being a credible event. The SRT should review Reference *49* which provides examples of undamaged, long raceway runs from the earthquake experience data base.

The Limited Analytical Review Guidelines in Section *9.2.1.3* include an evaluation for fatigue effects of fixed-end rod hanger trapeze supports. The walkdown team should note instances of occasional short, fixed-end rod hangers (stiff supports) in raceway runs with predominantly longer, more flexible supports. These should be specially evaluated for possible failure due to fatigue using the Rod Hanger Fatigue Evaluation methodology given in Section *9.2.1.3.5*. Rod hanger trapeze support systems which are eccentrically-braced should also be similarly evaluated.

9.2.1.2.4 Selection of Sample for Limited Analytical Review[6]

The purpose of this subsection is to provide guidelines for selecting representative, worst-case samples of raceway supports on which Limited Analytical Reviews will be performed. The samples should include representative samples of the major different types of raceway support configurations in the *facility*. The sample size will vary with the diversity and complexity of the design and construction of each specific *facility's* raceway support system. As a general guideline, 10 to 20 different sample supports should be selected.

Before the samples are selected, the *SCEs* should become familiar with the Limited Analytical Review Guidelines in Section *9.2.1.3* and should review the sample evaluations contained in Reference *47*.

During the *facility* walkdown, notes should be taken which describe the basis for selection of each sample. The location of the selected sample should be noted, and detailed sketches of the as-installed support should be made. As-built sketches should include the support configuration, dimensions, connection details and anchorage attributes, member sizes, and loading. Any additional information that may be considered relevant to the seismic adequacy of the sample support should be noted in detail.

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6 Section 8.2.4 of SQUG GIP (Ref. 1)

The *SCEs* should seek out the most heavily-loaded raceway support for each configuration. Deep cable fill, long spans, sagging raceways, multiple tier systems, top supports at vertical runs, and fire protective coatings are indicators of heavy load. Of particular importance are raceway support systems that appear to have possibly more load than originally designed for. These can be identified by the presence of other *facility* components attached to the raceway support, such as pipe supports, HVAC duct supports, and tack welded-on conduit supports.

Conduit and cable tray supports with anchorage that appear marginal for the supported weight are good candidates for sample evaluation. Anchorage of undersized welds, incomplete welds, or welds of poor quality should also be included as samples. When overhead miscellaneous support steel, such as steel angle, is used specifically as an anchor point to support the raceways, its anchorage to the building structure should also be reviewed, and included as part of the sample, especially if its anchorage appears to be the weak link in the load path back to the structure. In addition, the sample should also include worst-case large junction boxes that are also used to support conduit, if the anchorage for the box appears to be marginal for the supported weight. As an example, cable trays and junction boxes in electrical penetration areas may be good candidates as these can become heavily loaded.

It may facilitate decision-making processes in the *facility* if some sample or bounding calculations are performed prior to walkdowns. As an example, simple screening tables can be developed which list anchor capacities and raceway system weights. These tables would enable rapid assessment of certain anchors appearing marginal for the supported load.

9.2.1.2.5 Seismic Interaction[7]

The *SCEs* should use the seismic interaction assessment guidelines given in *Chapter 7* to look for and evaluate potential seismic interaction hazards. The interaction concerns to be addressed include potential proximity effects, structural failure and falling, and flexibility of attached cables. As an example, raceway systems attached to or in the vicinity of unanchored components, or unrestrained block walls, should be noted and evaluated.

It may also be necessary to evaluate the seismic interaction effect of a single isolated raceway support which could fail and fall onto a nearby fragile item of equipment *listed on the SEL.*

9.2.1.3 Limited Analytical Review Guidelines[8]

This subsection describes the Limited Analytical Review which should be performed on cable tray and conduit supports. Analytical review calculations should be conducted to evaluate the structural integrity of the raceway supports chosen as representative, worst-case samples of the *facility* raceway support systems. The Limited Analytical Review Guidelines given in this section address structural integrity by correlation with raceway support systems that performed well in past earthquakes. The purpose of the calculations is not to estimate actual seismic response and system performance during an earthquake. Rather, the purpose of the calculations is to show that cable tray and conduit supports are at least as rugged as those that performed well as evidenced by past experience. It is important to understand the difference between these two purposes.

The Limited Analytical Review Guidelines are primarily based on the back-calculated capacities of raceway supports in the seismic experience data base. The checks of these guidelines are formulated to ensure that cable tray and conduit supports are seismically rugged, consistent with the seismic experience success data. The checks include the use of static load coefficients, plastic

[7] Section 8.2.5 of SQUG GIP (Ref. 1)
[8] Section 8.3 of SQUG GIP (Ref. 1)

behavior structural theory, and engineering judgment. Reference *50* should be read by the *SCEs* since it provides considerable discussion and background information on the philosophy for the analytical review process.

The analytical checks and evaluations discussed in this section are as follows:

- Dead Load Check *(Section 9.2.1.3.1)*
- Vertical Capacity Check *(Section 9.2.1.3.2)*
- Ductility Check *(Section 9.2.1.3.3)*
- Lateral Load Check *(Section 9.2.1.3.4)*
- Rod Hanger Fatigue Evaluations *(Section 9.2.1.3.5)*
- Floor-to-Ceiling Support Evaluations *(Section 9.2.1.3.6)*
- Base-Mounted Support Evaluations *(Section 9.2.1.3.7)*

Allowable capacities and raceway system weights are also discussed in this section.

The relationship between the above analytical checks for suspended raceway support systems is shown in a logic diagram in Figure *9.2.1-6*. It is suggested that this figure be used while reading the following descriptions of these analytical checks.

The raceway supports should pass a normal engineering dead load design review to working stress level allowable loads. This Dead Load Check is described in Section *9.2.1.3.1.* This is the only check needed for rigid, wall-mounted supports. Rigid-mounted conduit and cable trays are inherently very stable and subject to minimal seismic amplification. A detailed dead load design review of these systems provides ample margin for seismic effects. The working stress level allowable loads which should be used are described in Section *9.2.1.3.8.* Supports not meeting the dead load check should be considered as outliers. If a support does not meet the Dead Load Check, but is not required in order to meet the span Inclusion Rules #1 and #2 of Section *9.2.1.2.2*, then the adjacent supports should be checked, with the support in question assumed to be not present.

All raceway supports except rigid-mounted conduit and cable trays, and base-mounted raceway supports should also pass a Vertical Capacity Check of 3 times dead load. This is described in Section *9.2.1.3.2.* The Vertical Capacity Check ensures that the vertical capacity to dead load demand ratio is at least as high as those of support systems in the *earthquake* experience data base that performed well.

The Ductility Check is described in Section *9.2.1.3.3.* As shown in Figure *9.2.1-6*, supports characterized as ductile do not require an explicit lateral load check. Instead, seismic ruggedness for ductile supports is assured by the Vertical Capacity Check (Section *9.2.1.3.2*). The high vertical capacity of the ductile data base raceway supports is the main attribute credited for their good seismic performance.

Supports that may not respond to seismic loads in a ductile manner should be checked for lateral load capacity. The Lateral Load Check, described in Section *9.2.1.3.4*, is in the form of an equivalent static lateral load coefficient. Because this static coefficient is derived from the earthquake experience data base, it is considered applicable to ground motion consistent with the

Reference Spectrum shown in Section *5.3.1*. A method for scaling down the load coefficient for sites with lower ground motion response spectra is provided in Section *9.2.1.3.4*.

The simple equivalent static lateral load method becomes overly conservative for suspended supports with long drop vertical support members from overhead. This is because calculated moments at the ceiling connection become very large. Unless the vertical support member is very rigid, lateral load effects may be limited by seismic response peak displacements. Section *9.2.1.3.4* provides a method for determining more realistic, deflection-controlled lateral loads for evaluation of these cases.

Although rod hanger trapeze supports may be characterized as ductile for seismic loading, the fatigue life of the threaded rod hangers may limit seismic capacity when fixed-end connections are subject to large bending strains. Rod Hanger Fatigue Evaluations should be done using the guidelines in Section *9.2.1.3.5* for rod hanger trapeze supports with fixed-end rods.

The checks described above and illustrated in the Figure *9.2.1-6* logic diagram directly apply only to seismic evaluations of suspended (and wall-mounted) raceway supports. Similarly, simple evaluation methods may also be applied to floor-to-ceiling supports and base-mounted supports, as long as consideration is given to lack of pendulum restoring force effects and instabilities that may arise from plastic hinge formation.

Floor-to-Ceiling Support Evaluations are discussed in Section *9.2.1.3.6*. Ductility arguments may only be used if the support's base mount can be neglected (i.e., treating the support as if it is suspended). When the base mount is required to help resist vertical load, Lateral Load Checks of the top and bottom connections, as well as buckling capacity checks of the vertical support member, are warranted.

Base-Mounted Support Evaluations are discussed in Section *9.2.1.3.7*. These supports cannot be characterized as inherently ductile, and strength checks are required for both equivalent lateral and longitudinal loads. In addition, the base connection hardware details should be reviewed for rigidity. Slight connection slips that may lead to acceptable behavior for suspended systems can result in an additional overturning moment due to P-delta effects (i.e., eccentric loadings) for base-mounted supports and should be reviewed.

If a support fails to meet the Limited Analytical Review Guidelines, then it should be considered to be an outlier. Further analyses or tests may be performed on this outlier to demonstrate its seismic ruggedness as described in Section *9.2.1.4*.

If supports of the worst-case sample selection do not meet the Limited Analytical Review checks (i.e., are outliers), then the review team should develop an understanding of what supports in the *facility* are impacted by this analysis result.

The Vertical Capacity and Lateral Load Checks should be done using realistic capacity allowables as discussed in Section *9.2.1.3.8*.

The raceway system weights that should be used for these Limited Analytical Reviews are described in Section *9.2.1.3.9*.

9.2.1.3.1 <u>Dead Load Check</u>[9]

Back-analysis of raceway supports in the data base indicates that most systems have adequate dead load design. A detailed dead load design review of the worst-case sample conduit and cable tray

[9] Section 8.3.1 of SQUG GIP (Ref. 1)

supports should be conducted using normal design working stress allowable loads. The check should consider the as-installed configuration, connection detailing, and loading condition of the raceway support. All components such as bracket members, support members, conduit clamps, internal framing connections, and support anchorage should be checked. All system eccentricities, including load to anchor point eccentricity, should be considered, excluding evaluation of clip angle bending stresses. (Note, however, that clip angle bending stress should be considered during evaluation of base connections of floor-mounted supports as discussed in Section *9.2.1.3.7*). Loads from other attached systems, such as piping or ducting, should be considered.

This is the only check recommended for cable tray and conduit supports directly mounted to or rigidly cantilevered from an adjacent structural wall. These support types have been shown to be inherently rugged by past experience. The mounting configuration is generally rigid for lateral response, so dynamic amplification of seismic motion is minimal. Performing a detailed dead load design review for these support types ensures adequate margin for seismic loads.

Consideration should also be given to the seismic adequacy of the wall to which cable tray and conduit raceway supports are attached. Reinforced concrete structural walls are not a concern. With the exception of very light conduit, anchorage into transite walls (asbestos fiber board) and gypsum board partitions should be considered outliers. Masonry walls should be checked to *evaluate* that they have been reviewed for seismic adequacy as *described in Section 10.5.1*. The anchor capacities in Section *6.3* cannot be used for expansion anchors in masonry block walls (especially if the anchorage are installed in hollow block cores or mortar joints) or in nonstructural material; reduced values should be used. The anchorage of partition walls and shielding walls should be checked.

9.2.1.3.2 Vertical Capacity Check[10]

This check concentrates on the support anchorage, focusing on the weak link in the support anchorage load path. Back-analysis of conduit and cable tray support systems in the data base indicates that most supports have relatively high, vertical anchorage capacity. The high capacities are inherent in standard available connection hardware used for raceway support systems. The high vertical capacity is one of the primary design attributes that is given credit for good seismic performance. The Vertical Capacity Check evaluates whether the vertical capacity to dead load demand ratio is in the range of support systems in the data base that performed well. The high vertical capacity provides considerable margin for horizontal earthquake loading.

This Vertical Capacity Check is only applicable to raceway supports suspended from overhead. The Vertical Capacity Check is an equivalent static load check, in which the support is subjected to 3.0 times Dead Load in the downward direction, using the capacities discussed in Section *9.2.1.3.8*. This check is limited to the primary raceway support connections and the anchorage of suspended support systems. It is not necessary to evaluate clip angle bending stress or secondary support members. Base-mounted supports are not subject to this check (see Section *9.2.1.3.7*); however, the lower support member of floor-to-ceiling configurations should be checked for buckling if the upper connection cannot resist 3.0 times Dead Load by itself as discussed in Section *9.2.1.3.6*.

Eccentricities resulting in anchor prying and eccentricities between vertical support members and anchor points should, in general, be ignored. This concept is the result of back-analyses of data base cable tray supports and is consistent with limit state conditions observed in test laboratories.

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10 Section 8.3.2 of SQUG GIP (Ref. 1)

For cantilever bracket support types, the eccentricity of the cantilevered dead load should be ignored. Even if overhead moment capacity is completely lost, the vertical support integrity is maintained, as the support balances itself with the center of mass below the anchor point. It is important to realize that this calculational method is only used to demonstrate seismic adequacy by comparison with experience data. It is not expected, and it has not been shown by the experience data, that a support will end up in this deformed position after an earthquake on the order of the *Reference* Spectrum shown in *Figure 5.3-2 divided by 1.5.*

For trapeze frame and rod-hung supports, load distribution between the two vertical framing members should be considered if the center of the load is significantly distant from the centerline of the support frame. The bending strength and stiffness of frame members should be checked for transfer of the load between anchor bolts when overhead support is provided by light metal framing with anchor bolts spaced at relatively large intervals and when multiple anchor bolts are needed to resist the vertical load.

For most conduit and cable tray support systems, the anchorage is the weak link in the load path. For these support systems the Vertical Capacity Check is simply a comparison of anchor capacity to 3.0 times the supported load.

The 3.0 times dead load static coefficient should not be reduced if the *in-structure response spectrum (see Section 5.2)* for that *facility* is less than the *Reference* Spectrum shown in *Figure 5.3-2.* This is because there are only a few supports in the earthquake experience data base which have back-calculated vertical capacities less than 3.0 times Dead Load. If the 3.0 times Dead Load guideline is not met, then the support should be classified as an outlier. Resolution of the outlier can be accomplished by the methods described in Section *9.2.1.4.*

9.2.1.3.3 Ductility Check[11]

An evaluation should be conducted of the supports selected for review to characterize their response to lateral seismic motion as either ductile or potentially non-ductile. Supports suspended only from overhead may be characterized as ductile if they can respond to lateral seismic motion by swinging freely without degradation of primary vertical support connections and anchorage. Ductile, inelastic performance such as clip angle yielding or vertical support member yielding is acceptable so long as deformation does not lead to brittle or premature failure of overhead vertical support.

Review of typical conduit and cable tray support systems in the earthquake experience and shake table test data bases indicates that many overhead mounted support types are inherently ductile for lateral seismic motion. Back-analysis of many data base conduit and cable tray supports predicts yielding of members and connections. These data base systems performed well, with no visible signs of distress. Ductile yielding of suspended supports results in a stable, damped swaying response mode. This is considered to be acceptable seismic response.

The ductility review of anchorage connection details is most important for rigid-type suspended raceway supports. Supports with rigid, non-ductile anchorage that do not have the capacity to develop the plastic strength of the vertical support members can possibly behave in a non-ductile fashion. Examples include large tube steel supports welded to overhead steel with relatively light welds, or rigid supports welded to large base plates and outfitted with relatively light anchorage. These types of support systems are not well represented in the data base.

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11 Section 8.3.3 of SQUG GIP (Ref. 1)

The seismic design of certain raceway support members may have been controlled by high frequency requirements rather than design loads, yet anchors may have been sized by the design loads. These types of supports may have low seismic margin due to loads placed on the support which were not considered by the original design. Supports with rigid, non-ductile anchorage are subject to further horizontal load strength review (see Section *9.2.1.3.4*).

Examples of ductile and non-ductile raceway support connection details and configurations are shown in Figures *9.2.1-7* and *9.2.1-8*, respectively, and are described below.

<u>Standard Catalog Light Metal, Strut Framing Members, Clip Angles, and Bolts With Channel Nuts</u>. The seismic experience data include many examples of unbraced supports suspended from overhead, constructed of standard catalog light metal, strut framing channels, clip angles, and bolts with channel nuts as shown in Figures *9.2.1-7*A, B, C, and D. The good performance of these support types indicates that they may be characterized as ductile. This is even true of supports constructed of standard catalog light metal strut framing, gusseted, clip angle connections. Review of shake table tests of raceway support systems shows that slight slipping of channel nuts due to prying action of gusseted clip angles leads to acceptable behavior for suspended supports. The tests show that once the overhead moment connection is relaxed by this slippage, the support system is free to swing without additional degradation of the overhead connection.

<u>Welded Steel Members</u>. The philosophy of acceptable seismic response involving clip angle connection yielding for supports constructed of light metal, strut framing is extended to supports constructed of welded steel members as shown in Figure *9.2.1-7*F. If an anchor point connection weld is stronger than the vertical member, then a plastic hinge will be able to form in the vertical member, allowing ductile response without weld failure. A support is seismically rugged so long as overhead support is maintained. In this case, plastic hinge action in the vertical member prevents transmission of loads capable of failing the welded anchorage point. For open channel structural sections, an all-around fillet weld whose combined throat thicknesses exceed the thickness of the part fastened, may be considered capable of developing the plastic hinge capacity of the open channel section vertical member. If the plastic hinge capacity of the framing support member exceeds the capacity of the weld, as shown in Figures *9.2.1-8*A and B, then a brittle failure is possible, which is not acceptable seismic performance. For light metal, strut framing members, welded connections are likely to be non-ductile and thus not capable of developing plastic moment capacity of the framing member.

<u>Ceiling Connection Plate Secured with Expansion Anchors</u>. Raceway supports with overhead anchorage provided by a plate attached to concrete with expansion anchors may also be shown to be ductile. The anchorage may be characterized as ductile if it is stronger than the plastic flexural strength of the vertical support member. A simple anchor moment capacity estimate may be used, by multiplying the bolt pullout capacity times the distance between the bolts or center of bolt groups. In some cases, it may be possible to demonstrate ductility if the ceiling connection plate is the weak link in the anchorage load path. This is similar to the case of clip angle bending. The key to characterizing a support as ductile or non-ductile is reviewing the anchorage load path, and determining if the weak link responds in a ductile or brittle manner.

<u>Braced Cantilever Bracket and Trapeze Frame Supports</u>. The presence of a diagonal brace in a support, as shown in Figures *9.2.1-8*E and F, has the potential of significantly increasing the pullout loads on anchorage when the support is subjected to horizontal motion. This is a function of the support geometric configuration, the realistic capacity of the brace, and the realistic capacity of the anchorage. Non-ductile behavior is possible when the brace reaction to horizontal load plus dead load has the capability of exceeding the primary the support anchor capacity. If a brace buckles or has a connection failure before primary support anchor capacity is reached, then the support may be considered as ductile. Braced supports are subject to further horizontal load capability review in Section *9.2.1.3.4* with a focus on primary support anchorage.

Unbraced Rigid Trapeze Frames. Trapeze frames constructed as moment-resisting frames, such as those with a number of stiff cross-beam members welded to the two vertical supports as shown in Figure *9.2.1-8*D, have the potential of significantly increasing the pullout loads on anchor bolts when the frame is subject to horizontal motion. Non-ductile behavior is possible when the rigid frame anchor point reactions to horizontal load exceed the anchor capacity. Unbraced rigid trapeze frames are subject to further horizontal load strength review in Section *9.2.1.3.4* with focus on anchorage.

Floor-Mounted Supports. Plastic behavior of floor-mounted supports may lead to structural instability. Ductility, as defined by these guidelines, only applies to suspended systems. Floor-mounted supports are characterized as non-ductile, and are subject to further horizontal strength review in Sections *9.2.1.3.6* and *9.2.1.3.7* with focus on stability.

Rod Hanger Trapeze Supports. Supports constructed of threaded steel rods with fixed-end connection details at the ends of the rods behave in a ductile manner under horizontal motion; however, relatively short rods may undergo very large strains due to bending imposed by horizontal seismic motion, at the fixed ends of the rods. Low cycle fatigue may govern response. Rod hanger trapeze supports with short, fixed-end rods should be evaluated for low cycle fatigue effects in Section *9.2.1.3.5*.

No further review of horizontal response capability is required of supports characterized as ductile. Only the support vertical capacity need be *evaluated*, as discussed in Sections *9.2.1.3.1* and *9.2.1.3.2*. If a support is characterized as non-ductile or has questionable ductility, then its lateral load capacity should be *evaluated,* as discussed in Section *9.2.1.3.4*, as shown in the logic diagram for making these decisions in Figure *9.2.1-6*.

9.2.1.3.4 Lateral Load Check[12]

A Lateral Load Check should be performed for the bounding case raceway supports that are characterized as potentially non-ductile. The Lateral Load Check is in the form of an equivalent static lateral load coefficient. The Lateral Load Check compares the ratio of horizontal load capacity divided by dead load demand (for potentially non-ductile supports) to the same ratios for support systems in the seismic experience data base that performed well. Because many of these data base raceway systems were subjected to earthquake ground motions that may have been greater than the *Design Basis Earthquake* for many *facilities*, provisions for scaling down the equivalent static horizontal loads are given below.

If a support is ductile, then no further review of horizontal response capability is required, and the support may be shown to be seismically rugged by the Vertical Capacity Check Section *9.2.1.3.2*). If a support is non-ductile or has questionable ductility, then it should be analyzed for one of the following transverse load conditions:

- Dead load plus a 2.0g horizontal acceleration in the transverse direction. The horizontal acceleration may be scaled down linearly by *multiplying 2.0g by the maximum* ratio of the *in-structure response spectrum (see Section 5.2)* spectral acceleration for the *facility* divided by the corresponding spectral acceleration of the *Reference* Spectrum shown in *Figure 5.3-2.*

- Dead load plus a transverse acceleration of 2.5 times the Zero Period Acceleration (ZPA) of the floor response spectrum *(see Section 5.2)* for the anchor point in the *facility* where the raceway system is attached.

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[12] Section 8.3.4 of SQUG GIP (Ref. 1)

For these loading conditions, only the tributary mass corresponding to dead load on the support should be considered. If large junction boxes are included in the worst-case sample, then the lateral load coefficients described above may be used as the seismic demand and the anchorage evaluated following the guidelines of *Chapter 6.*

The loading condition selected should be used consistently for all the *facility* raceway support systems selected as samples in any particular building. Different methods may be used for different structures. For example, the floor ZPA scaling method may be preferable for rock-founded structures or soil-founded structures for which realistic floor response spectra may be available. The scaled 2.0g method may be preferable for soil-founded structures, such as diesel generator buildings, for which realistic floor response spectra may not be available.

The simple equivalent static load coefficient method may be too conservative for supports with long drops from the ceiling anchorage to the raceways. The static coefficient method predicts very high connection bending moments in these cases. In this case, the bending moment imposed on the ceiling connection may be limited by peak seismic deflection and not seismic accelerations. This is consistent with observations of back-calculated static coefficient capacities from the experience data. The lowest back-calculated capacities were often from supports with long drops and were not considered representative (i.e., they were not used to attempt to justify a static coefficient less than 2.0g).

If the support has long vertical members and has low natural frequency, then an alternative loading condition of dead load plus reaction forces due to a realistic estimate for seismic deflection imposed in the transverse direction may be used. A conservative estimate for seismic deflection may be obtained by using floor spectral displacement at a lower bound frequency estimate considering only single degree of freedom pendulum response of the support.

For diagonally-braced supports with ductile overhead anchorage, the load reaction imposed on the support anchorage during the Lateral Load Check does not need to exceed the buckling capacity of the brace or its connections. For example, if it is shown that a brace buckles at 0.80g lateral load, then this load should be used for the Lateral Load Check and not 2.0g. For diagonally-braced supports where the anchorage is not ductile, the portion of the lateral load that is not resisted by the brace should be redistributed as bending stress to the overhead connection. The loads in the diagonal brace will cause additional vertical and horizontal loads on the anchorage, which should be accounted for.

An upper and lower bound estimate should be used for buckling capacity of the brace, whichever is worse, for the overhead anchorage. There is considerable variation in test data capacity for light metal strut framing connections. An upper bound estimate of 2.0 times the realistic capacities discussed in Section *9.2.1.3.8* can be used for these connection types.

9.2.1.3.5 Rod Hanger Fatigue Evaluations[13]

Shake table tests have shown that the seismic capacity of fixed-end rod hanger trapeze supports is limited by the fatigue life of the hanger rods. Rod hanger trapeze supports should be evaluated for possible fatigue effects if they are constructed with fixed-end connection details. This fatigue evaluation should be done in addition to the checks described in the previous sections.

13 Section 8.3.5 of SQUG GIP (Ref. 1)

Fixed-end connection details include double-nutted rod ends at connections to flanges of steel members, rods threaded into shell-type concrete expansion anchors, and rods connected by rod coupler nuts to nonshell concrete expansion anchors. Fixed-end connection details also include rods with lock nuts at cast-in-place light metal strut channels and rod coupler nuts welded to overhead steel.

This section describes a screening method for evaluating rod hangers for fatigue based on the use of rod fatigue bounding *(capacity)* spectra (shown in Figure *9.2.1-9*) and generic rod fatigue evaluation screening charts (shown in Figures *9.2.1-10* to *9.2.1-14*). This screening method is based upon generic, bounding case fatigue evaluations in Reference *48.*

The screening charts are directly applicable to hangers constructed of manufactured all-thread rods in raceway system runs with uniform length hangers. The charts may also be used for evaluation of supports constructed of field-threaded rods, and for short, isolated fixed-end rod hangers in more flexible systems with relatively much longer rod hangers; guidance is given later in this section on how to adjust the parameters when evaluating these special cases.

Manufactured All-Thread Rods

The fatigue evaluation for short, fixed-end rod hangers (manufactured all-thread) in trapeze supported raceway runs with all of the rods of uniform length, should proceed as follows:

- Obtain the 5% damped floor response spectrum *(see Section 5.2)* for the location of the support.

- Enter Figure *9.2.1-9* which contains Rod Fatigue Bounding *(Capacity)* Spectrum anchored to 0.33g, 0.50g, and 0.75g. Select a spectrum which envelopes the floor response spectrum. If the selected spectrum does not entirely envelop the floor response spectrum, then select a spectrum that envelops the floor response spectrum at the resonant frequency of the support.

  Support resonant frequency may be estimated as follows:

$$f_{support} = \frac{1}{2\pi}\sqrt{\frac{K_s}{M_s}}$$

  Where:

M_S	=	W / g
K_S	=	$2\,(12\,E\ I / L^3) + W / L$
W	=	total dead weight on the pair of rod supports
g	=	gravitational constant
E	=	elastic modulus of steel
I	=	moment of inertia of rod root section
L	=	length of rod above top tier

- Enter one of the Fatigue Evaluation Screening Charts shown in Figures *9.2.1-10* to *9.2.1-14* corresponding to the diameter of the threaded rod. Focus on the curve associated with the acceleration (0.33g, 0.50g, or 0.75g) of the Rod Fatigue Bounding Spectrum selected in the previous step. These charts do not directly apply to field-threaded rods (see discussion below).

- Compare the rod hanger length (L, length of rod above top tier) and rod hanger weight (W, total dead weight on the pair of rod supports) with acceptable combinations of length and weight on the screening charts. Acceptable regions of the Fatigue Evaluation Screening Charts are below and to the right of the Screening Chart curve selected in the previous step.

If the support parameters are within acceptable regions on the Fatigue Evaluation Screening Chart, then the rod hanger support is seismically adequate.

The screening charts also include the 3 times Dead Load limit associated with the Vertical Capacity Check (Section *9.2.1.3.2*) which can be used to facilitate evaluation of expansion anchors (based on *reduction factor of 0.75 for anchor capacity determination in Section 6.3*) for rod hanger trapeze supports.

Field-Threaded Rods

Rod fatigue tests have shown that field-threaded rods have less fatigue life than all-thread, manufactured rods. The evaluation method for field-threaded rods proceeds the same way as for manufactured threaded rods, except that adjusted weights and lengths should be used for comparison with the Fatigue Evaluation Screening Charts. For field-threaded rods, enter the Screening Charts with double the actual weight and 2/3 the actual length of the rods. If these modified parameters are in acceptable regions of the Screening Charts, then the rod hanger is seismically adequate.

Isolated, Short, Fixed-End Rod Hangers

If an isolated, short, fixed-end rod hanger is used in a system with predominantly longer, more flexible hangers, a special evaluation should be conducted that decouples the response effects of the short isolated rod. The special evaluation method is as follows:

- Estimate the frequency of the support system, neglecting the isolated, short rod. The frequency estimation formula given above may be used. The length of the longer rods should be used in the formula.

- Enter the applicable Fatigue Evaluation Screening Chart (Figures *9.2.1-10* to *9.2.1-14*) which corresponds to the Rod Fatigue Bounding Spectrum (Figure *9.2.1-9*) that envelops the *facility* floor response spectrum (5% damping) *(see Section 5.2)* at the frequency of interest which was calculated in the previous step.

- Back-calculate an equivalent weight for evaluation of the isolated short rod hanger, using the frequency of the longer rod hanger supports, with the following formula:

$$W_{equiv.} = \frac{24\,E\,I\,g}{(2\pi f)^2\,L^3 - g\,L^2}$$

- Enter the appropriate Fatigue Evaluation Screening Chart (Figures *9.2.1-10* to *9.2.1-14*) by using the above calculated equivalent weight and the length of the isolated short rod hanger.

If these parameters are in an acceptable region on the Fatigue Evaluation Screening Chart, then the isolated, short, fixed-end rod hanger is seismically adequate.

Reference *48* may be reviewed to obtain an understanding of the analytical methods used to develop the Fatigue Evaluation Screening Charts. When using the charts, the simple equations given in this section for calculating response frequency should be used for consistency since these are the same equations used to generate the screening charts (i.e., the screening charts are based on the simplified results obtained from detailed fatigue analysis, considering capacities determined by component test results).

9.2.1.3.6 Floor-to-Ceiling Support Evaluations[14]

Floor-to-ceiling supports may be evaluated as suspended raceway supports if they can meet the previous Limited Analytical Review Checks by conservatively neglecting the floor connection and anchorage.

Seismic ruggedness for floor-to-ceiling supports that depend on the floor connection may be evaluated as follows. The checks described here ensure seismic adequacy by showing that the supports maintain high vertical capacity, demonstrate ductility, and maintain connection shear resistance.

The lower vertical support column member should be checked for buckling. The imposed buckling load should be the portion of 3.0 times Dead Load that cannot be resisted by the overhead anchorage. In addition, the support should be subject to a Lateral Load Check. The imposed lateral load static coefficient should be obtained as described in Section *9.2.1.3.4*. The top and bottom connections and anchors should be checked for dead load plus the equivalent static lateral load reactions. Clip angle bending stresses may be ignored. The support columns themselves do not have to be checked for lateral loading; however, the entire support should be checked for design dead load as described in Section *9.2.1.3.1*.

9.2.1.3.7 Base-Mounted Support Evaluations[15]

Base-mounted supports present a different case than suspended supports in that, with excessive deflections and inelastic response effects, the base-mounted supports tend to become unstable whereas suspended supports have increased pendulum restoring force. The checks which should be performed include a detailed Dead Load Check and Lateral Load Check non-concurrently in both orthogonal directions, including P-delta effects if base hardware slip may be anticipated. P-delta effects include the second order increases in base overturning moment due to additional eccentricity of the supported dead load during seismic deflections of the support. These P-delta effects may become significant if the connection hardware at the base of the support does not remain rigid. Base hardware slips that should be considered are discussed below. Reference *50* provides considerable discussion on the philosophy of the base-mounted support evaluations.

A detailed, Dead Load Check should be performed, similar to the check described in Section *9.2.1.3.1*. The only exception is that clip angle bending stresses should be evaluated at the base connections. Base flexibility associated with clip angle inelastic behavior may lead to increased deflection and subsequent P-delta effects and possibly instability.

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14 Section 8.3.6 of SQUG GIP (Ref. 1)
15 Section 8.3.7 of SQUG GIP (Ref. 1)

A Vertical Capacity Check should not be conducted since the philosophy behind the Vertical Capacity Check only applies to ductile, suspended raceway supports. A Dead Load plus equivalent static Lateral Load Check should be performed instead, for loading non-concurrently in both orthogonal directions.

The equivalent static lateral load should be determined as outlined in Section *9.2.1.3.4*. The Lateral Load Check should evaluate all members, connections, and anchors associated with the primary support frame and its bracing (if present). Realistic capacities should be used for the evaluation. If brace members (lower bound capacity estimate) cannot resist all of the lateral load, the portion of load exceeding the brace capacity may be transmitted to the base and resisted by the base moment capacity.

If light metal strut framing clip angle construction is used, bolt (with channel nut) slip of 1/16 inch should be considered for P-delta evaluation. If the nominal capacities given in *Section 6.3* are used for nonshell expansion anchors, anchor bolt slip of 1/8 inch should be considered for P-delta evaluation. For P-delta evaluation, all these bolt slips should be used to obtain an estimate for maximum possible base connection rotation.

Using this base rotation, and considering the displacement due to the flexibility of the vertical support post, a deflection of the raceways should be calculated. This additional deflection times dead load provides the effective P-delta base moment. If this moment is more than about 5% of the total moment from the Dead Load plus Lateral Load Check, it should be included in the Dead Load plus Lateral Load Check.

Torsional moments at the base of the support post that may result from lateral or longitudinal load checks may be ignored. Stresses in the support brackets due to longitudinal loading may also be ignored. These forces resulting from longitudinal loading are not considered realistic due to raceway member framing action and inelasticity of other components in the load resistance chain such as restraining clips. The goal of the lateral and longitudinal checks is to demonstrate seismic ruggedness.

9.2.1.3.8 Allowable Capacities[16]

The allowable capacities which can be used in the Limited Analytical Review are discussed in this section. For the Dead Load Check (Section *9.2.1.3.1*), normal engineering design working stress allowable capacities should be used. For example, the capacities defined in Part 1 of the AISC Specification for Steel Design (Ref. *81*) can be used.

More realistic allowable capacities can be used for the remainder of the checks in the Limited Analytical Review (Sections *9.2.1.3.2* to *9.2.1.3.7*).

The remainder of this subsection defines these capacities for expansion anchors, cast-in-place anchors, embedded plates and channels, welds, steel bolts, structural steel, and other support members.

Capacity values for expansion anchors are provided in *Section 6.3*. The guidelines for using these anchorage capacities should be followed, including edge distance, bolt spacing, and inspection procedures. Note that tightness checks need not be conducted for anchor bolts of supports which resist tensile force under dead load. Tightness checks are waived because suspended and some wall-mounted raceway systems cause these types of anchorage to be subjected to constant tension under dead load and therefore the anchorage are, in effect, continuously proof-tested. The tightness checks should be carried out, however, for floor-mounted support anchors.

[16] Section 8.3.8 of SQUG GIP (Ref. 1)

Capacity values for embedded steel which uses headed studs are given in *Section 6.3*. These capacities should be used along with the generic guidelines contained in *Chapter 6*. For cast-in-place embedments, other than those which use headed studs, the capacity may be determined using the approach discussed in *Section 6.2.6*, Embedment Steel and Pads.

The *facility* design or as-built drawings for cast-in-place anchors and steel plates should be reviewed to obtain details on these anchorage types. Anchor capacities for cast-in-place light metal strut framing channels should be taken as the manufacturer's catalog values with published factors of safety, or may be determined by available test information with appropriate factors of safety.

Capacities for welds, structural steel, and steel bolts should be taken as defined in Part 2 of the AISC Specification for Steel Design (Ref. *81*). Capacity values for light metal strut framing hardware are taken as the manufacturer's recommended design values, including the published factor of safety. This factor of safety is considered sufficient to encompass the lower bounds of strength values, such as may result from minor product variation or low bolt torque.

When upper-bound strength estimates are required, such as in ductility reviews or limit state evaluations, the manufacturer's catalog capacities should be increased. A recommended upper bound estimate for bolts with channel nuts is double the manufacturer's published design values.

Tests may be used to establish realistic, ultimate capacities of raceway components. Appropriate factors of safety should be used with these test results. Dynamic tests should be performed to establish ultimate capacities of friction-type connections in most cases.

9.2.1.3.9 Raceway System Weights[17]

Cable tray weights may be estimated as 25 pounds per square foot for a standard tray with 4 inches of cable fill. It is suggested that the cable trays be considered to be completely full during the initial attempt at using the screening guidelines described above. Linear adjustment may be made for trays with more and less cable fill. Sprayed-on fireproof insulation may be conservatively assumed to have the same unit weight by itself as the cable in the tray it covers.

Estimated weights for steel and aluminum conduit may be taken as follows:

Conduit Diameter (inches)	Conduit Weight Including Cable (pounds per foot)	
	Steel	Aluminum
1/2	1.0	0.5
3/4	1.4	0.7
1	2.2	1.1
1-1/2	3.6	1.8
2	5.1	2.8
2-1/2	8.9	5.2
3	12.8	7.9
4	16.5	9.5
5	23.0	13.6

Conservative estimates should be made for the weights of other miscellaneous items attached to the raceway support, such as HVAC ducting, piping, and lighting.

[17] Section 8.3.9 of SQUG GIP (Ref. 1)

9.2.1.4 Outliers[18]

An outlier is defined as a raceway hardware feature which does not meet one or more of the screening guidelines contained in this section. Namely, an outlier:

- Does not meet the Inclusion Rules given in Section *9.2.1.2.2*,
- Has significant Other Seismic Performance Concerns as given in Section *9.2.1.2.3*,
- *Has potential adverse seismic interaction hazard as given in Section 9.2.1.2.5, or*
- Does not satisfy the Limited Analytical Review Guidelines given in Section *9.2.1.3*.

When an outlier is identified, proceed to *Chapter 12*, and document the cause(s) for not meeting the screening guidelines on an Outlier Seismic *Evaluation* Sheet (OS*E*S).

The screening criteria given earlier in this section are intended for use as a generic basis to evaluate the seismic adequacy of cable and conduit raceway systems. If a raceway hardware feature fails this generic screen, it may not necessarily be deficient for seismic loading; however, additional evaluations are needed to show that it is adequate. Some of the additional evaluations and alternate methods for demonstrating seismic adequacy are summarized below. Additional details are also found in the previous subsections where these generic screening guidelines are described. Other generic methods for resolving outliers are found in *Chapter 12*.

In some cases it may be necessary to exercise engineering judgment when resolving outliers, since strict adherence to the screening guidelines in the previous subsections is not absolutely required for raceway support systems to be seismically adequate. These judgments, however, should be based on a thorough understanding of the background and philosophy used to develop these screening guidelines as described in References *46*, *47*, and *50*. The justification and reasoning for considering an outlier to be acceptable should be based on mechanistic principles and sound engineering judgment.

The screening guidelines contained in the previous subsections have been thoroughly reviewed by industry experts to ensure that they are appropriate for generic use; however, the alternative evaluation methods and engineering judgments used to resolve outliers are not subject to the same level of peer review. Therefore, the evaluations and judgments used to resolve outliers should be thoroughly documented so that independent reviews can be performed if necessary.

9.2.1.4.1 Cable Tray Span[19]

As discussed in Inclusion Rules 1 and 2, the span lengths given there are not necessarily rigid requirements. For example, an isolated cable tray span of about 13 feet may be acceptable if the tray is lightly loaded and of rugged construction (for example, the tray meets the NEMA standards in Reference *89* and the cable loading is no more than one-half that in Table 3-1 of Reference *89*).

9.2.1.4.2 Conduit Span[20]

An isolated conduit overspan may be acceptable if its vertical deflection is limited by other *facility* features in proximity. In addition, 3.0 times dead load vertical static load tests can be used to show that an isolated overspan is acceptable.

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18 Section 8.4 of SQUG GIP (Ref. 1)
19 Section 8.4.1 of SQUG GIP (Ref. 1)
20 Section 8.4.2 of SQUG GIP (Ref. 1)

9.2.1.4.3 Raceway Member Tie-downs[21]

Tie-downs should be installed until Inclusion Rule 3 is satisfied. As an alternative, analyses or a static lateral pull test of the lateral load-carrying capacity of the as-built trays or conduit can be performed to show that the trays or conduit are not capable of falling off the support. The amount of static lateral force used in this evaluation should be consistent with one of the options in the Lateral Load Check given in Section *9.2.1.3.4.* It is preferable, and usually not a difficult maintenance activity, to add missing raceway member tie-downs.

9.2.1.4.4 Channel Nuts[22]

Channel nuts without teeth should be replaced with nuts with teeth or an extensive *facility*-specific dynamic testing program can be performed to show that the channel nuts without teeth are capable of carrying the anticipated seismic load.

9.2.1.4.5 Rigid Boot Connection[23]

Rigid boots are considered to be outliers even when there is only a small gap between the boot and the member it supports. If the boot was field assembled in such a way that no gaps exist and the boot fits the member tightly, then this connection can be considered acceptable. The basis for the finding that there are no gaps should be thoroughly documented. One simple fix to a rigid boot with gaps is to replace the individual bolts with one through bolt.

9.2.1.4.6 Beam Clamps[24]

The clamp should be replaced with a positive connection or the clamp oriented so that gravity loads are not resisted by the clamping friction; however, if supported loads are less than about 15 pounds, the adequacy of an isolated clamp oriented in the wrong direction can simply be *evaluated* by tugging and shaking it by hand.

If an entire run of small conduit with light support dead loads (less than about 15 pounds per support) is anchored with beam clamps which resist dead load only by clamping friction, then a sufficient number of supports representative of the entire conduit run should be tugged to *evaluate* adequacy.

9.2.1.4.7 Cast-Iron Anchor Embedments[25]

Cast-iron anchor embedments should be replaced with an acceptable anchorage or the support braced horizontally and the stress in the anchor kept very low.

9.2.1.4.8 Analytical Outliers[26]

Outliers that do not satisfy the Limited Analytical Review guidelines, as illustrated in Figure *9.2.1-6*, can be evaluated further using more detailed analytical models of the raceway system or testing to demonstrate that the raceways are as rugged as required. Remember, however, that the analytical guidelines only have to be satisfied in an approximate manner. For example, if a support has a capacity of only 2.7 times Dead Load rather than the desired 3.0 times Dead Load, the *SRT*

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21 Section 8.4.3 of SQUG GIP (Ref. 1)
22 Section 8.4.4 of SQUG GIP (Ref. 1)
23 Section 8.4.5 of SQUG GIP (Ref. 1)
24 Section 8.4.6 of SQUG GIP (Ref. 1)
25 Section 8.4.7 of SQUG GIP (Ref. 1)
26 Section 8.4.8 of SQUG GIP (Ref. 1)

performing the screening evaluation may still find the support acceptable based on their professional judgment. Examples of acceptable outlier evaluation methods include Limit State Evaluations, Lateral Load Evaluations, Redundancy and Consequence Evaluations, and Support Upgrades. These methods are described below.

Limit State Evaluation. A limit state evaluation may be used to resolve ductile supports that do not meet the Vertical Capacity Check (3.0 times Dead Load) in Section *9.2.1.3.2*. The Vertical Capacity Check provides a quick, generic means for assuring seismic ruggedness, consistent with the experience data. However, for certain configurations of raceway support systems, especially unbraced rod hanger trapeze systems, the Vertical Capacity Check may be too conservative.

The principle behind the Limit State Check is that the support anchorage capacity need only be greater than the maximum possible reactions from plastic hinge formation in the support, while the support is also subjected to dead load. This principle only applies to supports that are suspended from above and that are characterized as ductile, following the guidelines of Section *9.2.1.3.3*.

The Limit State Evaluation provides a check of anchorage and anchorage connection capacity. The seismic demand applied to the anchor point using the limit state evaluation method is based on dead load plus anchor reaction due to formation of plastic hinges at credible support joint locations. Realistic upper bound estimates should be used for the support joint plastic hinge moment capacities, based on test results if possible.

The basic philosophy for the Limit State Check is that for ductile supports suspended from the overhead, anchor connection capacity need only exceed the maximum possible reactions resulting from the plastic hinges developed in the support, plus dead loads.

For rod hanger trapeze supports with fixed-end connection details, the Limit State Check is straightforward. The anchor capacity should be greater than dead load reaction plus the reaction from plastic hinges formed in the hanger rods at fixed-end connections. For multiple tier hangers, as a first approximation, plastic hinge formation may be assumed at all joints at all tiers. If the lateral deflection corresponding to onset of all these plastic hinges is excessive, such as if it is greater than the peak floor spectral displacement, then a more refined evaluation may be conducted. This may be accomplished by considering a realistic deflected shape for those locations where credible plastic hinges can be formed.

For threaded rods, the plastic hinge moment capacity should be consistent with those observed in the rod hanger fatigue tests (see Reference *48)*. The plastic moment capacity may be calculated using the rod hanger's cross-sectional moment of inertia based on the root diameter of the threaded section, a 1.7 shape factor, and a 90 ksi apparent yield stress. For example, the plastic moment capacity of a 1/2-inch diameter threaded rod may be taken as 1,010 inch-pounds.

The anchorage shear load for the Limit State Evaluation may be calculated by estimating a point of inflection in the limit state deflection shape. For example, for a rod hanger trapeze support, the point of inflection may be taken as the mid-point between the top tier cross beam and the overhead anchorage.

Limit State Evaluations of light metal strut framing trapeze supports constructed with clip angles may assume that plastic hinges develop in all clip angles, with the strut framing members remaining rigid. The anchorage capacity should be greater than dead load reaction, plus frame reaction at the anchor point due to the formation of plastic hinges at all clip angles, plus reaction due to local prying action at the anchor due to a plastic moment in its clip angle.

The local prying anchor load may be taken as the connection ultimate moment capacity divided by the distance between anchors for double clip angle connections. For single clip connections, the moment may be divided by the distance from the anchor bolt to the far edge of the light metal strut framing vertical member. The moment capacities for clip angle connections can be very difficult to estimate by calculation so it is better to base these moment capacities on test data if possible.

Lateral Load Evaluation. The Lateral Load Check of Section *9.2.1.3.4* may be used to evaluate outliers that do not meet the Vertical Capacity Check (3.0 times dead load) in Section *9.2.1.3.2*. This is most applicable to supports characterized as non-ductile in Section *9.2.1.3.3*, but may also be used for ductile supports.

Redundancy and Consequence Evaluation. Isolated cases of an outlier support which does not meet the Limited Analytical Review Guidelines described in Section *9.2.1.3* may be resolved if the adjacent raceway support system has high redundancy, and if a postulated failure of the support in question has no adverse consequence to *facility* safety, e.g., it will not fall on safety-related equipment and damage it. High redundancy can be demonstrated by showing that the adjacent supports are suspended and meet the Vertical Capacity Check (3 times Dead Load) of Section *9.2.1.3.2*, and either the Ductility Check of Section *9.2.1.3.3* or the Lateral Load Check of Section *9.2.1.3.4*.

"Isolated" means that it is not acceptable for as many as every other support to fail to meet the guidelines. In other words, there should be at least two supports, each of which meets the guidelines of Section *9.2.1.3.2* and either Section *9.2.1.3.3* or Section *9.2.1.3.4*, between each "isolated" support.

The "consequence" of a failed isolated support should also be evaluated to determine whether there is any undesirable effect on nearby equipment. Engineering judgment should be used by the *SCEs* to make this evaluation. If it is not credible for the support to swing away or fall, then there is no safety consequence. If it is credible for the support to swing away or fall, then it should be treated as a source of seismic interaction. In this case, there is no safety consequence if there are no fragile, safety-related targets in the vicinity or below.

Acceptance of worst-case, bounding supports by the Redundancy and Consequency *Evaluation* described above does not provide, by itself, sufficient insight into the seismic ruggedness of the *facility's* raceway support systems. Rather, this option should be used during the walkdown to screen out isolated instances of supports which appear marginal, so as to exclude them from the bounding case sample.

Support Upgrade. For certain supports which do not meet the Limited Analytical Review Checks, it may be preferable to strengthen these supports rather than expend resources on more refined analyses and evaluations.

When upgrading raceway supports, the *facility* may wish to use the Limited Analytical Review guidelines in this section as the starting point in the design process. It is recommended that new designs or retrofit designs use additional factors of safety, especially for anchorage, since the incremental added cost for larger anchor bolts is not significant but it leads to significantly larger seismic margin.

9.2.1.5 Documentation[27]

A summary package should be assembled to document and track the *SCE's* evaluation activities. *Suggested* documentation should include records of the *facility* areas evaluated, the dates of the walkdowns, the names of the engineers conducting the evaluations, and a summary of results. Recommended *Seismic Evaluation Work Sheets (SEWS)* for the summary package are given in *Chapter 13*. Outlier Seismic *Evaluation* Sheets (OSES) are also given in *Chapter 13. Included in the SEWS are:*

Separate summary sheets should be completed for each designated room number or *facility* location where evaluations are conducted. The sheets include reminders, as a checklist, for primary aspects of the evaluation guidelines; however, the walkdown engineers should be familiar with all aspects of the seismic evaluation guidelines during screening reviews and not rely solely on the checklist. The *SCEs* who sign these sheets are ultimately responsible for the seismic evaluations conducted.

Analytical Review Data Sheet for recording information on the supports selected as the worst-case, representative samples.

Chapter 13 describes the Outlier Seismic *Evalution* Sheet. When collecting these data, the *SCEs* should record ample information so that repeated trips to the *facility* are not required for final outlier resolution.

Photographs may be used to supplement documentation, as required. When used as formal documentation for the summary packages, photographs should be clearly labeled for identification.

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27 Section 8.5 of SQUG GIP (Ref. 1)

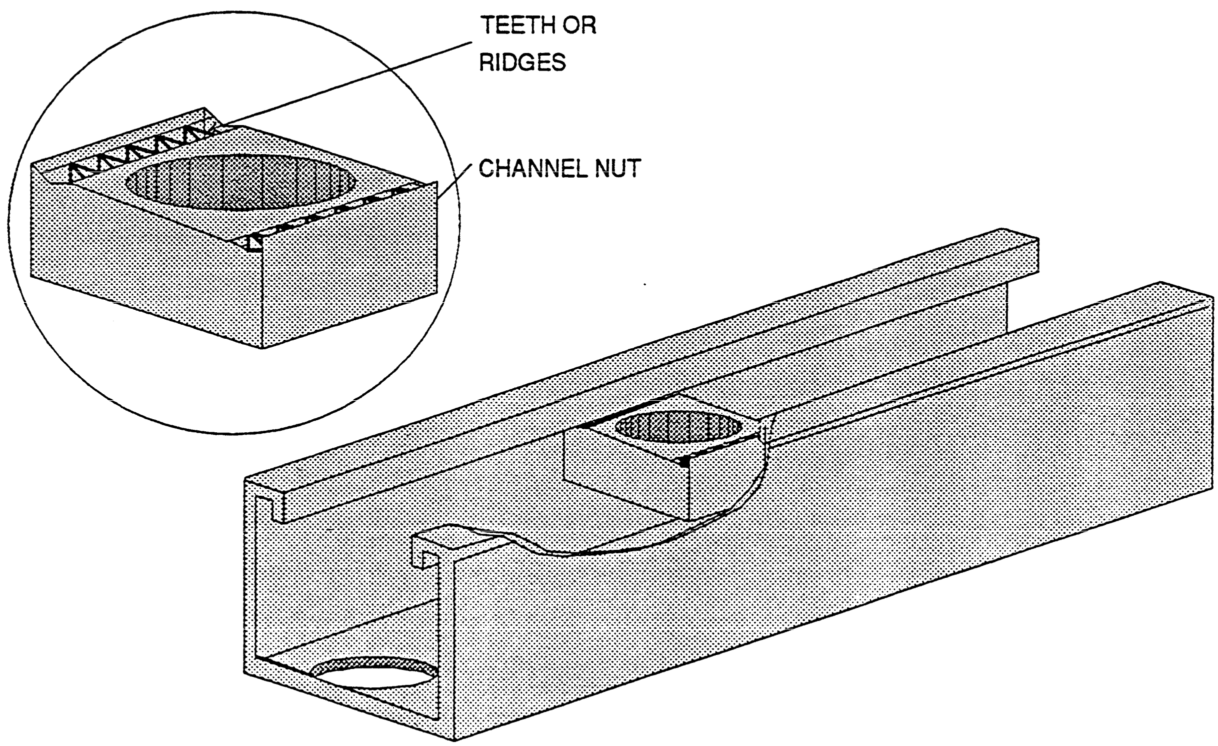
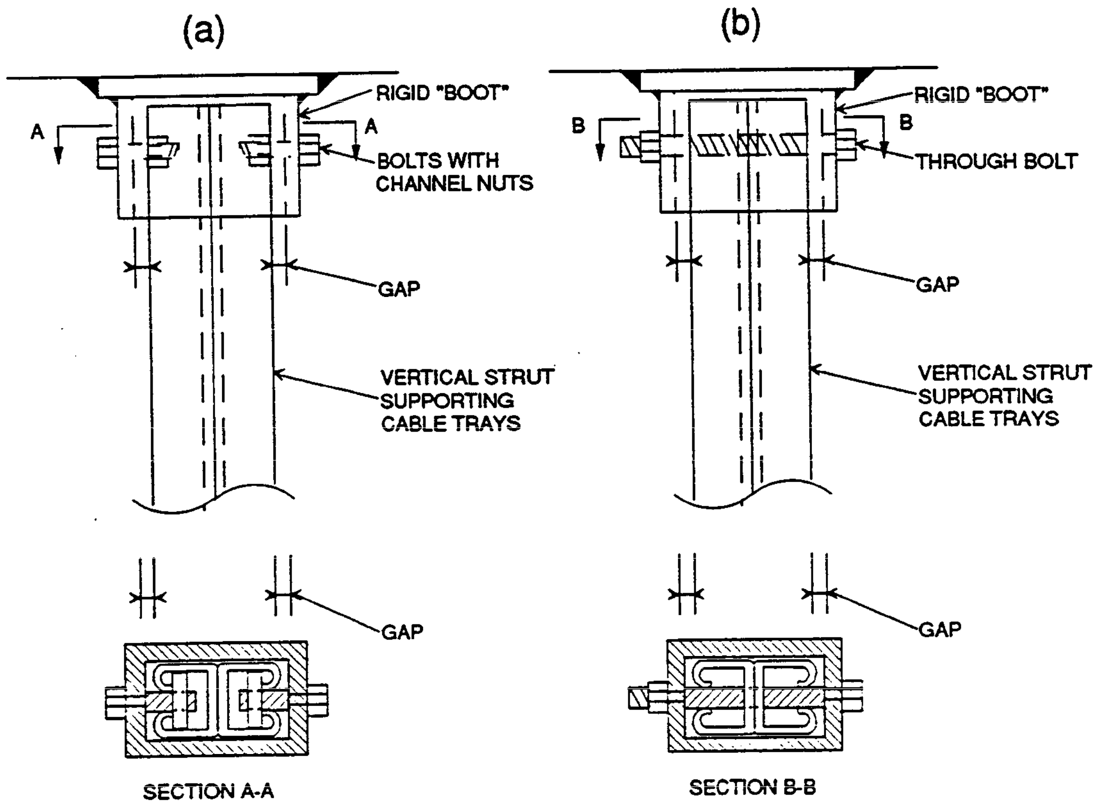


Figure 9.2.1-1 Channel Nut with Teeth or Ridges in Light Metal Framing Strut (Reference 47) (Figure 8-1 of SQUG GIP, Reference 1)

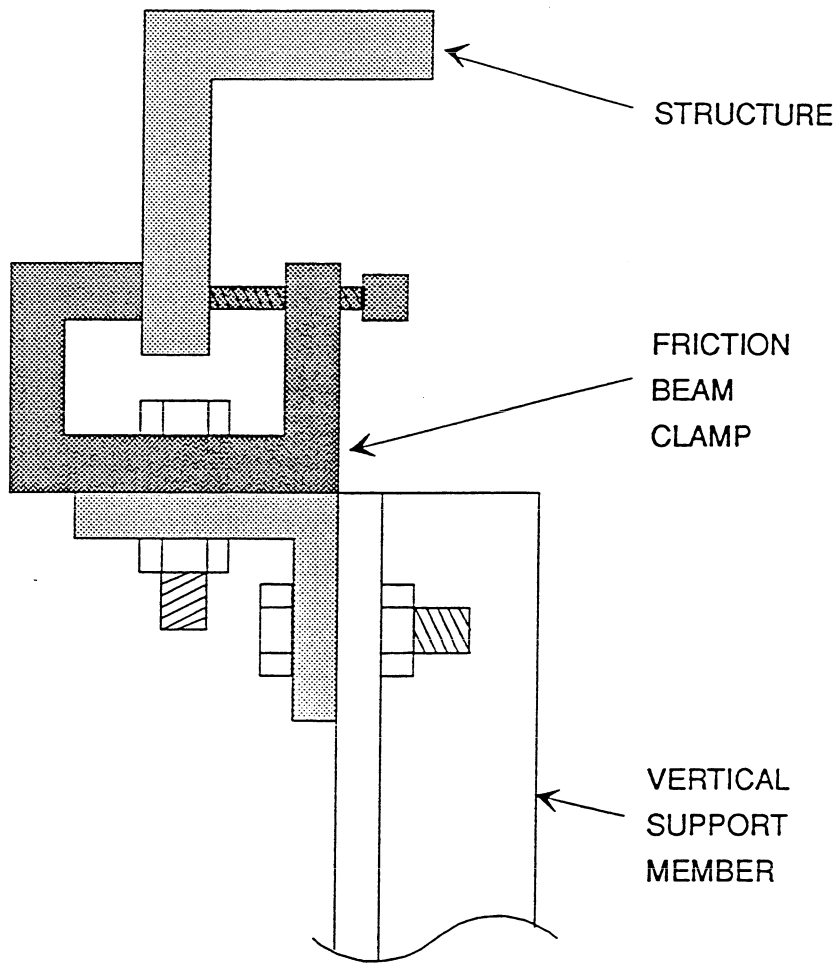


(a) Rigid "Boot" Connection Detail That Failed in Shake Table Test

(b) Addition of a Through Bolt Corrected the Design Flaw.

Note: The size of the gap is exaggerated for emphasis. Any size gap, no matter how small, is a possible concern.

Figure 9.2.1-2 Rigid Boot Connection Details (Reference 47) (Figure 8-2 of SQUG GIP, Reference 1)



Note: This arrangement may loosen and slip, resulting in support collapse.

Figure 9.2.1-3 Beam Clamps Oriented with Dead Load Resisted Only by Clamping Friction (Reference 47) (Figure 8-3 of SQUG GIP, Reference 1)

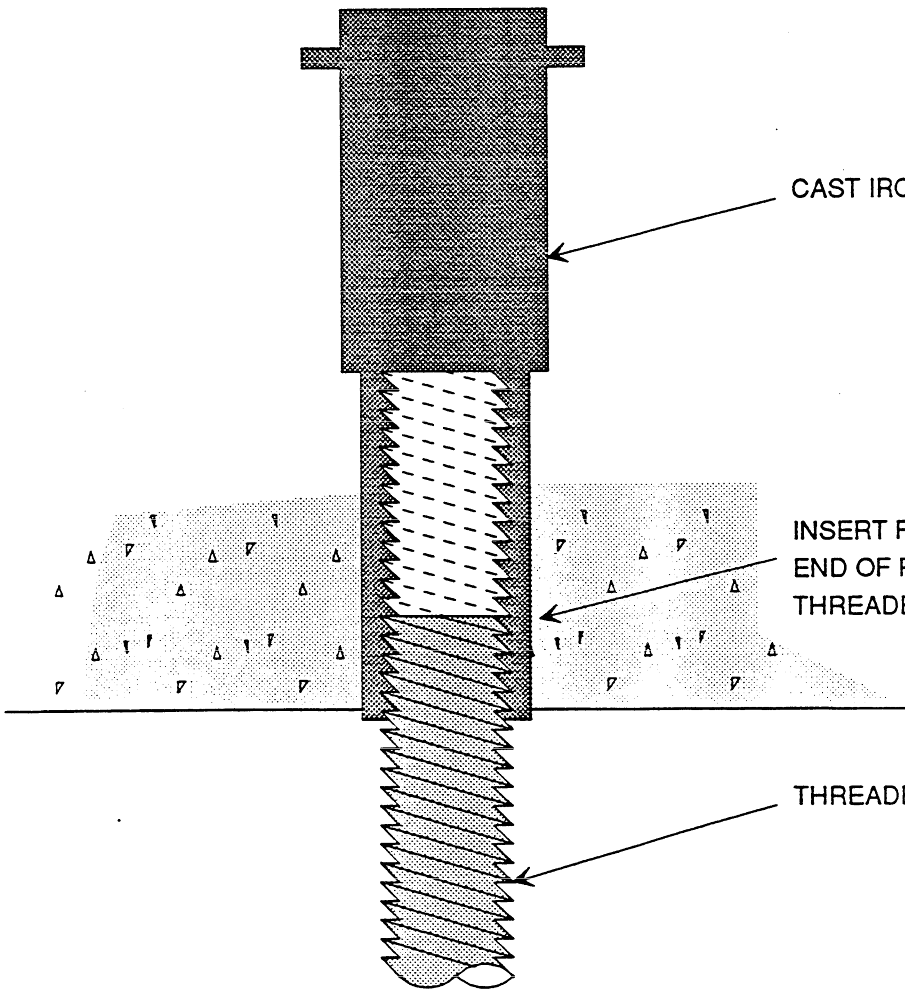
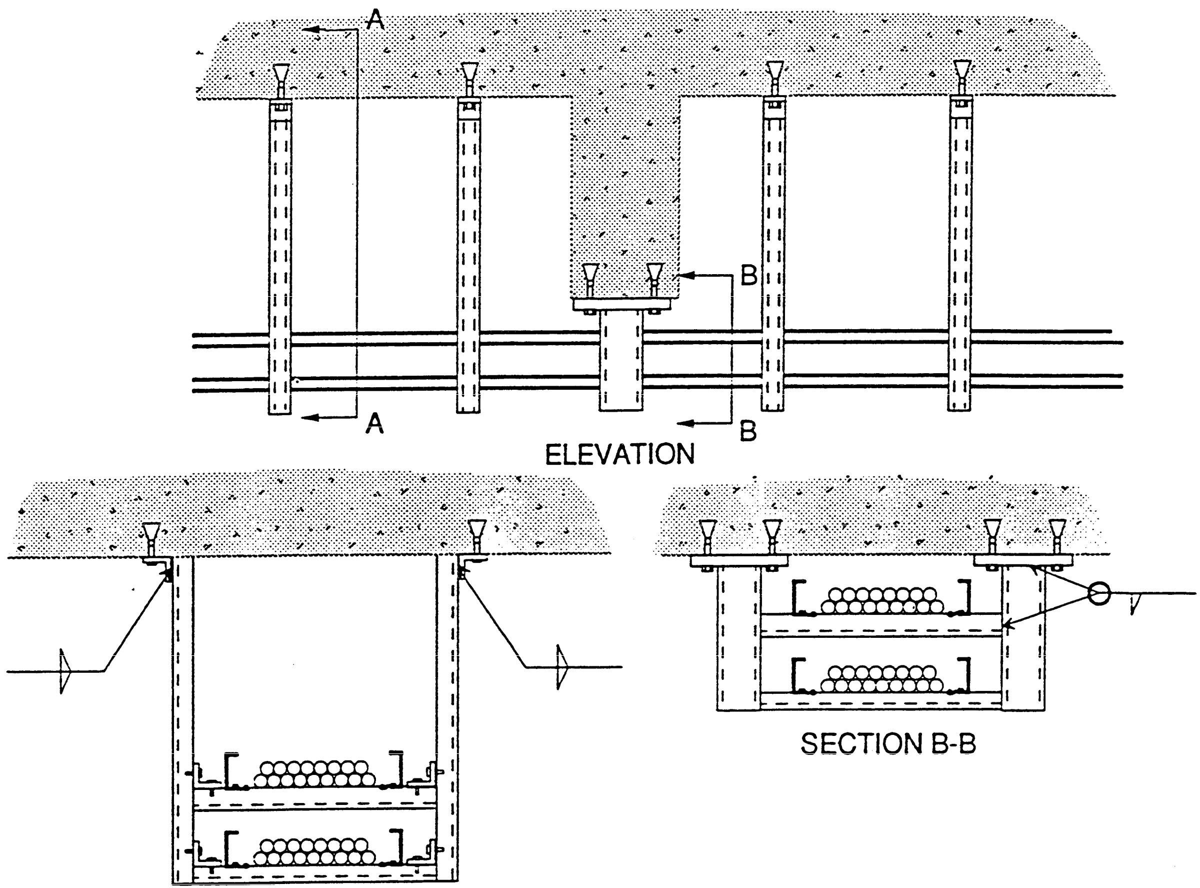


Figure 9.2.1-4 Cast-Iron Anchorage Detail that Failed at the Pacific Bell Alhambra Station, 1987 Whittier Earthquake (Reference 47) (Figure 8-4 of SQUG GIP, Reference 1)



Note: The short, stiff support may attract considerable load from longitudinal motion during an earthquake.

Figure 9.2.1-5 Short, Stiff Support in a System of Longer, More Flexible Supports (Reference 47) (Figure 8-5 of SQUG GIP, Reference 1)

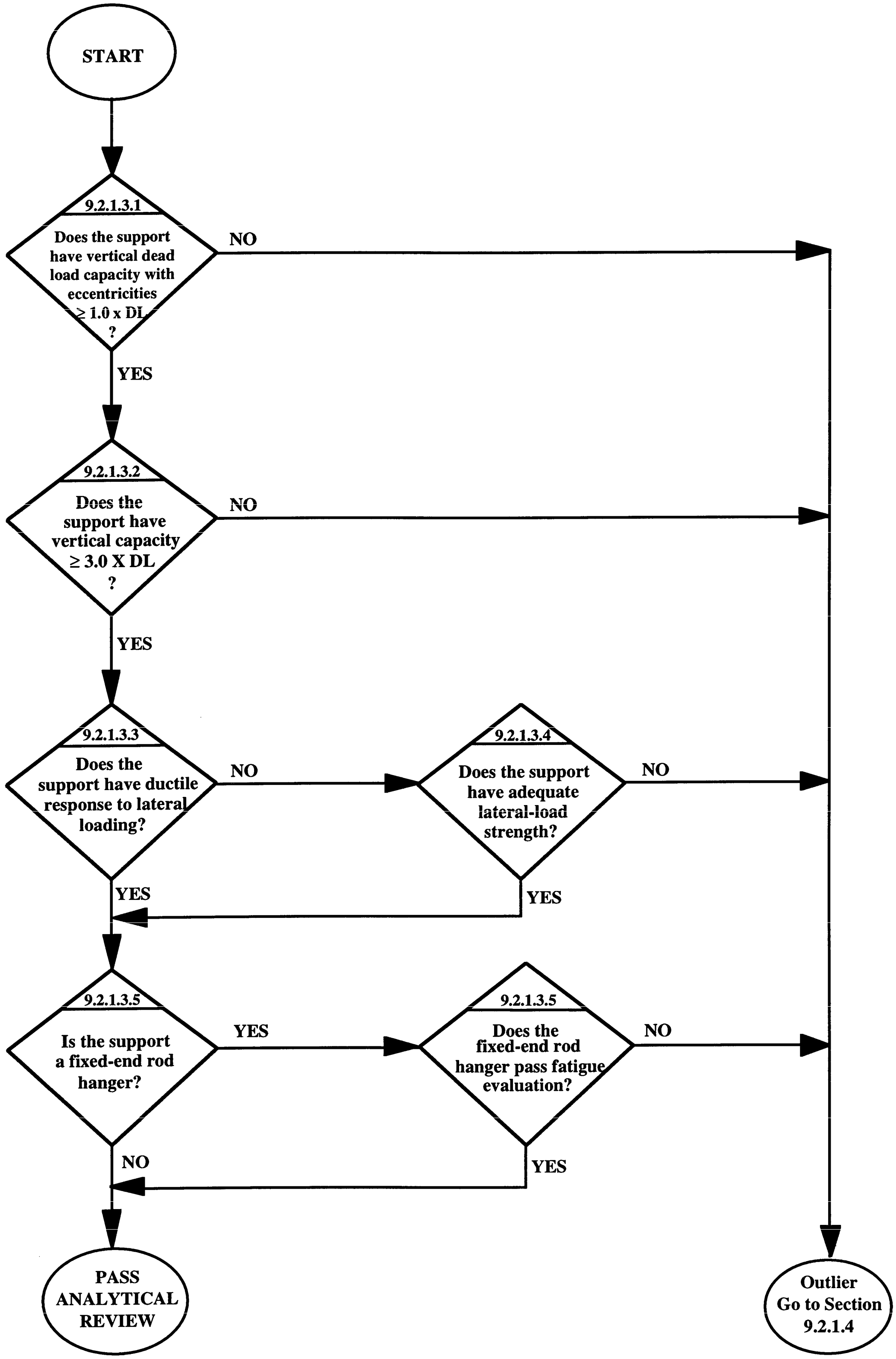
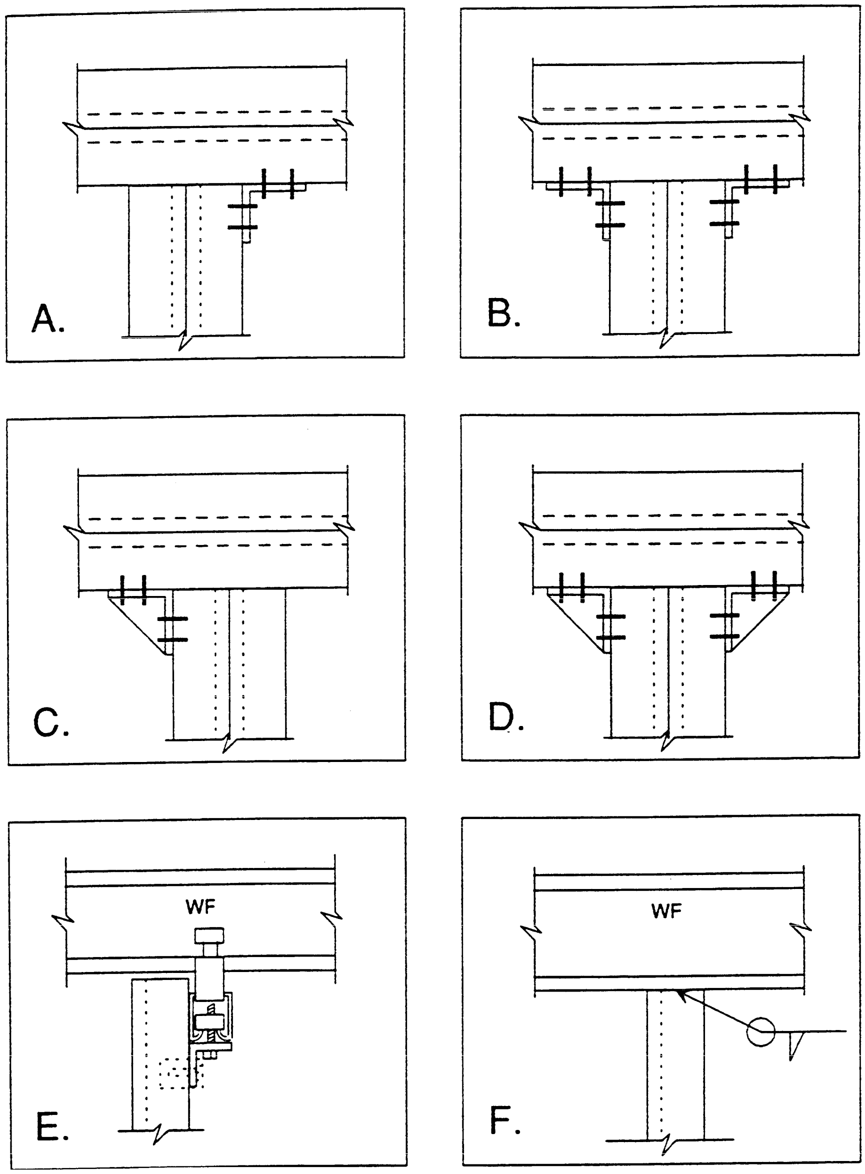


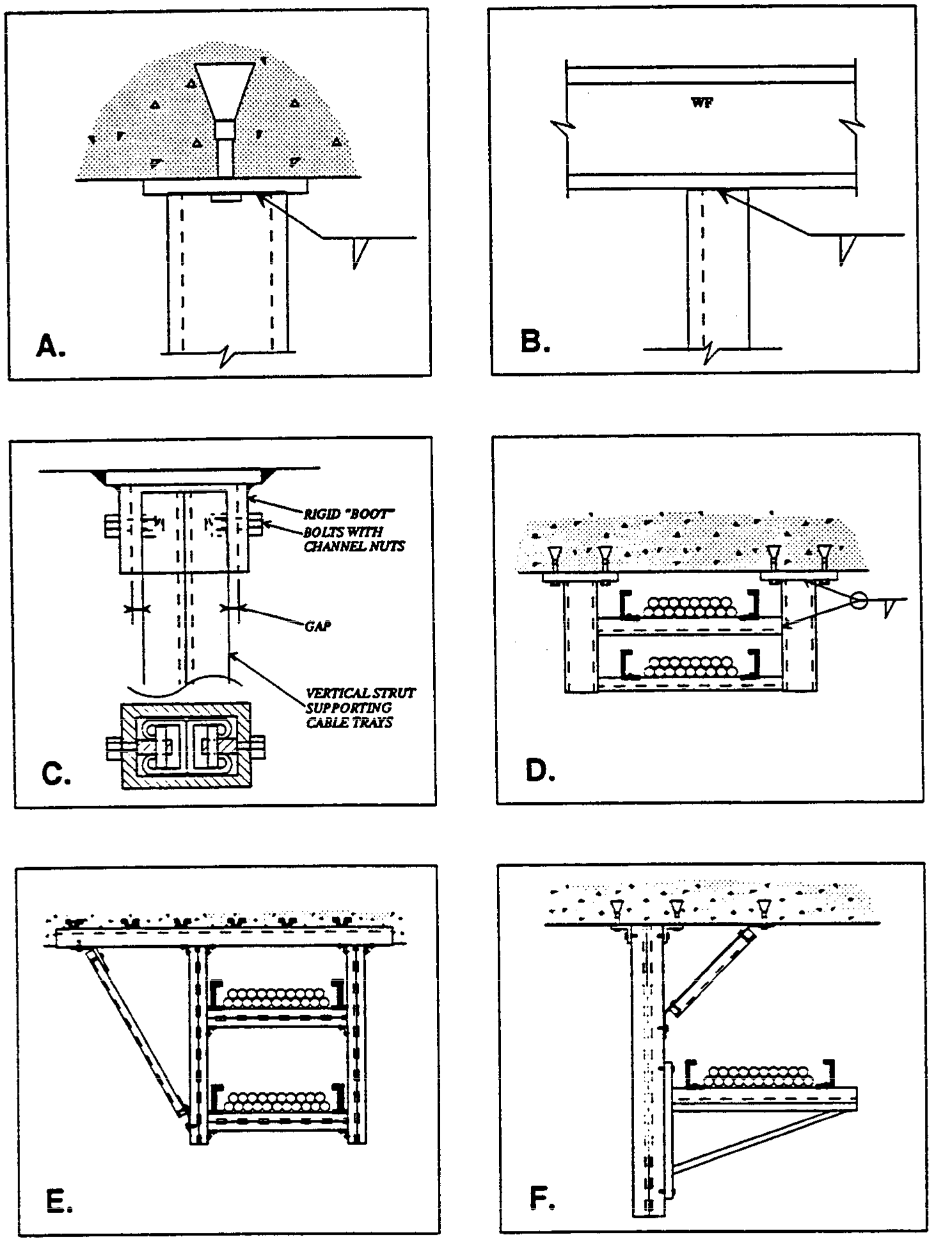
Figure 9.2.1-6 Logic Diagram for Limited Analytical Review of Suspended Raceway Supports (Figure 8-6 of SQUG GIP, Reference 1)



Notes:

- Connections A, B, C, and D are ductile connections of standard catalog, light metal, strut framing systems.
- Connection E is a properly oriented beam clamp, configures as a pin-ended connection. Pin-ended connections are considered ductile.
- Connection F is an all-around fillet weld on a structural steel angle section. If combined weld throat thickness is larger than the steel angle flange thickness, this may be considered a ductile connection.
- Connections C and D are ductile if the vertical bolts are into steel members as shown. If the vertical bolts are into concrete, the connections may not be ductile and should be checked.

Figure 9.2.1-7 Examples of Inherently Ductile Raceway Support Connection Details and Configurations (Reference 47) (Figure 8-7 of SQUG GIP, Reference 1)



Notes:

- Connections A and B are partially welded connection details. Partial welds cannot develop the plastic moment capacity of the vertical member, and are considered non-ductile.
- Connection C is the non-ductile rigid boot connection.
- Connection D is a rigid moment-resisting frame and should be checked for horizontal load.
- Connections E and F are diagonally braced, and should be checked for horizontal load.

Figure 9.2.1-8 Examples of Potentially Non-Ductile Connection Details and Configurations (Reference 47) (Figure 8-8 of SQUG GIP, Reference 1)

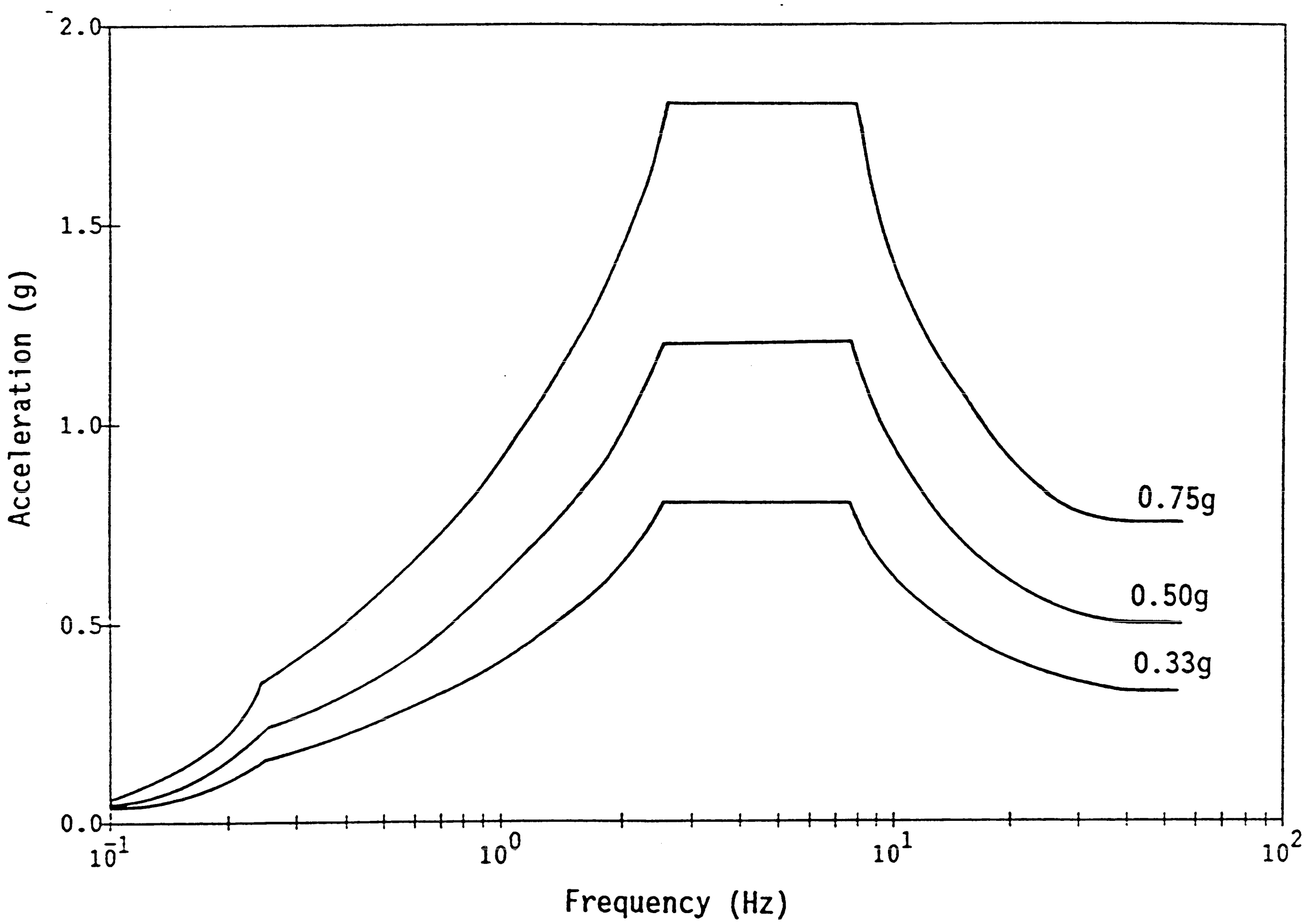
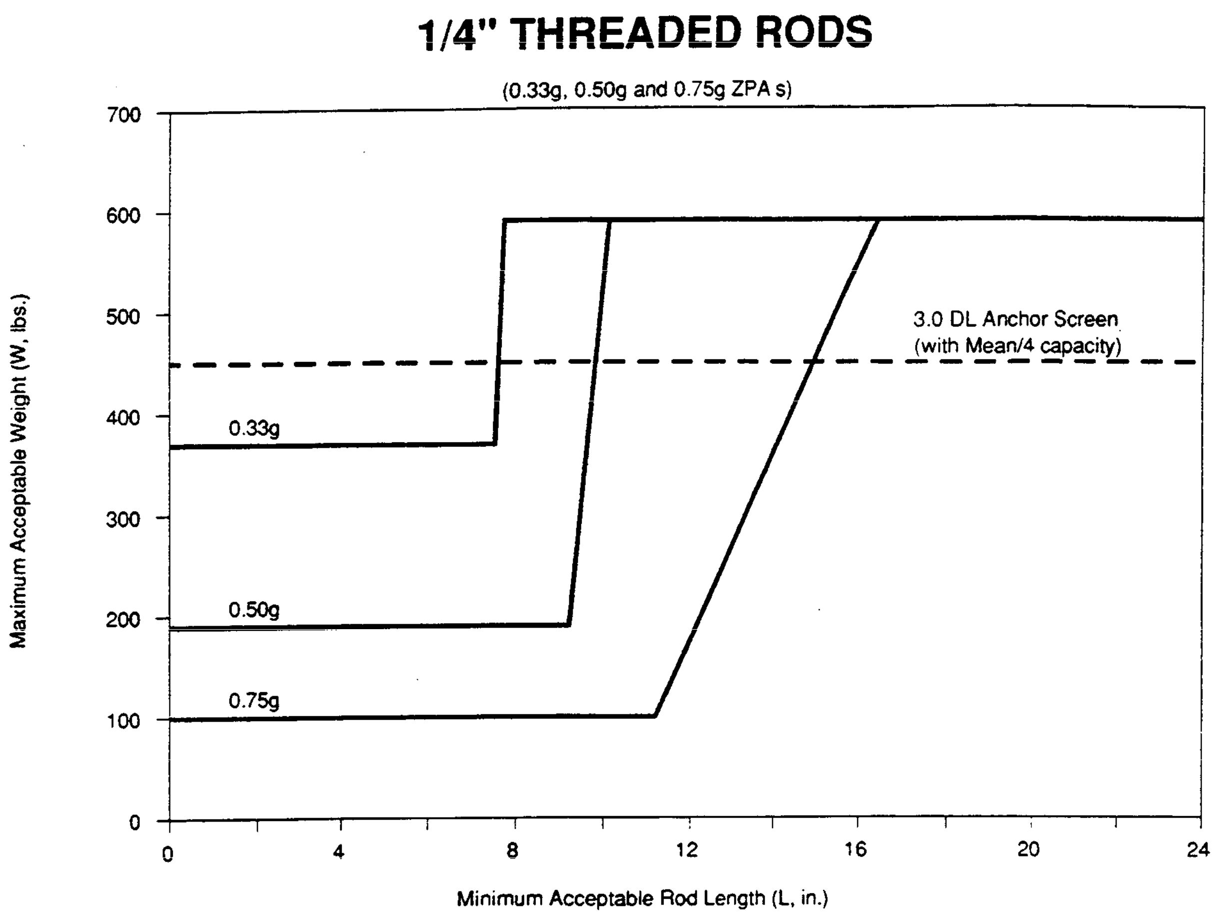
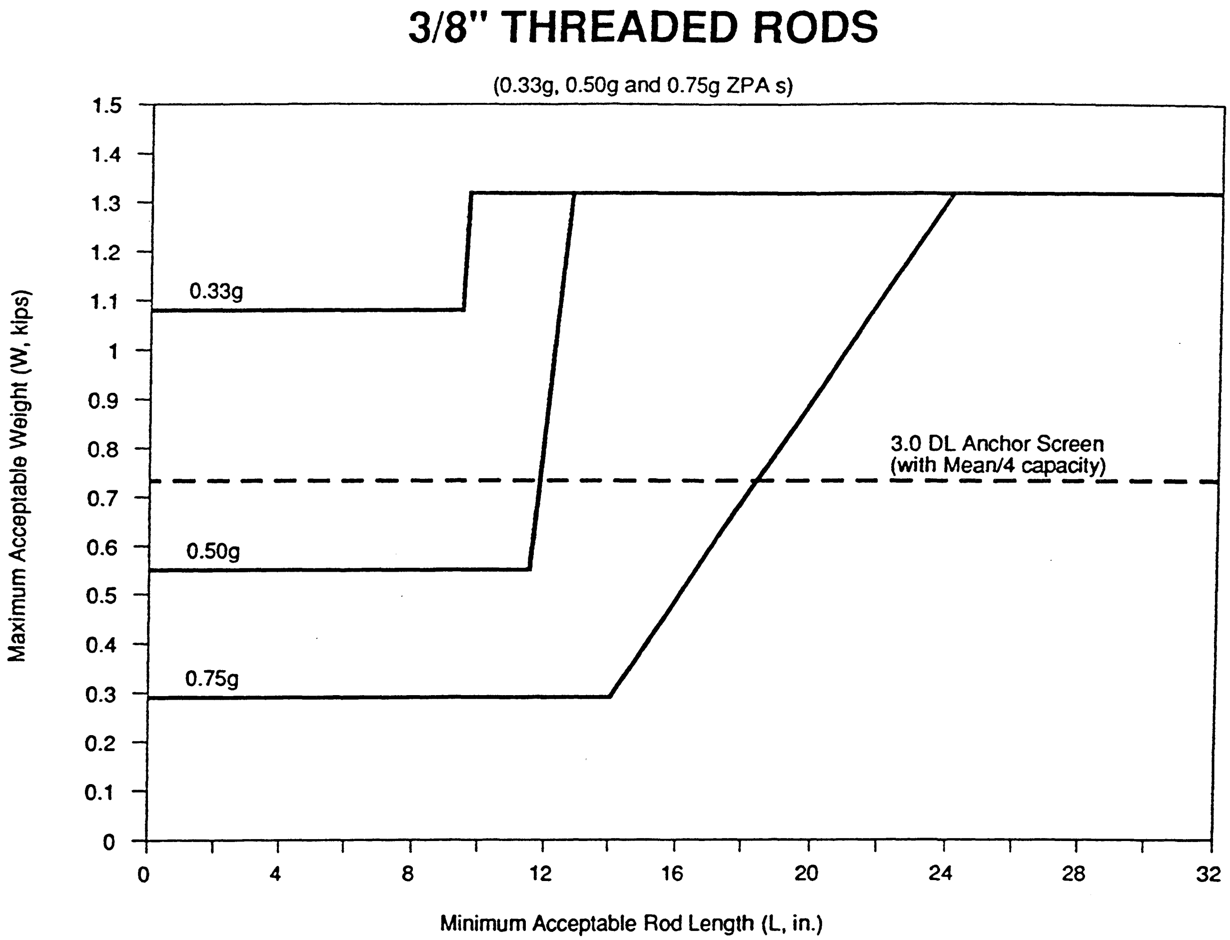


Figure 9.2.1-9 Rod Fatigue Bounding (Capacity) Spectrum Anchored to 0.33g, 0.50g, and 0.75g (Reference 47) (Figure 8-9 of SQUG GIP, Reference 1)



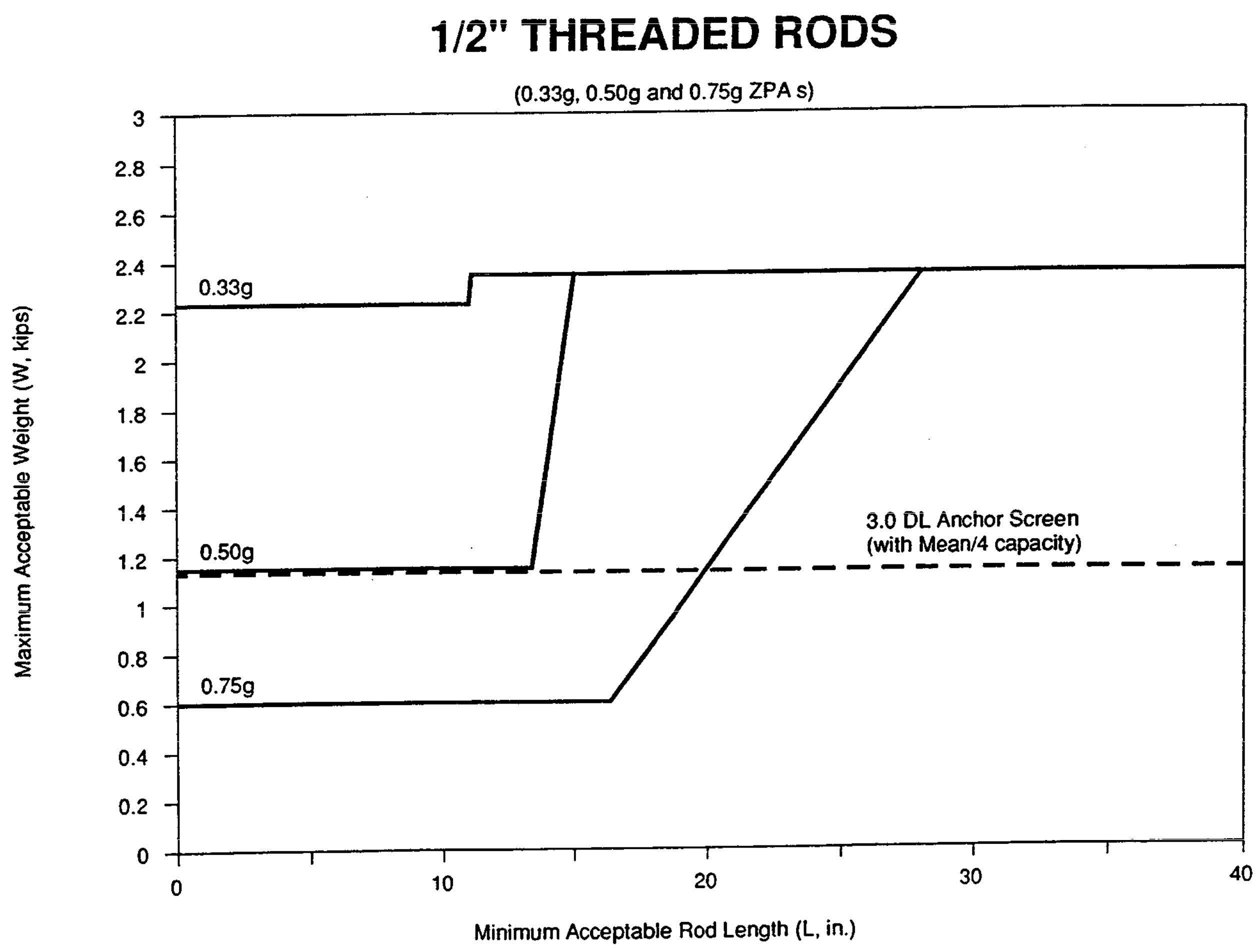
Notes:
- "W" corresponds to the total dead weight of the support (i.e., carried by both rods).
- "L" corresponds to the clear length above the top tier.

Figure 9.2.1-10 Fatigue Evaluation Screening Chart for 1/4-Inch Diameter Manufactured All-Thread Rods (Reference 47) (Figure 8-10 of SQUG GIP, Reference 1)



Notes:
- "W" corresponds to the total dead weight of the support (i.e., carried by both rods).
- "L" corresponds to the clear length above the top tier.

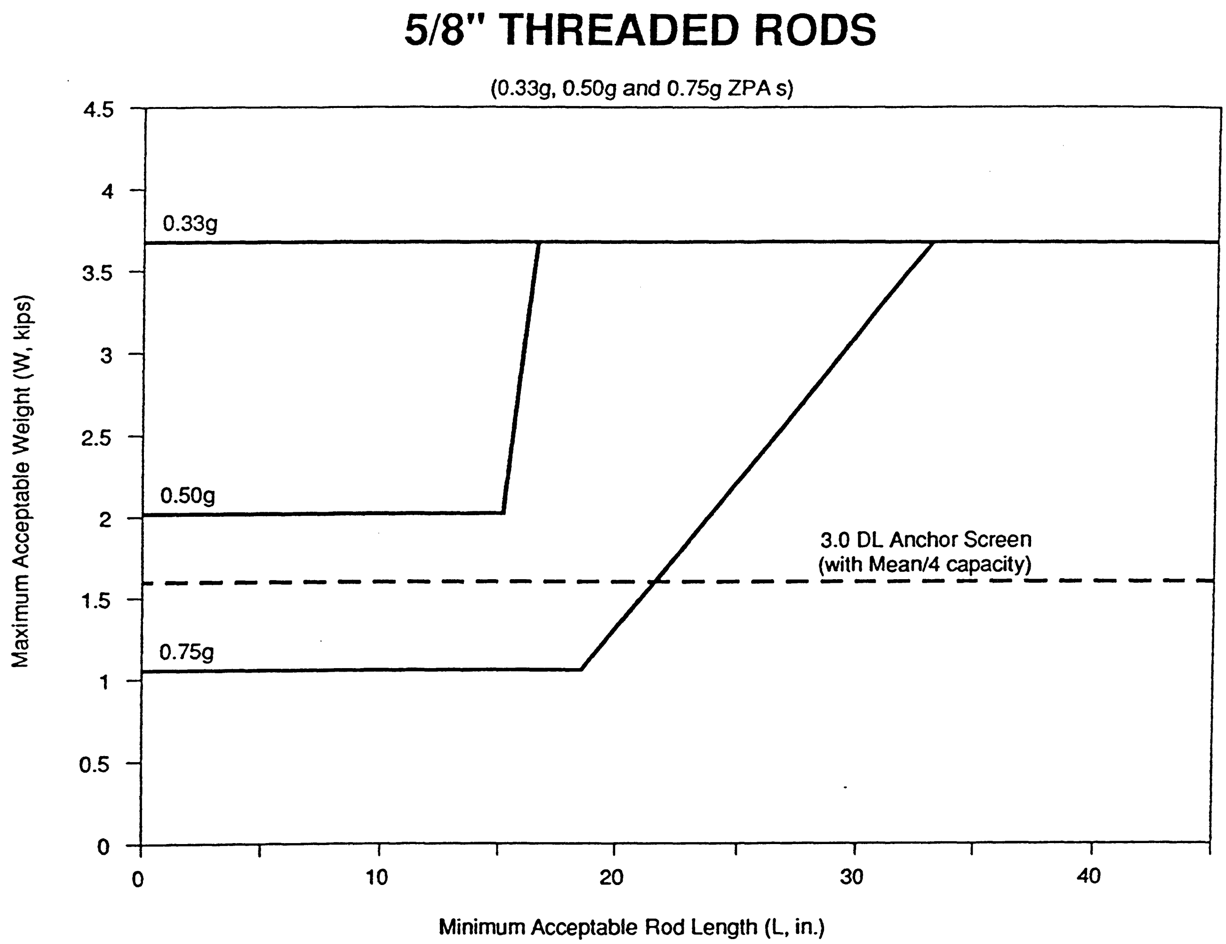
Figure 9.2.1-11 Fatigue Evaluation Screening Chart for 3/8-Inch Diameter Manufactured All-Thread Rods (Reference 47) (Figure 8-11 of SQUG GIP, Reference 1)



Notes:

- "W" corresponds to the total dead weight of the support (i.e., carried by both rods).
- "L" corresponds to the clear length above the top tier.

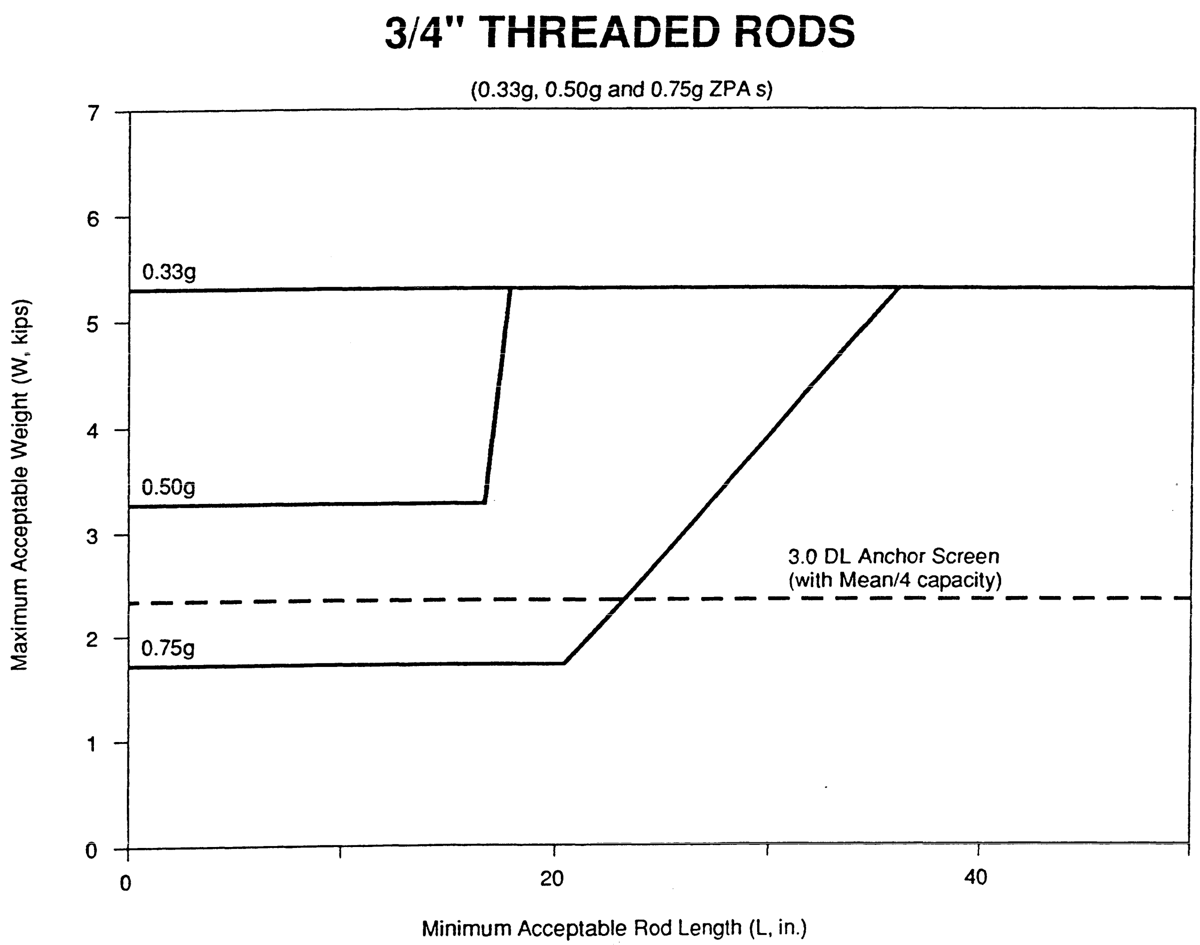
Figure 9.2.1-12 Fatigue Evaluation Screening Chart for 1/2-Inch Diameter Manufactured All-Thread Rods (Reference 47) (Figure 8-12 of SQUG GIP, Reference 1)



Notes:

- "W" corresponds to the total dead weight of the support (i.e., carried by both rods).
- "L" corresponds to the clear length above the top tier.

Figure 9.2.1-13 Fatigue Evaluation Screening Chart for 5/8-Inch Diameter Manufactured All-Thread Rods (Reference 47) (Figure 8-13 of SQUG GIP, Reference 1)



Notes:
- "W" corresponds to the total dead weight of the support (i.e., carried by both rods).
- "L" corresponds to the clear length above the top tier.

Figure 9.2.1-14 Fatigue Evaluation Screening Chart for 3/4-Inch Diameter Manufactured All-Thread Rods (Reference 47) (Figure 8-14 of SQUG GIP, Reference 1)