Cable Tray and Conduit System Seismic Evaluation Guidelines

On behalf of Seismic Qualification Utility Group

Technical Report

Cable Tray and Conduit System Seismic Evaluation Guidelines

NP-7151-D
Research Project SQ01-1

Final Report, March 1991

Prepared by
EQE ENGINEERING
595 Market Street, Eighteenth Floor
San Francisco, California 94105

Prepared for
Seismic Qualification Utility Group

Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, California 94304

EPRI Project Manager
R. E. Schaffstall

Nuclear Power Division

ORDERING INFORMATION

Requests for copies of this report should be directed to the EPRI Distribution Center, 207 Coggins Drive, P.O. Box 23205, Pleasant Hill, CA 94523, (510) 934-4212. There is no charge for reports requested by EPRI member utilities.

ACKNOWLEDGEMENTS

The following individuals provided valuable technical input to the SQUG Raceway Evaluation Guidelines program, mainly by their participation in several review meetings during the course of this study:

Senior Seismic Review and Advisory Panel (SSRAP)

P. Ibañez

R. Kennedy, Chairman

A. Schiff

W. Von Riesemann

L. Wyllie

Seismic Qualification Utility Group (SQUG) Steering Committee

H. Hanneman

W. Metevia

D. Ostrom

N. Smith, Chairman

J. Thomas

In addition, certain concepts of these evaluation guidelines are taken directly from the Reference 2 SSRAP report.

CONTENTS

ILLUSTRATIONS

SECTION 1

INTRODUCTION

1.1 BACKGROUND

Cable tray and conduit systems have consistently performed well at conventional power and industrial facilities subjected to past strong-motion earthquakes larger than eastern U.S. plant safe shutdown earthquakes (1). This is so even though the systems are typically not designed for earthquake loading. Cable trays found in conventional power and industrial facilities have out-performed structures, piping systems, mechanical and electrical equipment components and systems, and equipment anchorages. A number of shake table tests on portions of cable tray and conduit systems confirm these observations from past earthquakes and demonstrate that typical configurations perform well under repeated high-level seismic input test spectra on the order of 1.0g zero period acceleration.

There are only a few cases of collapse of conduit or cable tray support systems in earthquakes or on shake tables. One collapse occurred during a shake table test of trapeze frame supported cable trays with a nonstandard anchorage connection. The connection was a customized rigid ceiling boot (2). The guidelines presented below screen out these types of non-ductile connections that may lead to poor seismic performance.

A second collapse occurred during the 1984 Morgan Hill, California, Earthquake. These were heavily loaded cable trays supported on cantilever bracket supports, which were attached to base-mounted cantilever posts constructed of light metal strut channels. There were no lateral restraints to the posts and they were near capacity just under gravity load. The post channels suffered local buckling during the earthquake, which caused the cable tray system to collapse. There was no reported loss of cable electrical function. The guidelines presented below include analytical review screening to specifically evaluate these types of support systems. Base-mounted supports can behave very differently than suspended-type supports.

A third collapse occurred in a shake table test of a heavily loaded rod hanger supported cable tray system. The collapse was caused by low cycle, high strain fatigue of the threaded rods. The guidelines presented below screen out supports subject to low cycle fatigue.

Other severe damage occurred at the Pacific Bell Alhambra Station in the 1987 Whittier, California, Earthquake. These were extremely heavily loaded rod hanger supported cable tray systems (over 1 foot of cable on the tray). The rods were threaded into cast-iron sleeve anchors embedded in the concrete ceiling. Several cast-iron anchors pulled out or broke near the tip of the rod insert. The guidelines presented below screen out cast-iron anchor embedments.

There is only one known instance of damage to an electrical cable in a raceway, which occurred at the Pacific Bell Grand Central Station in the 1987 Whittier, California, Earthquake. The damaged cable was taut and was routed over a rough cut sheet metal edge. The guidelines presented below screen out these types of plant conditions that may lead to undesirable seismic performance.

Review of shake table test programs (3 and 4) and earthquake experience data shows that, for the vast majority of raceway support systems, damage rarely threatens overall structural integrity. Although minor structural damage was noted in some instances, maintenance of primary overhead support typically ensured that the electrical cable function was maintained. The shake table test data show that flexible support systems perform well under seismic loads with little or no visible distress. More rigid support systems exhibited significant plastic deformation in shake table tests, but did not fail under repeated high-level seismic input test spectra on the order of 1.0g zero period acceleration.

The good performance of these support systems is credited to the many sources of energy dissipation in their seismic response. Sources include slippage of friction connections, minor yielding of support members, ductile response of raceway components, redundant systems load paths (system network), and cable movement (bouncing and sliding), all of which cause high effective damping. Damping observed in tests range from 10% to over 40% of critical. The damping levels appear to be a function of several parameters, including response acceleration, systems flexibility, and cable load. The major portion of the mass of these systems is from the cables, which are not attached rigidly to the conduit or cable trays. This means that the entire structural and mass system does not behave as a typical structural system. These factors make it difficult, complex, and costly to approximate the actual seismic behavior of raceway systems using analytical means.

The observed lack of damage to conduit and cable tray systems, even when they are not designed for earthquake loads, leads to the conclusion that detailed seismic analyses are not justified. Thus these guidelines were developed to be as simple as possible and yet maintain adequate conservatism for evaluating seismic ruggedness for nuclear plant raceway systems. The purpose of this report is to outline these guidelines.

1.2 OVERVIEW OF THE GUIDELINES

Considerable research and effort has been undertaken by several individuals to develop these simplified evaluation guidelines. Seismic capability engineers should develop an understanding of this background. A summary of available data from earthquake and shake table test experience can be found in Reference 1. The Senior Seismic Review and Advisory Panel (SSRAP) report (2) provides additional background discussion of the philosophy behind several aspects of the guidelines.

Seismic ruggedness of raceway systems is defined as protecting electrical cable function and maintaining overhead support. Minor damage, such as member buckling or connection yielding, is considered acceptable behavior.

The guidelines include the following sections:

- Walkdown Guidelines
- Limited Analytical Review Guidelines
- Example Evaluations

The walkdown guidelines are established to direct in-plant screening reviews of raceway systems to show the raceway support systems are bounded by the data base. They are also used to screen out details that may result in damage. Identified outliers should be documented and require further evaluation. The walkdown guidelines also direct sample selection for the limited analytical review.

The limited analytical review of selected worst-case representative samples ensures the raceway supports are at least as rugged under seismic load as those in the data base that performed well. When samples do not pass the analytical review, further evaluations should be conducted and the sample expanded as appropriate.

Finally, example evaluations are provided to guide the limited analytical review. Credible weak links in raceway support systems are illustrated in the examples.

The Walkdown Guidelines and Limited Analytical Review Guidelines below are, in general, applicable to metal cable tray and conduit systems at any elevation in a plant where the nuclear plant free-field ground motion 5% damped seismic design spectrum does not exceed the Seismic Motion Bounding Spectrum of Reference 5. The Bounding Spectrum is shown in Figure 1-1. For threaded rod-supported systems, plant-specific in-structure (floor) response spectra are used for fatigue evaluation.

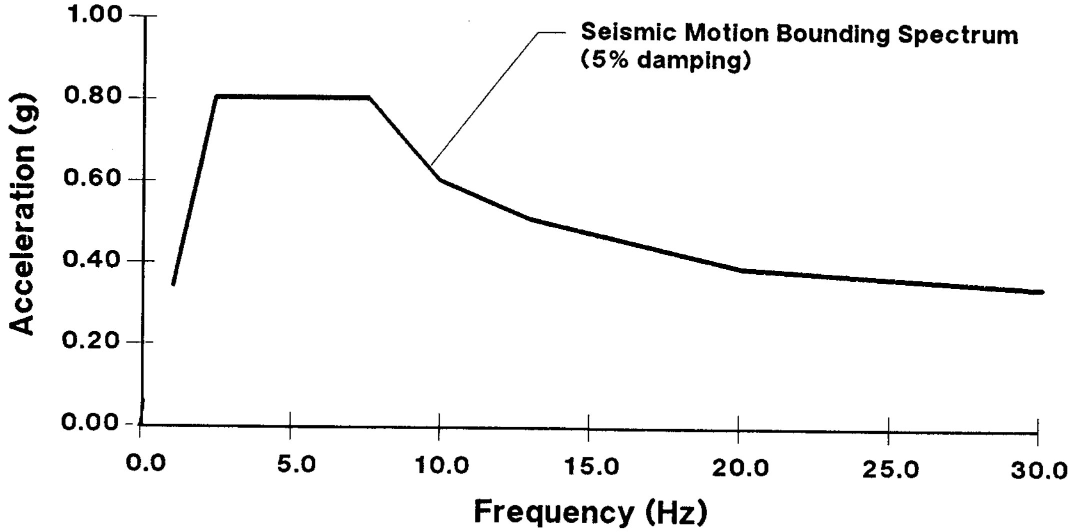


Figure 1-1. Seismic Motion Bounding Spectrum.

SECTION 2

BACKGROUND TO THE GUIDELINES

The evaluation team is expected to use professional judgement in the evaluations of the nuclear plant raceways. This applies both to the in-plant walkdowns discussed in Section 3 and to the limited analytical reviews discussed in Section 4. Strict adherence to the guidelines in these sections is not absolutely required. It is more important that the evaluation team with their professional judgement becomes satisfied that the raceways are adequately supported. The team should provide a written explanation of the bases for their judgement in those cases where the guidelines are not followed.

It is absolutely essential for the evaluation team to understand the philosophy behind the guidelines and the reasons for them. As discussed in Section 1, raceways have exhibited superior performance in past earthquakes and in shake table tests with few exceptions, even when the raceways have not been designed for earthquakes. Normal industrial practice has been shown to result in seismically rugged raceway construction in many cases. The evaluation team needs to understand those aspects of raceway construction that provide acceptable performance, those features that might lead to poor performance, and what acceptable performance is.

It is interesting to note that raceways have performed so well in past earthquakes that seismic standards have not evolved for raceways in conventional power and industrial plants in seismically active regions such as California. This is in contrast to fire protection systems or equipment anchorage, for example, where such standards have evolved.

Certain specific issues are identified in Sections 3 and 4 for walkdown or analytical evaluation. Because of the proven seismic ruggedness of raceways in past earthquakes and testing programs, the team should be aware of and examine certain features when they are noticed, but there is no need to rigorously check for these features in every raceway run in the plant. Heavily loaded trays are an exception. Raceways that performed well in past earthquakes were found to be adequately designed for dead load. This is why the analytical review guidelines include a check of the dead load capacity. In the Seismic Qualification Utility Group (SQUG) trial walkdowns of raceway systems it was not found to be difficult for the walkdown team to identify those raceway supports that were most heavily loaded. After the walkdown, a bounding analytical evaluation of the most heavily loaded supports determines the adequacy of all similar raceway supports for gravity load.

The evaluation team should understand that raceways are unusual and atypical structural systems. First, the mass of the system is primarily in the cables, which are secured to the structural system in only limited ways. Cables have been observed to flap, bounce, and slide vigorously in shake table tests. This means raceways are highly nonlinear systems. In linear models the nonlinear behavior due to cable flapping and other nonlinear effects is approximated by using large damping; values over 40% of critical have been reported in some tests.

Second, there are many other sources of nonlinear behavior such as yielding of connections or members; friction at bolted connections; clamping type connections in members and trays; the many branches and spatial layout of the trays or conduit; the large number of supports in a raceway system; and interferences with proximate plant features. The result is that raceways do not respond like simple linear models predict. For example, raceways are expected to move much less than piping systems. A possible exception is long straight runs of uniform construction with no lateral branches.

Third, in many cases of earthquake-resistant design the focus is on developing an adequate lateral force-resisting system. This does not appear to be the primary factor for designing a raceway system that will perform adequately in an earthquake (floor-mounted systems are an exception). What does appear to be important is a support system that will maintain primary overhead vertical support. If the structural elements challenged by lateral movement are ductile, the lack of any significant lateral load resistance capability appears to be a relatively insignificant consideration. This is because while the earthquake may exercise the lateral ductility, this typically does not at the same time challenge the vertical load-carrying capacity of supports. However, if the lateral load-resisting system is non-ductile rather than ductile, then it may be possible for lateral loads to cause loss of vertical load-carrying capability, which could lead to system collapse. These raceway evaluation guidelines take credit for ductility, and thus it is very important to assess whether the system being evaluated is ductile or non-ductile. Moreover, the purpose of lateral bracing should typically be thought of as a means to limit lateral or longitudinal movement of the system in order to prevent safety-related spatial interactions[1] where needed, rather than considering lateral or longitudinal bracing as hardware required to ensure structural adequacy.

Finally, the ultimate objective is to prevent loss of cable electrical function, not to prevent damage to or yielding of connections or supports. There is only one known instance of loss of electrical raceway system cable function in an earthquake, and this did not result from connection yielding, damage, or support or system collapse. Furthermore, where system collapse has occurred there was no loss of cable electrical function. While system collapse is not acceptable performance, it is possible that it could occur without loss of cable electrical function. This illustrates that a raceway system can experience considerable local damage to trays or conduit without loss of safety-function. As an example, this is in contrast to a piping system where one crack in a pipe may result in loss of safety function.

---

1. Past earthquake experience shows that most spatial interactions involving raceways are not harmful (the impacts do not cause damage that would be considered to be safety-related). The impacts that do occur seem to introduce another nonlinearity in the structural system that prevents the resonant build-up of motion. This is based on the observed numerous spatial interactions in piping systems. There are few known cases of spatial interaction in raceway systems. Nevertheless it is important to determine if there are fragile equipment proximate to raceways that could become damaged.

SECTION 3

WALKDOWN GUIDELINES

3.1 OVERVIEW OF WALKDOWN GUIDELINES

Guidelines are presented here for conducting in-plant seismic ruggedness review of conduit, cable trays, and their support systems. The in-plant review has two purposes.

First, the raceway systems are reviewed against certain guidelines (see Section 3.2) on specific raceway hardware or plant features to show the raceway systems are enveloped by the earthquake experience and test data base. Outliers (see Section 6) require a more detailed review. The in-plant review also addresses raceway system features that may result in damage, as evidenced by the earthquake experience or test data.

Second, the in-plant review guidelines discuss the selection of sample raceway supports for the limited analytical review. Guidelines direct the sample selection to include the plant's worst-case as-installed raceway supports. The sample selection should include supports that encompass the diversity of the plant's support systems. The analytical reviews show the plant's supports are as rugged as those that experience has shown to perform well. The analytical review guidelines are in Section 4.

3.2 GENERAL WALKDOWN PROCEDURE

These evaluation guidelines describe the means for the walkdown team to perform a detailed in-plant screening and assessment of conduit and cable tray systems for seismic ruggedness, relying in part upon engineering judgement exercised in the plant during the walkdown. The engineering judgement is based on a good understanding of the performance of raceways in past earthquakes and shake table and other tests.

The raceway evaluation walkdown team members will conduct the walkdown in teams of at least two. The walkdown team should have a clear understanding and working knowledge of the evaluation guidelines presented below and have studied References 1 and 2 thoroughly. They should also become familiar with the plant's raceway design and construction practices, as well as with the general layout of the plant, raceway routing, and raceway systems crossing building separations.

The walkdown team should spend one to two weeks in the plant. The duration may vary depending on the number of walkdown teams, the size of the plant, the complexity and accessibility of the plant raceway systems, and so forth.

General notes, including rough sketches or photographs as appropriate, should be taken on 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 walkdown team to review notes and sketches, to collect plant drawings or information if needed, and to check selected supports by preliminary calculations if warranted.

Sections 3.2.1 through 3.2.7 contain specific walkdown guidelines, called Inclusion Rules, which represent significant identified limits of the data base or significant details that are undesirable if found in nuclear plants.

It is not intended that compliance with the Inclusion Rules be checked in detail for every raceway system span or support, or even a large number of them. The intent is that at the beginning of the walkdown several supports or spans at a variety of locations be examined to determine if plant construction practice is in agreement with the Inclusion Rules. Thereafter, the walkdown team should be alert for and note and evaluate any instances of noncompliance with the Inclusion Rules, if and when they are noticed as part of the walkdown. The walkdown team should observe essentially all the safety-related raceways in the plant.

If Inclusion Rule violations are noted, then the walkdown team needs to investigate or reinvestigate sufficiently so that the team is convinced they understand the extent of the identified condition. If conditions that do not meet the Inclusion Rules are assessed as acceptable by the review team, then written justification and reasoning for the acceptability of the condition should be provided. The justifications should be based on mechanistic principles and sound engineering reasoning.

In general, the level of effort of the review should be enough to give the review team confidence in the seismic adequacy of the plant raceway systems. The bottom line is that the review team is ultimately responsible for the seismic evaluations. Their sound engineering judgement is the key to a successful execution of these guidelines that is at the same time safety effective and cost effective. In this spirit, these guidelines are only guidelines, not requirements; the sound engineering judgement of the review team is the most important factor.

3.2.1 Cable Tray Span

The length of an unsupported cable tray between adjacent supports should not exceed about 10 feet. The length of an unsupported cable tray that cantilevers out from a support should not exceed about 5 feet. These spans are selected because they are supported by earthquake experience data.

3.2.2 Conduit Span

The length of unsupported conduit between adjacent supports, or the length of unsupported conduit that cantilevers out from a support, should not exceed that in the following table. These spans are selected because they are supported by earthquake experience data and are consistent with the National Electrical Code (6).

Conduit Size (inches)	Approximate Maximum Distance 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

3.2.3 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.

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 the supports are at the maximum span of 10 feet described in Section 3.2.1, then there would be seven supports in the 60-foot run. Trays need to be secured to only seven supports in any 60-foot run, regardless of how many supports there actually are in the run.

3.2.4 Channel Nuts

For use of these evaluation guidelines, channel nuts used with light metal framing systems need to have teeth or ridges stamped into the nut where it bears on the lip of the channel (Figure 3-1). Test experience has shown that channel nuts lacking the teeth or ridges have capacities (slip resistance) significantly less than channels nuts with the teeth or ridges.

3.2.5 Rigid Boot Connection

Strut systems supported by "boots" or similar rigid devices, especially plant-specific designs, need to be evaluated on a case-by-case basis. Shake table tests have shown that a rigid boot overhead connection detail, as shown in Figure 3-2, 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. The customized rigid boot detail is not included in the earthquake experience data base.

3.2.6 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 3-3, might loosen and slip off in an earthquake and possibly cause a collapse.

3.2.7 Cast-iron Anchor Embedment

Threaded rod hanger anchor embedments constructed of cast iron should be specially evaluated because of potential brittle failure modes. Whether anchor embedments are cast iron may be able to be determined from plant documentation. The earthquake experience data base includes examples where heavily loaded rod hangers threaded into cast-iron inserts failed (see 1, 1987 Whittier, California, Earthquake). The cast-iron anchor detail is shown in Figure 3-4. Failure modes included anchor pullout and anchor fracture where rods were only partially threaded into the anchor.

3.2.8 General Guidance

There are other seismic performance concerns in addition to the Inclusion Rules in Sections 3.2.1 through 3.2.7 that the walkdown team needs to keep in mind. These issues are discussed in this section. The presentation of these issues here should not be interpreted to suggest that the entire plant be inspected for these conditions as the walkdown progresses. Instead, the walkdown team should note and evaluate any of the conditions described below, if and when these conditions are noticed as part of the walkdown.

A major portion of the walkdown should be conducted from the floor level. As different support configurations are observed during the walkdowns, the walkdown team members should examine them to familiarize themselves with the construction and details. When any suspect condition is observed from the floor level, such as those described in the Inclusion Rules, a closer examination should be carried out.

The walkdown team should pay close attention to the review of anchorages for the raceway supports. The team should pay particular attention to system anchorages 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, providing the review team is convinced they understand the actual details. For example, the plant design drawings, construction records, or procurement specifications may provide the unknown details. If overhead welds are not visible because they are covered by fire retardant, or for other reasons, other similar supports without the coating can be inspected or as-installed plant documentation reviewed to gain understanding of the weld adequacy. Adequacy of other types of anchorage such as plastic inserts or lead shield plugs for cable tray systems is 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 class-specific basis, utilizing manufacturers' information, plant-specific test programs, or proof testing. In addition, anchorage adequacy for lightly loaded conduit supports rigidly attached to a wall, with less than about 15 pounds dead load, may be verified by giving the conduit a tug by hand.

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 structural 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 4). Similarly, excessive corrosion of cable trays, conduit, or supports should be evaluated for its effect on structural integrity. Evaluations should consider the alternative of estimating the strength reduction due to corrosion, if appropriate.

There should not be a noticeable sag of the conduit or cable tray. As a general guideline, noticeable sags are about 1 inch of deflection in 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 4).

Broken or missing cable tray and conduit components should be repaired or replaced. Locations where cable is routed through rough, sharp edges should be evaluated for their potential to cause insulation damage in an earthquake.

Any cables above the top of the side rail should be restrained to keep them in the tray in 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 there is a credible earthquake hazard to the cables (through flopping or falling out of the trays and becoming pinched or cut) or whether the cables may present a hazard to proximate plant 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 proximate fragile equipment, the cables should be restrained to keep them in the tray.

There is concern about aging of cable ties made of plastic-type materials that are frequently used to restrain cables within the cable trays. If restraining straps are required on vertical drops or when trays are filled above the top of their side rails and those restraining straps are of a plastic-type material, then the walkdown engineers should make a brief qualitative evaluation by physically pulling or tugging on a few of the straps or enclosed cables to 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 replacement should be provided in those areas where they are needed.

Occasional stiff supports in long flexible runs of cable trays or conduit should be evaluated to determine if the longitudinal movement of the run could cause the stiff support to fail. Cable tray or conduit systems may contain a long run of supports that are relatively flexible in the longitudinal direction, and then a support that is relatively stiff (Figures 3-5 and 3-6). The stiff support may thus be subjected to considerable load during earthquake-induced longitudinal movement and might fail. 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 walkdown team should review Reference 7, which provides examples of long longitudinal runs from the earthquake experience data base.

The limited analytical review guidelines of Section 4 address 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, which should be specially evaluated for possible failure due to fatigue using the methodology described in Section 4. Eccentrically-braced rod hanger trapeze support systems should also be evaluated.

The walkdown team members should become familiar with the seismic interaction assessment guidelines being used for the equipment seismic reviews. They should be alert for potential seismic interaction hazards. Raceway systems attached to or in the vicinity of unanchored components or unrestrained block walls should be noted and evaluated.

If an isolated support that has questionable structural adequacy is found, the walkdown team should evaluate its adequacy or exercise judgement regarding the likely consequences of failure. If the adjacent spans are not excessive, and if adjacent supports have a sufficiently high factor of safety (as defined in Section 4), failure of a single support can be acceptable. The effect of the assumed failed support swinging or falling should be evaluated as a seismic spatial interaction hazard for proximate fragile components.

3.3 SELECTION OF SAMPLE FOR LIMITED ANALYTICAL REVIEW

The walkdown team engineers need to understand the limited analytical review guidelines presented in Section 4 and the sample evaluations of Section 5, prior to plant raceway walkdowns and selection of samples. The goal is to establish a biased, worst-case sampling, representative of and bounding the major different raceway support configurations in the plant. The sample size will vary with the diversity and complexity of each specific plant's raceway support system design and construction. As a general guideline, 10 to 20 different example supports should be sufficient.

Notes should be taken describing 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 ruggedness of the sample support should be noted in detail.

The walkdown team engineers 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 their original design intended. These can be identified by the presence of other plant 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 anchorages that appear marginal for the supported weight are good candidates for sample evaluation. Anchorages of undersized welds, incomplete welds, or welds of poor quality should also be included as samples. When overhead miscellaneous support steel, such as structural steel angle or channel, 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.

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

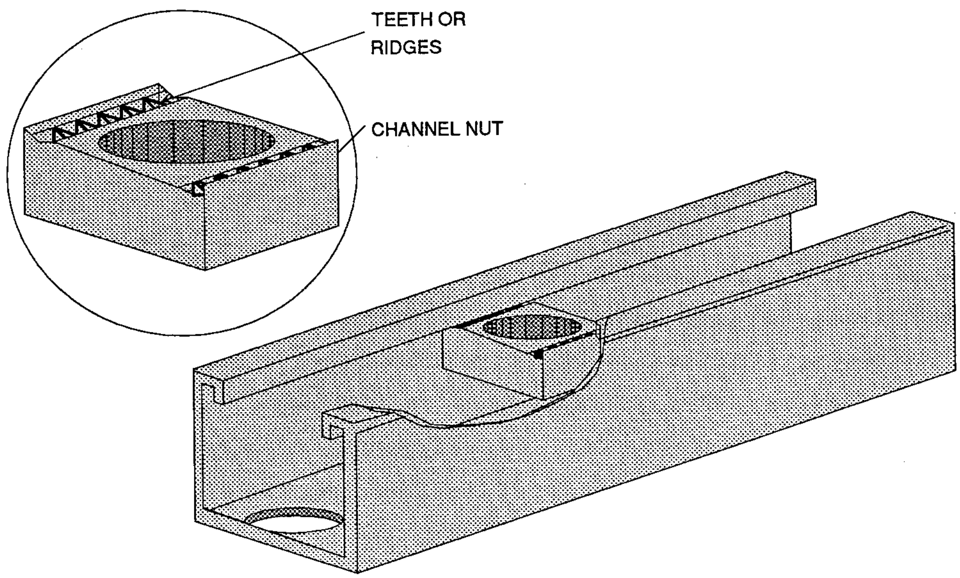
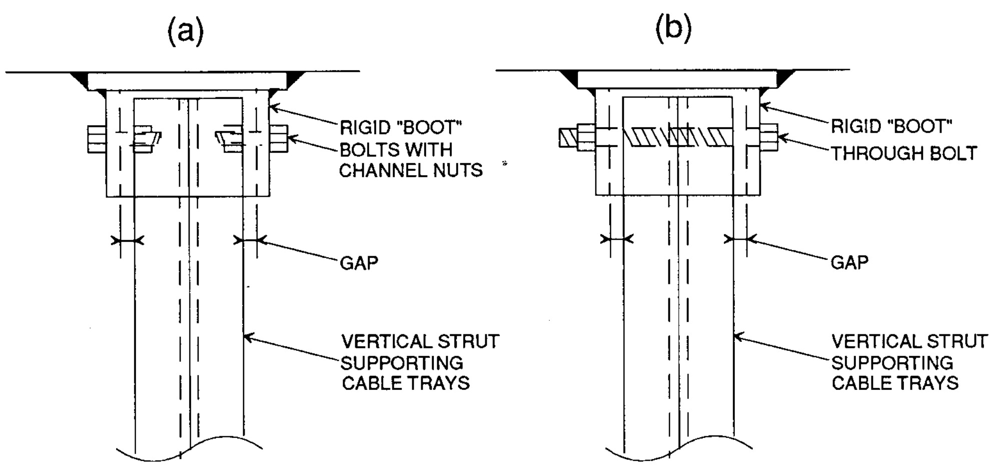


Figure 3-1. Light metal framing strut channel nut. Location of channel nut teeth or ridges is indicated.



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

Figure 3-2. (a) Rigid "boot" connection detail that failed in shake table test. (b) Addition of a through bolt corrected the design flaw.

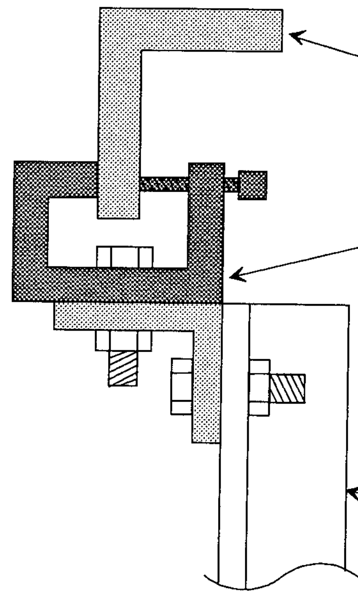


Figure 3-3. Beam clamps oriented with dead load resisted by only friction clamping may loosen and slip, resulting in failure.

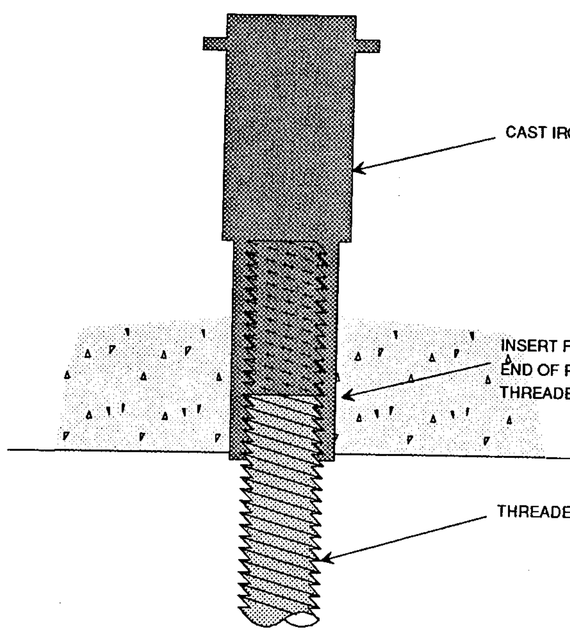


Figure 3-4. Cast-iron anchorage detail that failed at the Pacific Bell Alhambra Station, 1987 Whittier Earthquake.

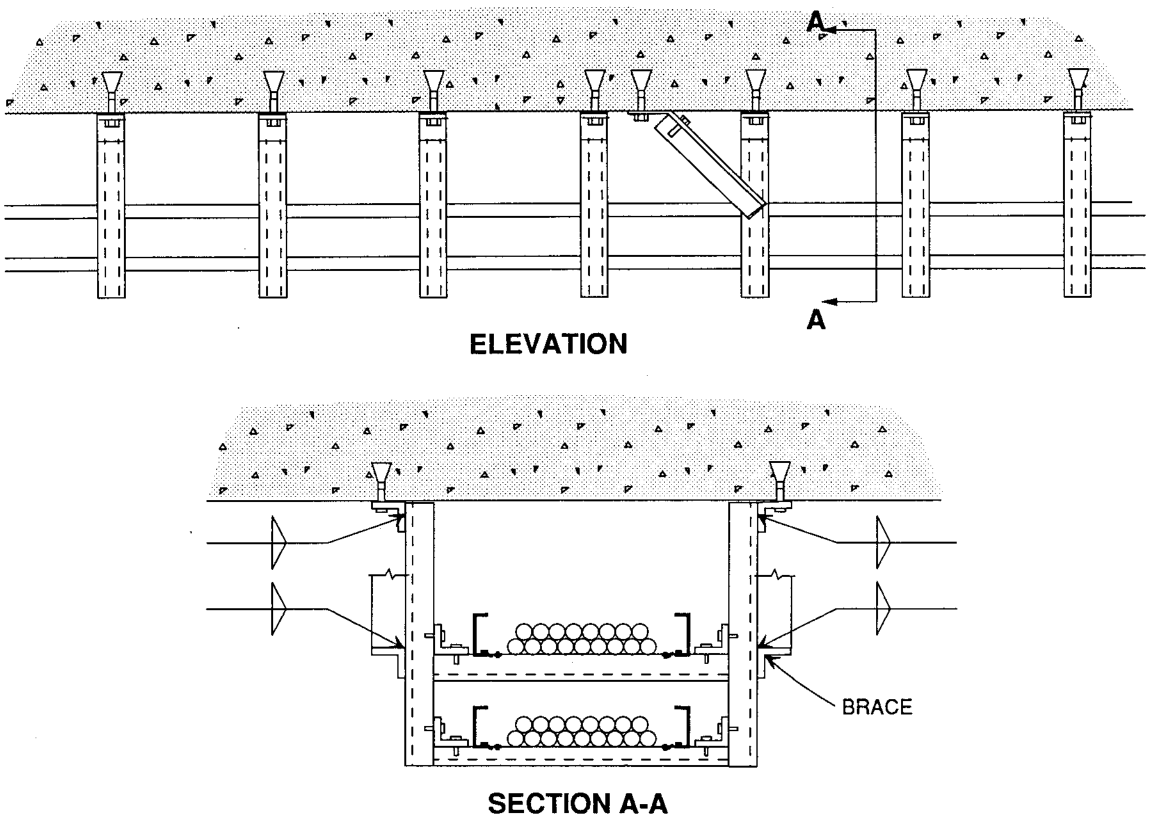


Figure 3-5. Stiff, longitudinal brace in this flexible run of trapeze frame supported cable trays may attract considerable load during an earthquake.

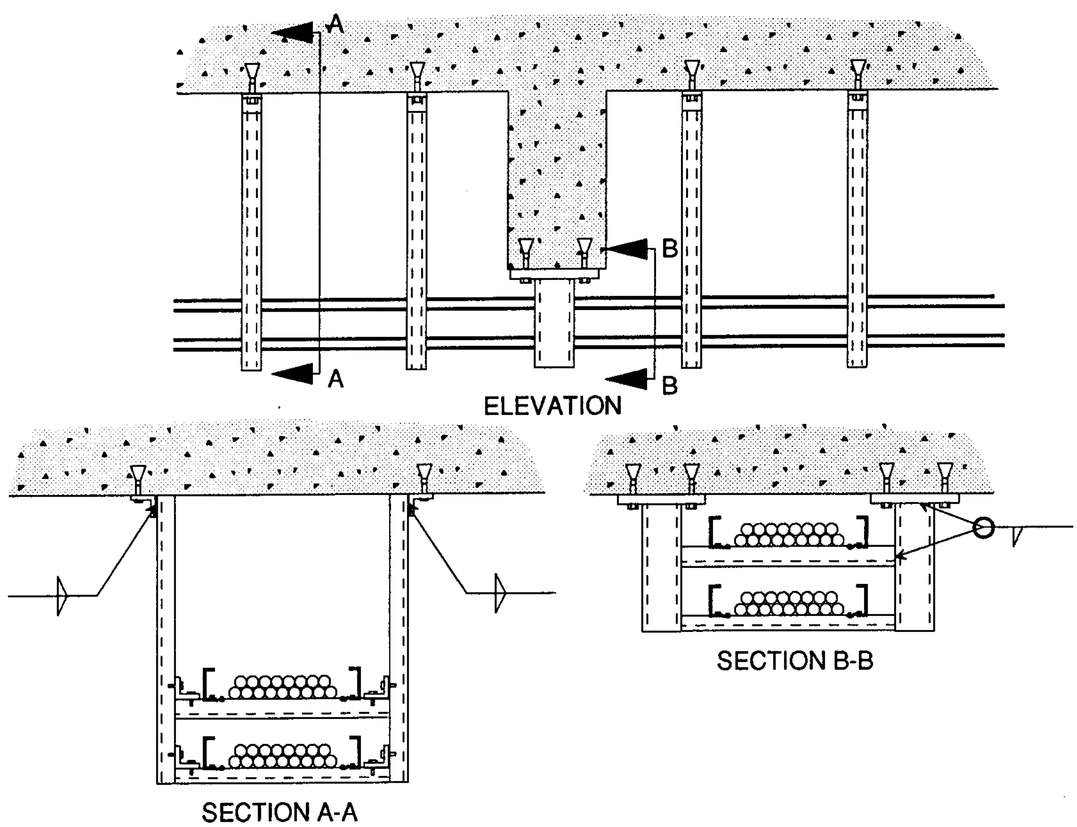


Figure 3-6. Short, stiff support in a system of longer, more flexible supports may attract considerable load due to longitudinal motion during an earthquake.

SECTION 4

LIMITED ANALYTICAL REVIEW GUIDELINES

A limited analytical review of cable tray and conduit supports should be performed. Analytical review calculations are conducted to check the structural integrity of the raceway supports chosen as a representative bounding sample of the plant raceway support systems. The limited analytical review guidelines 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. 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. Observations from the data base capacity back-calculations are summarized as follows:

1. Most of the raceway supports in the earthquake experience data base have adequate dead load design.

2. The data base raceway supports that are hung from above have high vertical load capacity of primary overhead connections and anchorage. Most have a vertical capacity greater than 3.0 times dead load (ignoring eccentricities); few have lower vertical capacities.

3. The majority of the data base raceway supports have no conventional lateral load-resisting structural system. This is especially true for supports hung from above. However, the support members and connections are in general very ductile, and because the supports are suspended, plastic hinge formation does not lead to instability. This ductility is considered to lead to a dampened, pendulum-like swaying response.

4. For the data base raceway supports with significant lateral load-resisting systems, most have a capacity equivalent to more than about 2.0g uniformly applied acceleration in the transverse direction. These back-calculated lateral load capacities only consider the failure mode of loss of primary overhead vertical

support. Bending of ductile members or buckling of diagonal braces is considered acceptable behavior so long as overhead support is maintained.

5. Data base raceway supports suspended from above or attached to a wall have negligible resistance to longitudinal load effects, and had no visible signs of damage or distress to the electrical cables or loss of primary vertical support integrity. Examples from the earthquake experience data base are summarized in Reference 8.

6. One example of a base-mounted post cable tray support system had very low calculated lateral and longitudinal load-resisting capacity, and collapsed.

7. Shake table tests of rod hanger trapeze raceway supports show that the seismic capacity is limited by the low-cycle fatigue life of the hanger rods. Component tests of threaded rods provide a well-defined basis for fatigue life acceptance criteria for rods with axial dead load stress up to about 6 ksi.

The checks of the analytical review guidelines are formulated to ensure that cable tray and conduit supports are seismically rugged, consistent with the above observations from the seismic experience success data. The checks include the use of static load coefficients, plastic behavior structural theory, and considerable engineering judgement based on an understanding of the intent of these guidelines.

The example evaluations of Section 5 provide conceptual guidance for the analytical review calculations for several typical raceway support configurations. The SSRAP report "Review Procedure to Assess Seismic Ruggedness of Cantilever Bracket Cable Tray Supports" (2) should be read by the raceway evaluation engineers as it provides considerable discussion and background information on the philosophy for the analytical review process.

The checks for the analytical review process are consistent with the observed back-calculated attributes of the seismic experience success data as summarized above. There are four basic checks in the analytical guidelines:

- Check 1: Dead Load
- Check 2: Vertical Capacity
- Check 3: Ductility Review
- Check 4: Lateral Loads

A logic diagram illustrating these checks is shown in Figure 4-1. This logic diagram is applicable only to the evaluation of suspended raceway supports, but the evaluation process for all support types is similar.

All raceway supports should pass a normal engineering dead load design review, to working stress level allowable loads. This is described in Section 4.1. 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. 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 guidelines of Sections 3.2.1 or 3.2.2, then the adjacent supports should be checked, with the support in question neglected.

All raceway supports except rigid-mounted conduit and cable trays should also pass a vertical capacity check of 3 times dead load. This is described in Section 4.2. The high vertical capacity is one of the primary design attributes that is given credit for good performance. The vertical capacity check ensures that the vertical capacity to dead load demand ratio is as least as high as those of support systems in the data base that performed well.

The ductility review check is described in Section 4.3. As shown in Figure 4-1, supports characterized as ductile and passing Checks 1 and 2 do not require further evaluation. Seismic ruggedness for ductile supports is ensured by the vertical capacity check (Section 4.2). The high vertical capacity of the ductile data base raceway supports is the main attribute credited for the good seismic performance.

Supports that may not respond to seismic loads in a ductile manner need to be checked for lateral load capacity, as described in Section 4.4. The lateral load check is in the form of an equivalent static lateral load. Because this static coefficient is derived from the earthquake experience data base, it is considered applicable to ground motion consistent with the Seismic Motion Bounding Spectrum (5). A method for scaling down the load coefficient for sites with lower ground motion response spectra is provided in Section 4.4.

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 4.4 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. Section 4.5 provides fatigue evaluation guidelines for rod hanger trapeze supports with fixed-end rods.

The checks described above and illustrated in the Figure 4-1 logic diagram directly apply only to seismic evaluation of suspended (and wall-mounted) raceway supports. Similar, 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 evaluation checks are discussed in Section 4.6. Ductility arguments may only be used if the support's base mount can be neglected (i.e., treating the support as if it were 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 needed.

Base-mounted support evaluation checks are discussed in Section 4.7. 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 need to 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 for base-mounted supports and need to be reviewed.

The analytical review guidelines are considered to provide, in general, a conservative means for screening evaluation of raceway supports. Isolated instances of outlier supports may be shown to be acceptable if there is adequate support system redundancy for the raceway run, and if there is no safety consequence associated with failure of the isolated support. The redundancy and consequence outlier evaluation method is described in Section 6.

If the supports fail to meet these limited analytical review guidelines, then they should be considered to be outliers. Further analyses or tests may be performed to demonstrate seismic ruggedness as follows.

Ductile supports not passing the vertical capacity check are outliers which can be resolved by a limit state evaluation. The simple vertical capacity check of Section 4.3 provides a quick, conservative means for ensuring 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 evaluation check for outliers, as described in Section 6, is that the support anchorage capacity need only be greater than the maximum reactions from plastic hinge formation in the support while also under dead load. This principle only applies to supports that are suspended from above and characterized as ductile following the guidelines of Section 4.2.

Isolated cases of a support outlier may be shown to be acceptable if the raceway support system has high redundancy, and if postulated support failure has no consequence to plant safety. "Isolated cases" and "high redundancy" are defined and discussed in Section 6. Evaluation of plant safety impact is also discussed in Section 6.

If supports of the worst-case sample selection do not meet the analytical checks (i.e., are outliers), then the review team should develop an understanding of what supports in the plant are impacted by the analysis results. It is not intended that the bounding sample be grossly expanded and that several calculations be generated if the analytical checks are not met.

For certain supports not meeting the analytical checks, strengthening measures may be warranted. Plant upgrades may consider retrofits using these analytical review guidelines as the starting point for design criteria, depending on existing plant procedures. New designs or retrofit designs may impose additional factors of safety, especially for anchorage, as the incremental added cost for larger anchor bolts is not significant but leads to significantly higher seismic margins.

The dead load design check uses normal design strengths and working stress level allowable loads. These are not discussed in detail herein. The vertical and lateral load checks consider realistic capacity estimates. Realistic capacities are discussed in Section 4.8. The raceway system weights for the analytical checks should be consistent with the weight estimates used for back-analysis of the data base support systems. These raceway system weights are described in Section 4.9. If alternate weights are used for the evaluations, the static coefficient values for analysis may need to be revised.

4.1 CHECK 1: DEAD LOAD

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 supports needs to 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. (Clip angle bending stress should be considered during evaluation of base connections of floor-mounted supports as discussed in Section 4.7. See the clip angles in the figure in Section 5.5.2.) 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 by past experience to be inherently rugged. The mounting configuration is generally rigid for lateral response, so dynamic amplification of seismic motion is minimal. The exercise of performing a detailed dead load design review for these support types ensures adequate margin for seismic loads.

The dead load design review checks that the rigid wall-mounted supports are seismically adequate. Also, consideration should be given to the seismic adequacy of the wall to which they are attached. Reinforced concrete structural walls are not a concern. With the exception of very light conduit, anchorage into transite walls and gypsum board partitions should be considered outliers. It should be checked if masonry walls have had seismic adequacy previously verified by other evaluation efforts. The anchor capacities in Reference 8 cannot be used for expansion anchors into masonry-block walls (especially if into hollow block cores or mortar joints) or nonstructural material. Reduced values should be used. The anchorage of partition walls should be checked.

4.2 CHECK 2: VERTICAL CAPACITY

The 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 shows that 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, submitting the support to 3.0 times dead load in the downward direction, considering capacities discussed in Section 4.8. The check is limited to the primary framing connections and the anchorage. This check does not include clip angle bending stress evaluations. Support members for suspended supports should not be checked. 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 (see Section 4.6).

Eccentricities resulting in anchor prying and eccentricities between vertical support members and anchor points should in general be ignored. This concept is important as this is the procedure used for back-calculation of the experience data base supports that form the basis for the 3.0 times dead load static coefficient.

For cantilever bracket support types, the eccentricity of the cantilevered dead load should be ignored. This concept, developed by SSRAP (2), is also the result of back-analyses of data base cable tray supports and is consistent with limit state conditions observed in test laboratories. 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 is only a calculation method used to demonstrate seismic ruggedness 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 Seismic Motion Bounding Spectrum (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. When overhead support is provided by light metal framing with anchor bolts spaced at relatively large intervals, and if multiple anchors are needed to resist the vertical load, then the bending strength of the frame member should be checked for transfer of the load between bolts.

For most conduit and cable tray support systems, the vertical capacity check is simply a comparison of anchor capacity to 3.0 times the supported load. Base-mounted supports are not subject to this check (see Section 4.7).

The 3.0 times dead load static coefficient should not be reduced if the site design basis earthquake ground motion response spectrum is less than the Seismic Motion Bounding Spectrum. This is because there are only a few data base supports with 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 6.

4.3 CHECK 3: DUCTILITY REVIEW

An evaluation should be conducted of the supports selected for review to characterize their response to lateral seismic motion as ductile or potentially non-ductile. Supports suspended from overhead (only) 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 non-ductile 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 base 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. Yielding of floor-mounted supports may cause instability and is not acceptable. (This is discussed further in Sections 4.6 and 4.7.)

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. The good performance of these support types indicates that they may be characterized as ductile. This is even true of supports constructed of gusseted clip angle connections, see Figure 4-2, C and D.

Back-analysis of many data base raceway supports predicts overstressed connection bolts due to prying action of standard catalog light metal strut framing gusseted clip angles during seismic motion. Their good seismic performance and lack of visible distress suggest that this analytical phenomenon does not occur. Review of raceway support system shake table tests 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.

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 follows. 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. If weld capacity can be exceeded, then a non-ductile failure is possible, which is not acceptable seismic performance.

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 capacity 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 fails in a ductile or non-ductile manner.

For unbraced raceway supports, examples of inherently ductile raceway support system anchorage types are shown in Figure 4-2. These include clip angles, standard catalog light metal strut framing gusseted clip angles, flexible base plates, and welds to overhead steel capable of developing the plastic moment capacity of the vertical members.

Properly detailed fillet welds may be considered capable of developing the plastic moment capacity of open channel sections typically used in raceway support construction. 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 (9). For light metal strut framing members with incomplete welded connections, like that in Figure 4-3, A and B, are likely to be non-ductile and thus not capable of developing plastic moment capacity of the framing member.

The ductility review of anchorage connection details is most important for rigid-type 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.

Certain past raceway support member seismic designs in nuclear plants may have been controlled by high frequency requirements rather than loads, yet anchors may have been sized by loads. These supports may have low seismic margin due to loads placed on the support that were not considered by the original design. Supports with rigid, non-ductile anchorage are subject to further horizontal load strength review (see Section 4.4). Examples of non-ductile supports are shown in Figure 4-3.

Certain raceway support configurations may lead to non-ductile behavior even if the anchorage connection details are of the ductile type. Examples of potentially non-ductile raceway support system configurations include the following:

- Braced Cantilever Bracket and Trapeze Frame Supports. The presence of a diagonal brace in a support has the potential of significantly increasing the pullout loads on anchorage when the support is subject to horizontal motion. This is a function of the support geometric configuration, brace realistic capacity, and anchorage realistic capacity. Non-ductile behavior is possible when the brace reaction to horizontal load plus dead load has the capability of exceeding the primary support anchor capacity. If a brace may buckle or have 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, with focus on primary support anchorage (Section 4.4).

- 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, 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 plus dead load exceed the anchor capacity.

Unbraced rigid trapeze frames are subject to further horizontal load strength review, with focus on anchorage (Section 4.4).

- 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, with focus on stability (Sections 4.6 and 4.7).

- 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 are subject to further evaluation, with focus on low cycle fatigue effects (Section 4.5).

No further review of horizontal response capability is required for supports characterized as ductile. If a support is characterized as non-ductile or has questionable ductility, then its lateral load capacity should be verified as discussed in Section 4.4.

4.4 CHECK 4: LATERAL LOAD

A lateral load capacity check should be performed for the bounding case raceway supports that are characterized as potentially non-ductile. The lateral load capacity check is in the form of an equivalent static lateral load coefficient.

The horizontal capacity check ensures that the horizontal load capacity to dead load demand ratio, for potentially non-ductile supports, is at least higher than the lower ratios for support systems in the seismic experience data base that performed well. Because the earthquake ground motion that many of these data base raceway systems were subject to may be greater than that of specific plant site earthquakes, provisions for scaling down the equivalent static horizontal loads are given.

If a support is ductile, then no further review of horizontal response capability is required and the support is shown to be seismically rugged by solely the vertical capacity evaluation. 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 acceleration may be scaled down linearly by the minimum ratio of site design basis earthquake ground motion spectral acceleration divided by the corresponding spectral acceleration of the Seismic Motion Bounding Spectrum (0.33g, 5).
- Dead load plus a transverse acceleration of 2.5 times the floor spectral zero period acceleration (ZPA) for the plant area being assessed.
- For elevations less than about 40 feet above plant grade, dead load plus a transverse acceleration of 2.5 times the floor spectral ZPA obtained as follows:

$$\text{Free-field ground ZPA} \times 1.5 \times 1.25$$

For these loading conditions, only the tributary mass corresponding to dead load on the support should be considered.

The loading condition selected should be used consistently for all the plant raceway support systems selected as samples in any building. Different methods may be used for different structures. For example, the floor spectra 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 example, 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 calculated capacities in many instances correspond to supports with long drops from the ceiling and were not considered representative (i.e., were not used 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 the single-degree-of-freedom pendulum response of the support.

For diagonally braced supports with ductile overhead anchorages, 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 lateral load should be used for evaluation 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 may be transferred as a bending moment to the overhead connection. In addition, note that loads in the diagonal brace will cause additional vertical and horizontal loads at the anchorage, which must 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 4.8 should be considered for these connection types.

4.5 ROD HANGER FATIGUE EVALUATIONS

Rod hanger trapeze supports should be evaluated for possible low cycle fatigue effects if they are constructed with fixed-end connection details. Fixed-end connection details include double-nutted rod ends at the connection to flanges of steel members, rods threaded into shell-type concrete expansion anchors, and rods connected by rod coupler nuts to non-shell concrete expansion anchors. Fixed-end connection details also include rods with lock nuts at cast-in-place light metal strut framing channel sections and rod coupler nuts welded to overhead steel.

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. Reference 10 provides generic, bounding case fatigue evaluations.

The results are summarized by rod fatigue screening charts corresponding to rod fatigue bounding spectra. The rod fatigue bounding spectra are shown in Figure 4-4, and the generic rod fatigue evaluation screening charts are shown in Figures 4-5 to 4-9.

The screening charts are only 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 cases of short, isolated, fixed-end rod hangers in more flexible systems with much longer rod hangers, by using adjusted parameters when using the screening charts.

Rod hanger trapeze supports with uniform length short, fixed-end rods are subject to a fatigue evaluation. The fatigue evaluation for short, fixed-end rod hangers, in raceway runs with rods of uniform length, proceeds as follows:

- Obtain the 5% damped floor response spectrum for the location of the support.
- Select a Rod Fatigue Spectrum that envelopes the floor response spectrum. Rod Fatigue Spectra anchored to 0.33g, 0.50g, and 0.75g are shown in Figure 4-4. If the Rod Fatigue Spectrum does not entirely envelop the floor response spectrum, then select a Rod Fatigue Spectrum that envelopes the floor response spectrum at the frequency of the support. Support frequency may be estimated as follows:

$$f_{support} = \frac{(K_S/M_S)^{\frac{1}{2}}}{2\pi}$$

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

- Obtain the rod fatigue screening chart associated with the selected Rod Fatigue Bounding Spectrum. Rod fatigue screening charts associated with 0.33g, 0.50g, and 0.75g Rod Fatigue Bounding Spectra are shown in Figures 4-5 to 4-9 for 1/4-inch to 3/4-inch diameter rods, respectively. 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 support, for both

rods) with acceptable combinations of length and weight on the screening charts.

If the support parameters are in acceptable regions on the screening chart, then the rod hanger support is seismically rugged. The screening charts also include the weight limit associated with Check 3, the 3.0 times dead load vertical capacity check for anchorage. For rods attached to expansion anchors (only) this may be used for anchorage evaluation. If the anchors do not pass this screening check, then the support is an outlier and a more detailed limit state evaluation may be performed (Section 6).

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 as manufacturer rods, except that adjusted weights and lengths must be used for comparison with the acceptance screening chart. For field threaded rods, when entering the screening chart, use double the actual weight and two-thirds the actual length of the rods. If these modified parameters are in acceptable regions on the screening charts, then the rod hanger is seismically rugged.

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

- Estimate the frequency of the system, neglecting the isolated, short rod. The frequency estimation formula given above may be used, providing that the length of the predominant longer rods is considered.
- Obtain the applicable rod fatigue screening chart that corresponds to a rod fatigue bounding spectrum that envelopes the plant floor response spectrum (5% damping) at this frequency of interest.
- Back-calculate an equivalent weight for evaluation of the isolated short rod hanger, considering the frequency of the predominant longer rod hanger supports, by the following formula:

$$W_{equiv.} = \frac{24EIg}{(2\pi f)^2 L^3 - gL^2}$$

- Enter the screening chart by using this equivalent weight and the length of the isolated short rod hangers.

If these parameters are in acceptable regions on the screening chart, then the rod hanger is seismically rugged.

Reference 11 should be reviewed to obtain an understanding of the analytical methods used to develop the rod fatigue evaluation screening charts. When using the charts, the simple equations used to approximate response frequency should be followed. These are the same equations used to generate the screening charts and should be used for consistency.

4.6 FLOOR-TO-CEILING SUPPORT EVALUATIONS

Floor-to-ceiling supports may be evaluated as suspended raceway supports if they can meet the evaluation checks by neglecting the floor connection and anchorage. This is a conservative evaluation method. Seismic ruggedness for floor-to-ceiling supports that depend on the floor connection may be evaluated as follows. The checks ensure seismic ruggedness by maintaining high vertical capacity, demonstrating ductility, and maintaining 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 4.4. 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 do not have to be checked for lateral loading. (The entire support should be checked for dead load design as described in Section 4.1.)

4.7 BASE-MOUNTED SUPPORT EVALUATIONS

Base-mounted supports present a different case than suspended supports. With large lateral deflections and inelastic response effects, the base-mounted supports tend to become unstable where the suspended supports have increased pendulum restoring force. The recommended checks include a detailed dead load design review and lateral load checks nonconcurrently in both orthogonal directions, including P-delta effects if base hardware slip may be anticipated.

The Reference 2 SSRAP report provides considerable discussion on the philosophy of the base-mounted support evaluations.

A detailed, dead load design review should be performed, similar to the check described in Section 4.1. The only exception is that clip angle bending stresses should be evaluated for base connections. Base flexibility associated with clip angle inelastic behavior may lead to increased deflection and subsequent P-delta effects and possibly instability.

A vertical capacity check should not be conducted as 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, for loading nonconcurrently in both orthogonal directions.

The equivalent static lateral load should be determined by following the applicable rules of Section 4.4. 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 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 mean/3 capacities are used for concrete 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 neglecting 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 P-delta effect 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 evaluation.

Torsional moments at the base of the support post that may result from lateral or longitudinal load checks may be ignored. Stresses in the cantilevered support brackets due to longitudinal loading may also be ignored. These forces resulting from the 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.

4.8 ALLOWABLE CAPACITIES

Capacity values for expansion anchors are defined in the EPRI report *Seismic Anchorage Guidelines for Nuclear Plant Equipment* (8). The provisions of these anchorage guidelines should be followed, including edge distance, bolt spacing, and inspection procedures, except that for overhead-mounted supports, tightness checks need not be conducted for bolts resisting tensile force due to dead load. This provision is waived because suspended raceway systems subject anchorages to constant tension under dead load and therefore effectively proof-test the anchor set. The tightness checks should be carried out for floor-mounted support anchors. Ordinarily, the walkdown team should use mean/4 expansion anchor capacity values since this means the concrete does not have to be inspected in close detail for cracks. Mean/3 capacity values can be used if a close inspection reveals cracks in the concrete are not larger than about 10 mils (8).

Capacities for other anchor types, such as cast-in-place anchors or embedded plates, should be estimated by factored ultimate strength design calculations following *ACI Standard 349* (11). The plant design or as-built drawings for cast-in-place anchors and steel plates should be reviewed to obtain details on these anchorage types. Cast-in-place light metal strut framing channel anchor capacities should be considered as the manufacturer's catalog values with published factors of safety, or may be determined by available test information with appropriate factors of safety, or may be calculated as in Reference 11.

Capacities for welds, structural steel, and steel bolts should be taken as defined in Part 2 of the *AISC Specification for Steel Design* (12). Light metal strut framing hardware capacity values are defined 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 outlier evaluations (Section 6), the manufacturer catalog capacities should be increased. A recommended upper bound estimate for bolts with channel nuts is double the manufacturer published design values.

Tests to determine ultimate capacities of raceway components, with appropriate factors of safety, are an acceptable basis for establishing realistic capacity estimates.

4.9 RACEWAY SYSTEM WEIGHTS

Weight estimation for cable trays may be taken as 25 pounds per square foot for a standard tray with 4 inches of cable fill. Wherever possible, it may be advantageous to consider the cable trays as completely full as a first try screening evaluation. Linear adjustment may be made for trays with more and less cable fill. Sprayed on fireproof insulation may be conservatively considered to have the same unit weight as cable fill.

Weight estimation for steel and aluminum conduit may be taken as given in the following table:

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

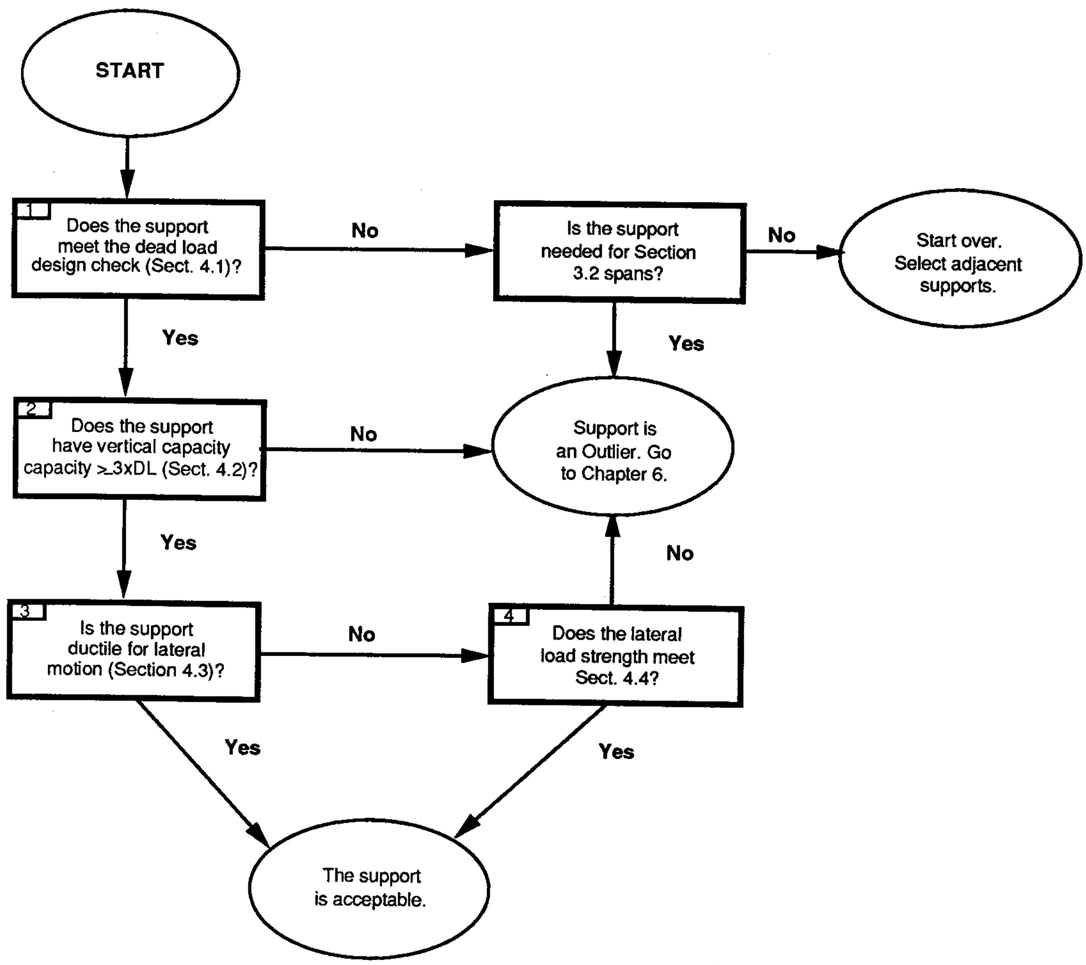


Figure 4-1. Flow diagram illustrating the checks used in the limited analytical review process to demonstrate seismic ruggedness. Note that this diagram is not applicable to floor-mounted supports.

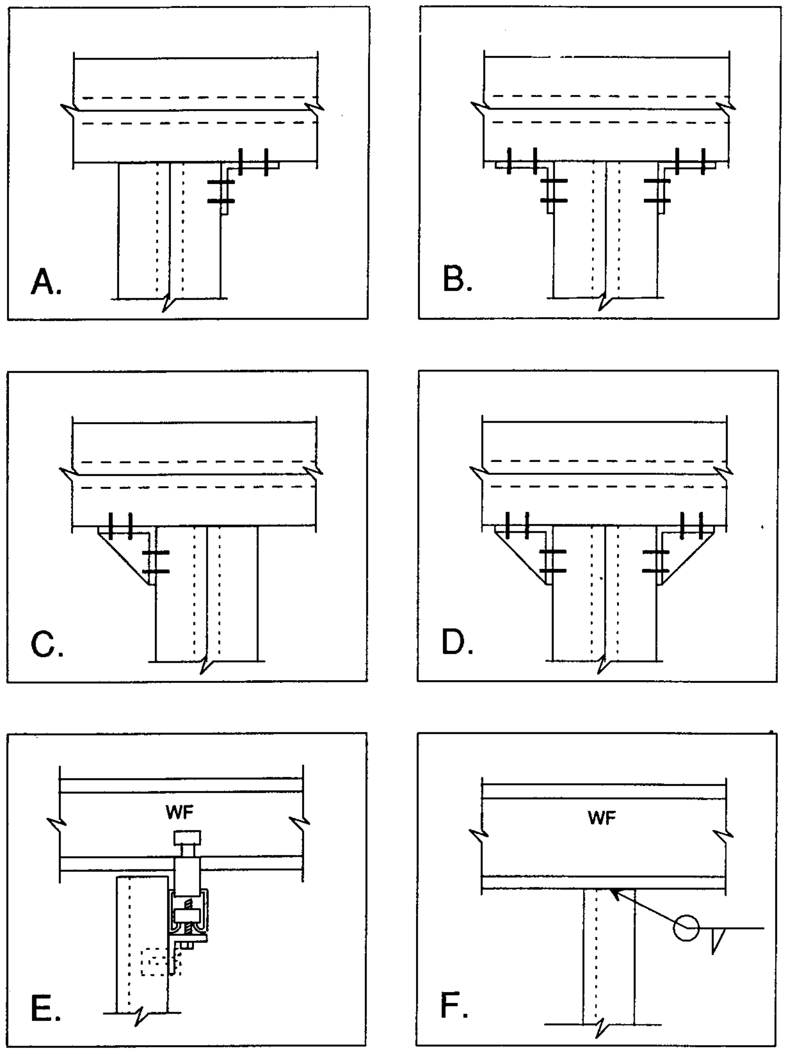


Figure 4-2. Examples of raceway support ductile connection details. A, B, C, and D are ductile connections of standard catalog light metal strut framing systems. E is a properly oriented beam clamp, configured as a pin-ended connection. Pin-ended connections are considered ductile. F is an all-around 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 are not considered ductile.

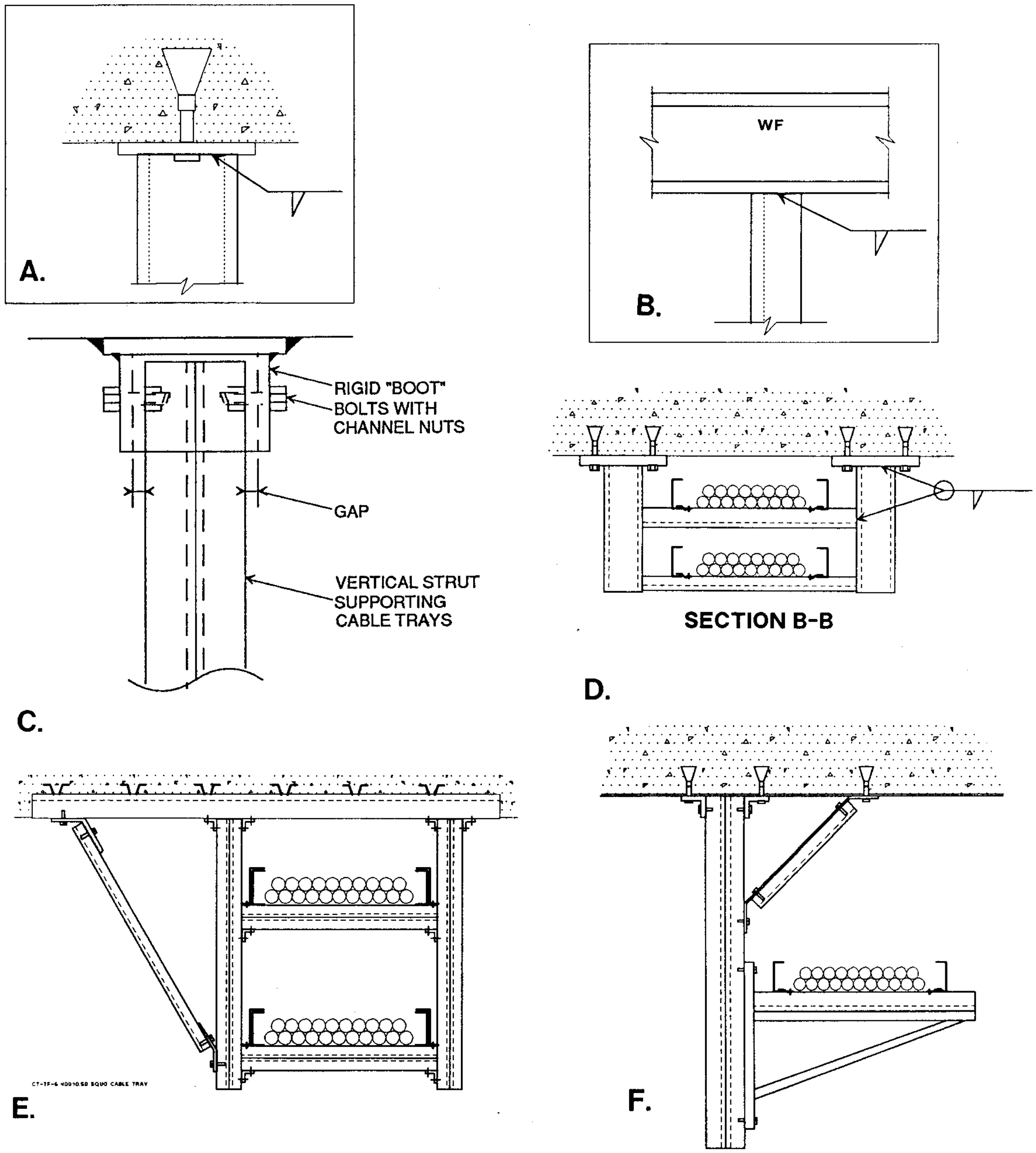


Figure 4-3. Examples of potentially non-ductile connection details and configurations. A and B are partially welded connection details. Partial welds cannot develop the plastic moment capacity of the vertical member, and are considered non-ductile. C is the non-ductile rigid boot connection. D is a rigid moment-resisting frame and should be checked for horizontal load. E and F are diagonally braced and should be checked for horizontal load.

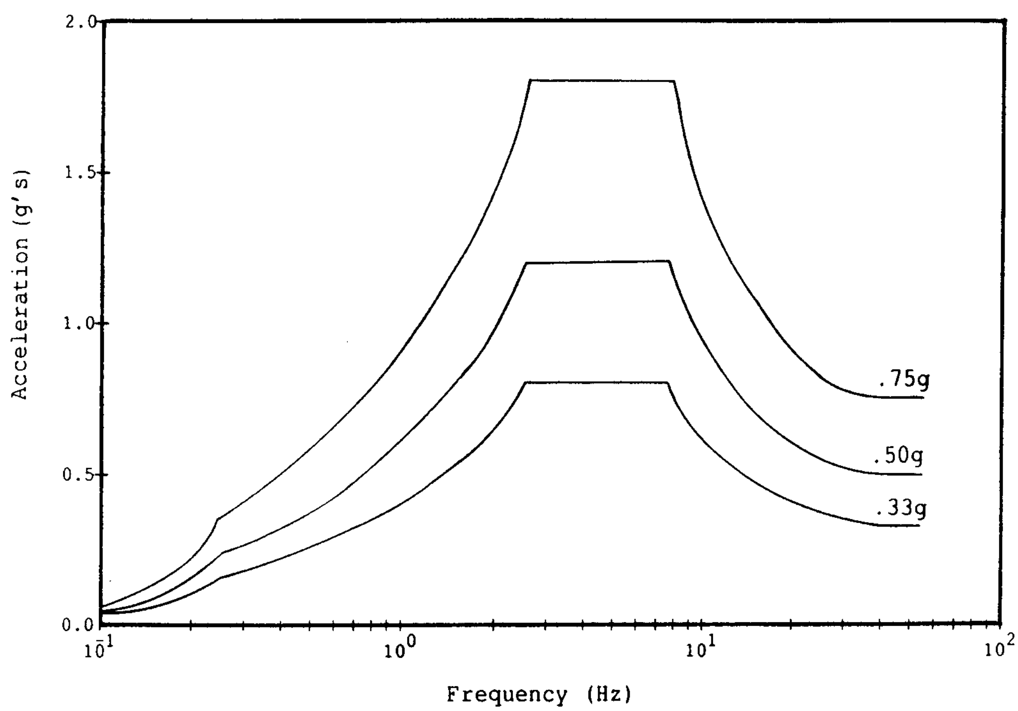
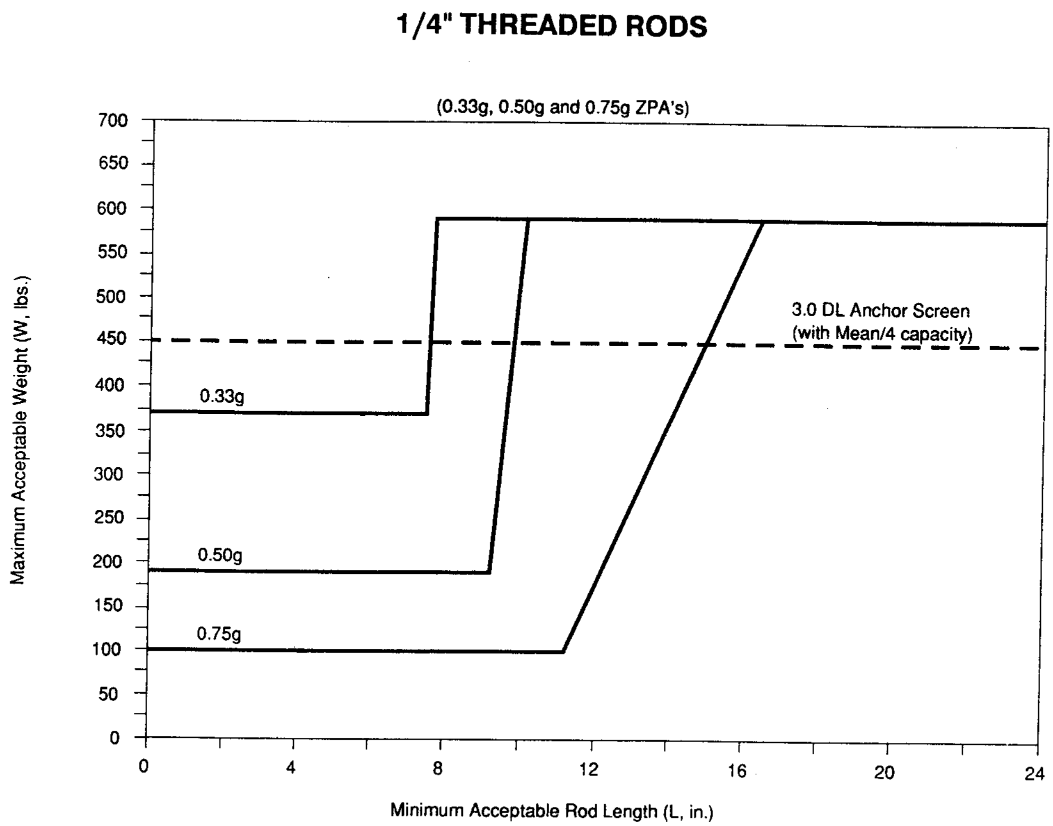


Figure 4-4. Rod fatigue bounding spectra anchored to 0.33g, 0.50g, and 0.75g.

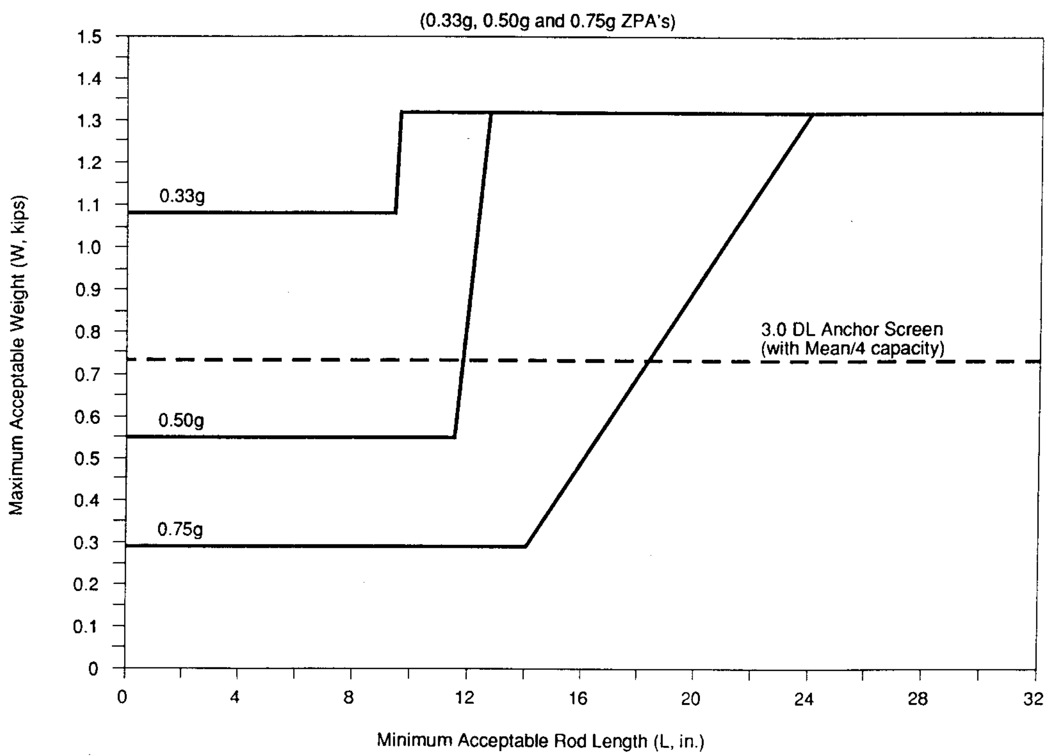


Note: W corresponds to total dead load on the support (i.e., carried by both rods).

L corresponds to the clear length above the top tier.

Figure 4-5. Fatigue evaluation screening chart for 1/4-inch diameter manufactured all-thread rods.

3/8" THREADED RODS

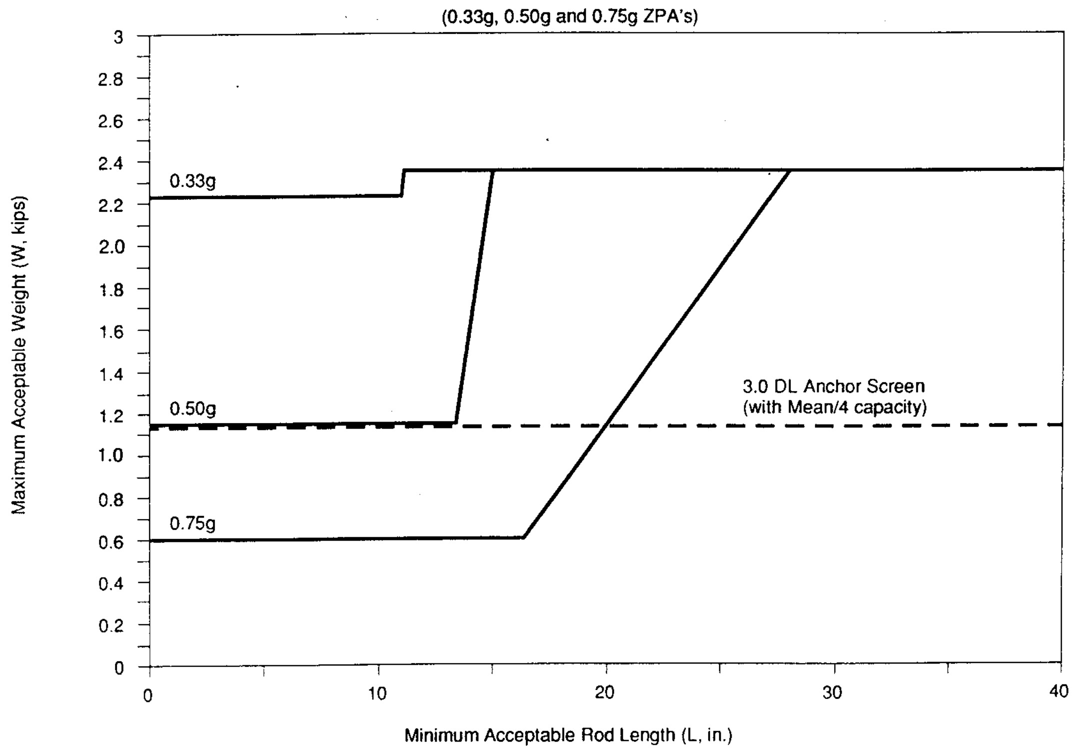


Note: W corresponds to total dead load on the support (i.e., carried by both rods).

L corresponds to the clear length above the top tier.

Figure 4-6. Fatigue evaluation screening chart for 3/8-inch diameter manufactured all-thread rods.

1/2" THREADED RODS



Note: W corresponds to total dead load on the support (i.e., carried by both rods).

L corresponds to the clear length above the top tier.

Figure 4-7. Fatigue evaluation screening chart for 1/2-inch diameter manufactured all-thread rods.

5/8" THREADED RODS

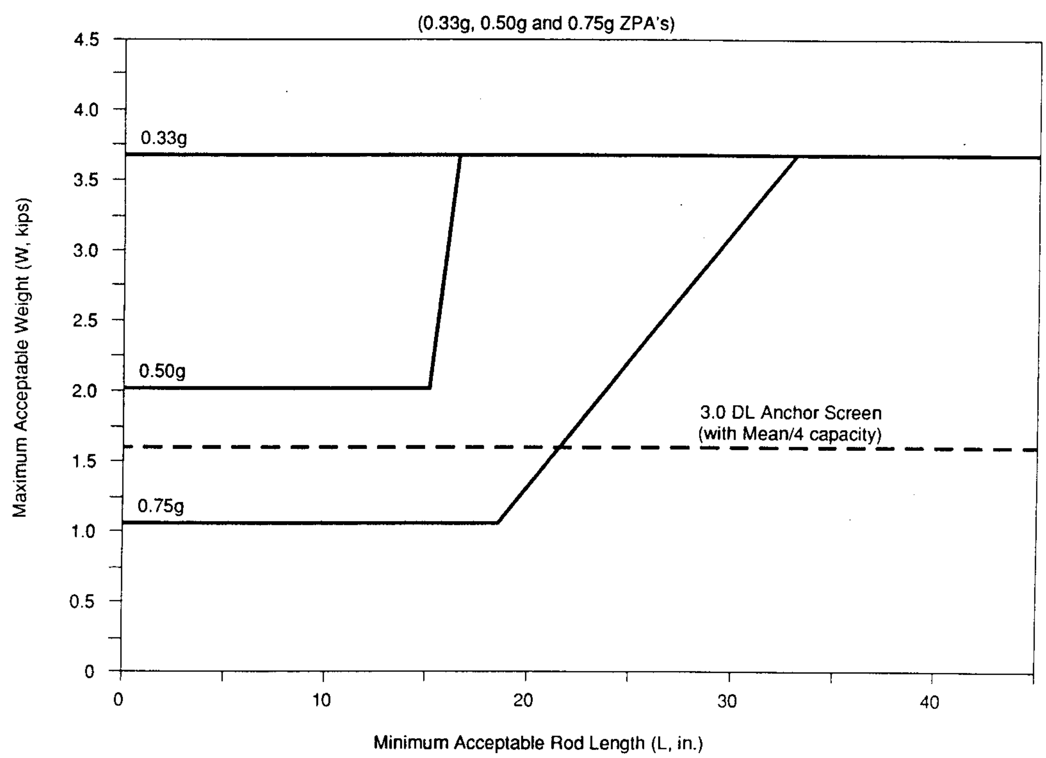
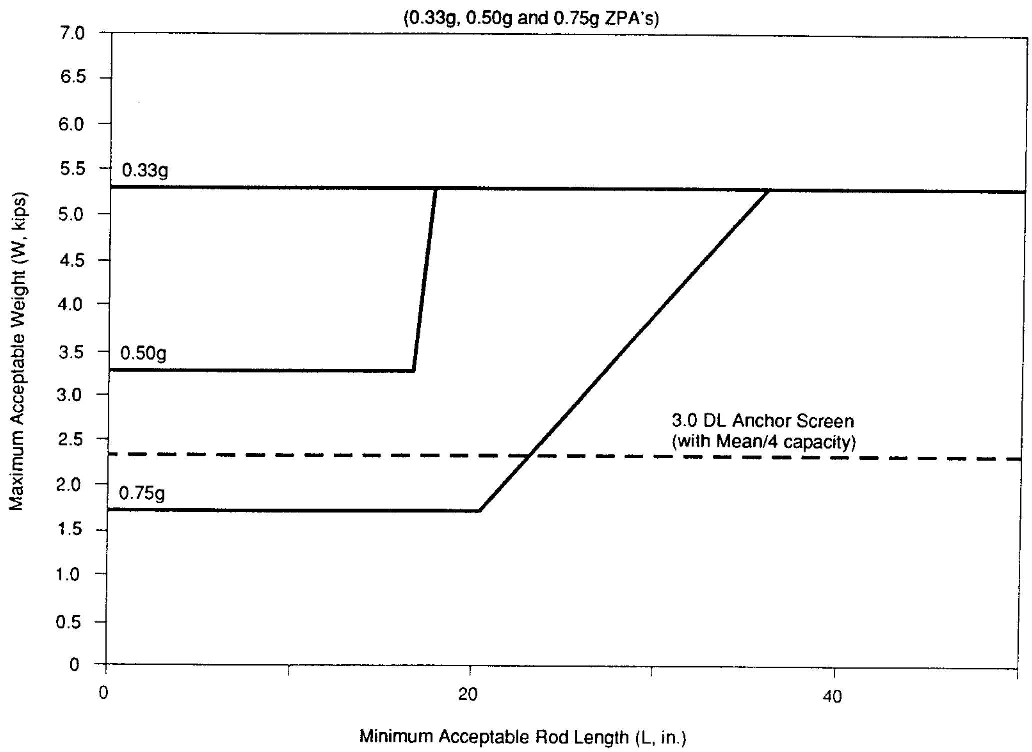


Figure 4-8. Fatigue evaluation screening chart for 5/8-inch diameter manufactured all-thread rods.

3/4" THREADED RODS



Note: W corresponds to total dead load on the support (i.e., carried by both rods).

L corresponds to the clear length above the top tier.

Figure 4-9. Fatigue evaluation screening chart for 3/4-inch diameter manufactured all-thread rods.

SECTION 5

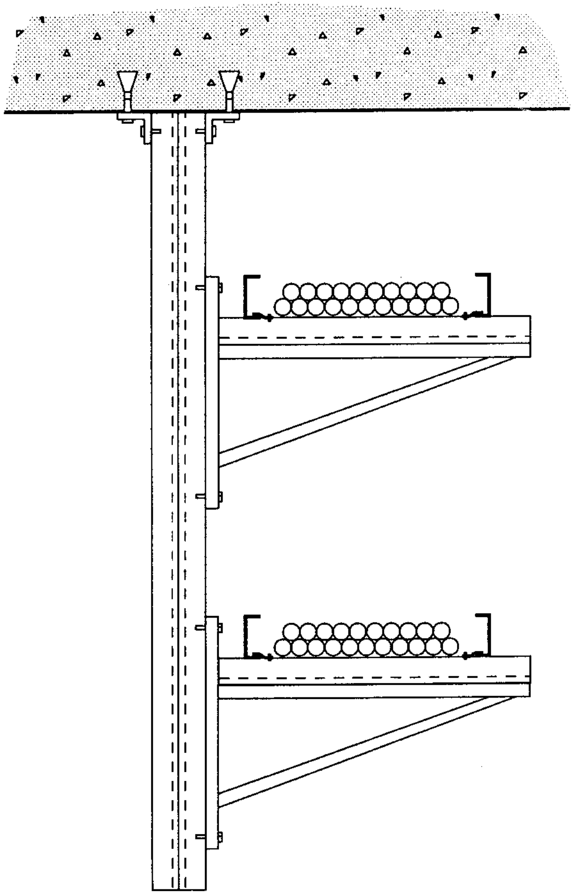
EXAMPLE EVALUATIONS

The following sections provide example limited analytical review seismic ruggedness evaluations for cantilever bracket (Section 5.1), trapeze frame (Section 5.2), rigid-mounted (Section 5.3), and rod hanger trapeze (Section 5.4) cable tray and conduit supports. Example evaluations for floor-mounted supports are in Section 5.5. Seismic Capability Engineers should review these examples and understand the intent of the limited analytical reviews, and understand application of the principle to other similar raceway supports. In the following, note that satisfying Check 3 means that Checks 3.1, 3.2, etc., are satisfied. For example, in Example 5.1.1 satisfying Check 4 means that Checks 4.1 and 4.2 are satisfied.

In these example evaluations, appropriate and acceptable outlier resolution methods as discussed in Section 6 are also presented. Refer to Section 6 for details. The examples do not provide all acceptable methods for outlier resolution (e.g., the redundancy and consequence test of Section 6.9 is not presented in the example evaluations).

5.1 EXAMPLE CANTILEVER BRACKET RACEWAY SUPPORT EVALUATIONS

5.1.1 Cantilever Bracket Support Example 1



Check 1: Dead Load

1.1 Check the support for 1.0 Dead Load, including load eccentricity of the cable trays and using working stress allowable loads.

This check includes all support members and connections. Clip angle bending stress need not be checked.

Check 2: Vertical Capacity

2.1 Check the overhead expansion anchors for 3.0 Dead Load, ignoring load eccentricity of the cable trays.

2.2 Check the bolts at the top connection for 3.0 Dead Load, ignoring eccentricity of the cable trays.

Check 3: Ductility Review

3.1 This support may be considered as inherently ductile. Lateral loading leads to bending of clip angles and slight slip of the bolts with channel nuts.

Check 4: Lateral Load

4.1 Check the overhead expansion anchors for 1.0 Dead Load plus reaction from equivalent static lateral load.

4.2 Check the bolts at the top connection for 1.0 Dead Load, plus reaction from equivalent static lateral load.

5.1.1 Cantilever Bracket Support Example 1 (cont.)

Check 5: Limit State

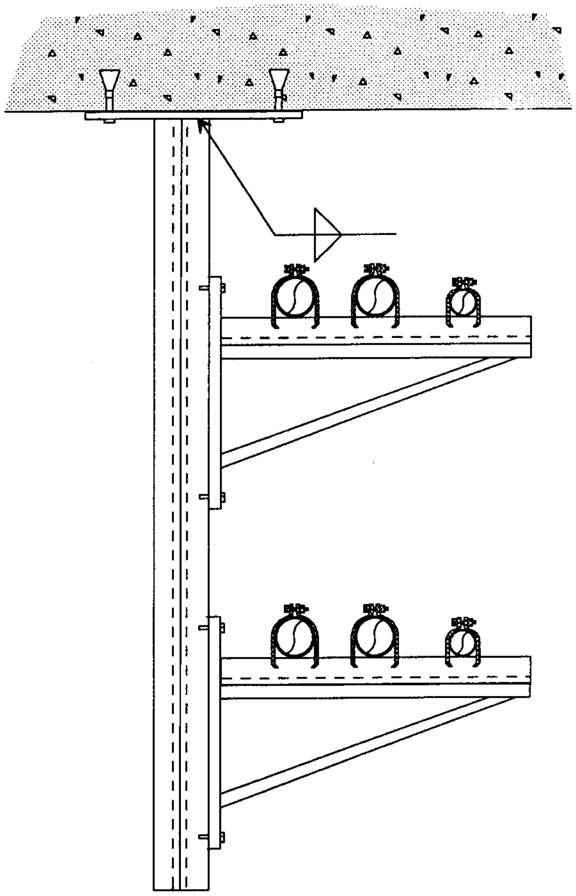
5.1 Check the overhead expansion anchors for 1.0 Dead Load, plus reaction from the lesser of the plastic hinge moment capacities of the vertical member or dual clip angle connections.

The support is seismically rugged if Checks 1 and 2 and 3 is satisfied.

If the support does not pass these checks, it is an outlier. Resolution of this outlier may be achieved if one of the following combination of checks is satisfied:

- Checks 1 and 4
- Checks 1 and 3 and 5

5.1.2 Cantilever Bracket Support Example 2



Check 1: Dead Load

1.1 Check all support members and connections for 1.0 Dead Load, including load eccentricity of the conduit and using working stress allowable loads.

Check 2: Vertical Capacity

2.1 Check the overhead expansion anchors for 3.0 Dead Load, ignoring load eccentricity of the conduit.

2.2 Check the top welded connection for 3.0 Dead Load, ignoring load eccentricity of the conduit.

Check 3: Ductility Review

3.1 This support may be considered as ductile if the expansion anchors and welded connection capacities are large enough to enable plastic hinge formation in ductile support members for lateral loading.

3.2 Check if the expansion anchors can develop the lesser of the plastic moment capacities of the vertical member or the ceiling connection plate.

3.3 Check if the top welded connection can develop the plastic moment capacity of the vertical member.

Check 4: Lateral Load

4.1 Check the overhead expansion anchors for 1.0 Dead Load, plus equivalent static lateral load.

5.1.2 Cantilever Bracket Support Example 2 (cont.)

4.2 Check the overhead weld for 1.0 Dead Load, plus equivalent static lateral load.

Check 5: Limit State

5.1 Check the overhead expansion anchors for 1.0 Dead Load, plus the reaction from the lesser of the plastic hinge moments of the vertical member or the ceiling connection plate.

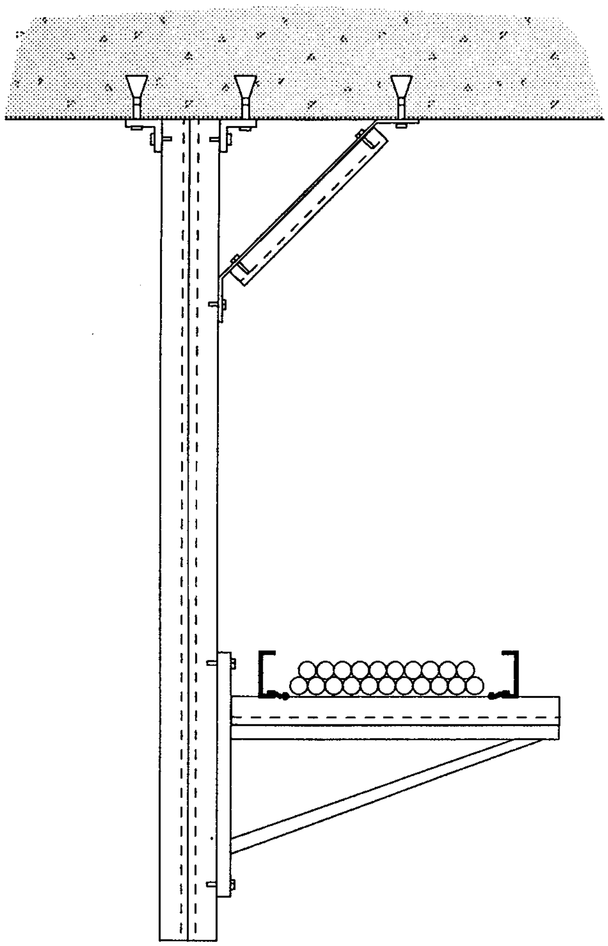
The support is seismically rugged if one of the following combinations of checks is satisfied:

- Checks 1 and 2 and 3
- Checks 1 and 2 and 4

If the support does not pass these checks, it is an outlier. Resolution of this outlier may be achieved if one of the following combination of checks is satisfied:

- Checks 1 and 3 and 5
- Checks 1 and 4

5.1.3 Cantilever Bracket Support Example 3



Check 1: Dead Load

1.1 Check all support members and connections for 1.0 Dead Load, including load eccentricity of the cable tray and using working stress allowable loads.

Check 2: Vertical Capacity

2.1 Check the vertical support member overhead expansion anchors for 3.0 Dead Load, ignoring load eccentricity of the cable tray. The anchor bolt of the brace should not be included.

2.2 Check the bolts at the vertical member overhead connection for 3.0 Dead Load, ignoring load eccentricity of the cable tray.

Check 3: Ductility Review

3.1 This support may be considered as ductile if the bolts at the top connection and vertical member's expansion anchor capacities each exceed the reaction from 1.0 Dead Load, plus the vertical component of the compressive load capacity of the diagonal brace and its connections. If so, it is similar to the support of example 5.1.1 and will exhibit ductile response characteristics after brace "failure." It may then be evaluated as the support of example 5.1.1.

5.1.3 Cantilever Bracket Support Example 3 (cont.)

Check 4: Lateral Load

4.1 Check the overhead expansion anchors, the top connection bolts, and the brace and its connections for 1.0 Dead Load, plus equivalent static lateral load.

Check 5: Limit State

5.1 Check the vertical support member's overhead expansion anchors for 1.0 Dead Load, plus the reaction from the brace compressive load capacity. Limit the brace capacity to the lesser of the brace critical buckling load or lowest brace connection capacity.

The support is seismically rugged if one of the following combinations of checks is satisfied:

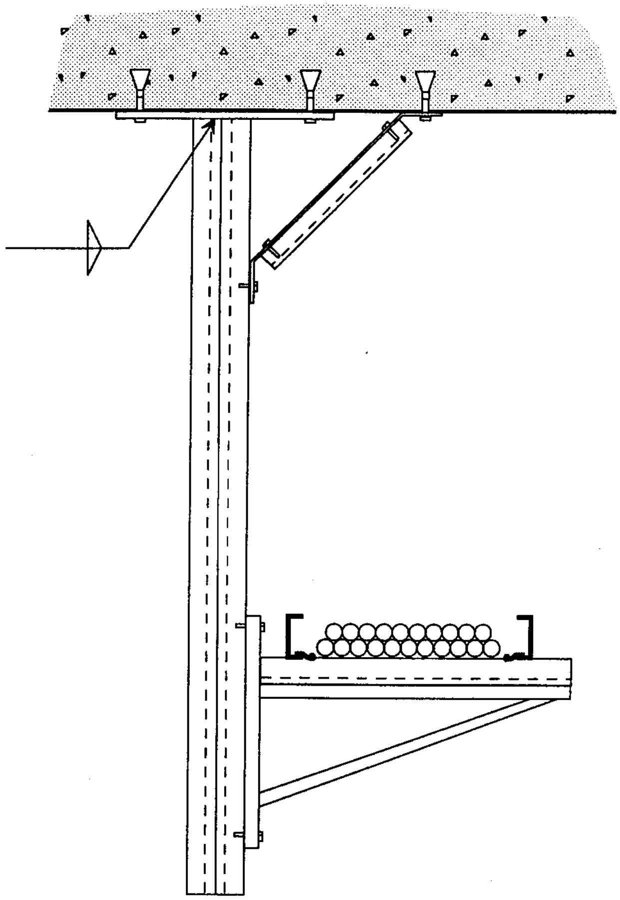
- Checks 1 and 2 and 3
- Checks 1 and 2 and 4

An alternate approach for verification of seismic ruggedness of this support is to consider plastic hinge formation in the vertical support member, located just below the connection of the diagonal brace to the vertical member. In this approach, if the primary overhead connections, anchors, and the brace and its connections are strong enough to allow plastic hinge formation in the vertical member, the support may be considered as ductile. This check should follow Check 2.

If the support does not pass these checks, it is an outlier. Resolution of this outlier may be achieved if one of the following combination of checks is satisfied:

- Checks 1 and 3 and 5
- Checks 1 and 4

5.1.4 Cantilever Bracket Support Example 4



Check 1: Dead Load

1.1 Check all support members and connections for 1.0 Dead Load, including load eccentricity of the cable tray and using working stress allowable loads.

Check 2: Vertical Capacity

2.1 Check the vertical support member overhead expansion anchors for 3.0 Dead Load, ignoring load eccentricity of the cable tray. The expansion anchor of the brace should not be included.

2.2 Check the top welded connection for 3.0 Dead Load, ignoring load eccentricity of the cable tray.

Check 3: Ductility Review

3.1 This support may be considered as ductile if the top welded connection and the vertical member's expansion anchor capacities each exceed the reaction from dead load, plus the vertical component of the compressive load capacity of the diagonal brace and its connections, and if the support with the brace neglected meets the ductility review as follows in Checks 3.2 and 3.3.

If so, it may be shown to exhibit ductile response characteristics after brace "failure," similar to the support of example 5.1.2.

3.2 With the brace neglected, check if the expansion anchors can develop the lesser of the plastic moment capacities of the vertical member or the ceiling connection plate.

3.3 With the brace neglected, check if the top welded connection can develop the plastic moment capacity of the vertical member. (This may be difficult where the vertical member is light metal strut framing.)

Check 4: Lateral Load

4.1 Check the expansion anchors, the overhead weld, and the brace connections for 1.0 Dead Load, plus equivalent static lateral load.

Check 5: Limit State

5.1 Check the vertical member's overhead expansion anchors for 1.0 Dead Load, plus the reaction from the brace compressive load capacity (limit the brace capacity to the lesser of the brace critical buckling load or lowest brace connection capacity), plus the reaction from the lesser of the plastic hinge moments of the vertical member or the ceiling connection plate.

The support is seismically rugged if one of the following combinations of checks is satisfied:

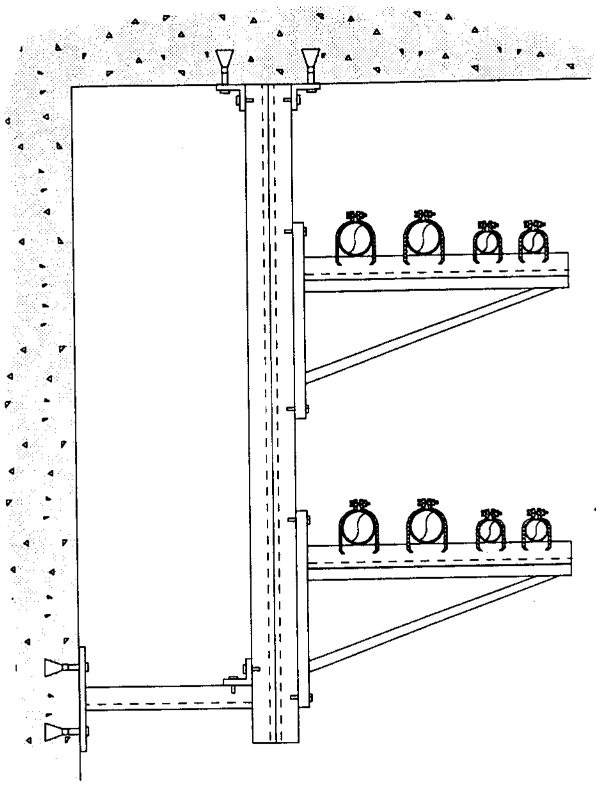
- Checks 1 and 2 and 3
- Checks 1 and 2 and 4

An alternative approach for verification of seismic ruggedness of this support is to consider plastic hinge formation in the vertical support member, located just below the connection of the diagonal brace to the vertical member. In this approach, if the primary overhead connections, anchors, and the brace and its connections are strong enough to allow plastic hinge formation in the vertical member, the support may be considered as ductile. This check should follow Check 2.

If the support does not pass these checks, it is an outlier. Resolution of this outlier may be achieved if one of the following combination of checks is satisfied:

- Checks 1 and 3 and 5
- Checks 1 and 4

5.1.5 Cantilever Bracket Support Example 5



Check 1: Dead Load

1.1 Check all support members and connections for 1.0 Dead Load, including load eccentricity of the conduit and using working stress allowable loads.

Check 2: Vertical Capacity

2.1 Check the overhead expansion anchors for 3.0 Dead Load, ignoring load eccentricity of the conduit.

2.2 Check the bolts at the top connection for 3.0 Dead Load, ignoring load eccentricity of the conduit.

Check 3: Ductility Review

3.1 This support may be considered as inherently ductile. If the horizontal strut or its connections fail under lateral loads, the support will be in a ductile configuration similar to the support of example 5.1.1.

Check 4: Lateral Load

4.1 Check the overhead expansion anchors for 1.0 Dead Load, plus reaction from the equivalent static lateral load.

4.2 Check the bolts at the top connection for 1.0 Dead Load, plus reaction from equivalent static lateral load.

4.3 Check the horizontal brace, its connections, and its expansion anchor bolts for reaction from equivalent static lateral loads.

5.1.5 Cantilever Bracket Support Example 5 (cont.)

Check 5: Limit State

5.1 Neglect the horizontal brace and check the overhead expansion anchors for 1.0 Dead Load, plus reaction from the lesser of the plastic hinge moment capacities of the vertical member or dual clip angle connection.

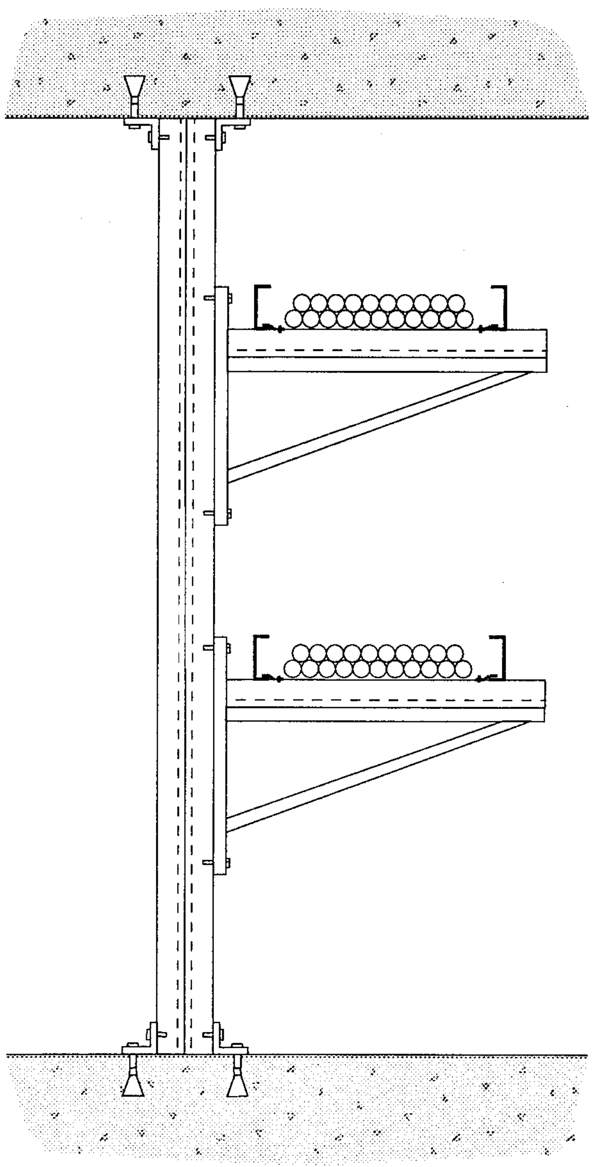
The support is seismically rugged if one of the following combinations of checks is satisfied:

- Checks 1 and 2 and 3
- Checks 1 and 2 and 4

If the support does not pass these checks, it is an outlier. Resolution of this outlier may be achieved if one of the following combination of checks is satisfied:

- Checks 1 and 3 and 5
- Checks 1 and 4

5.1.6 Cantilever Bracket Support Example 6



Check 1: Dead Load

1.1 Check all support members and connections for 1.0 Dead Load, including load eccentricity of the cable tray and using working stress allowable loads.

Check 2: Vertical Capacity

2.1 Check the overhead expansion anchor bolts and top connection bolts for 3.0 Dead Load, assuming all the loads are resisted at the top connection. Ignore load eccentricity of the cable trays.

2.2 If the overhead anchors and the top connection can resist only a portion of the Dead Load from Check 3.1, check the vertical support member in compression for remainder of the load not resisted at the top anchorage. Also check that the bottom connections have capacity to resist the compression loads in the vertical support member.

Check 3: Ductility Review

3.1 This support may be considered as ductile only if its seismic ruggedness can be verified by neglecting the bottom connection. In this case, it is similar to the support of example 5.1.1.

5.1.6 Cantilever Bracket Support Example 6 (cont.)

Check 4: Lateral Load

4.1 Check the top and bottom connection and expansion anchors for reaction from 1.0 Dead Load, plus the equivalent static lateral loading. The vertical strut does not need to be checked if it was evaluated in Check 2.2.

4.2 Check the top and bottom connections, expansion anchors, and vertical support member for 1.0 Dead Load, plus equivalent static lateral load.

Check 5: Limit State

5.1 Neglect the bottom connection and check the overhead expansion anchors for 1.0 Dead Load, plus reaction from the lesser of the plastic hinge moment capacities of the vertical member or dual clip angle action. Note that a limit state evaluation is only valid for suspended supports, as plastic action may lead to instability for base-mounted supports.

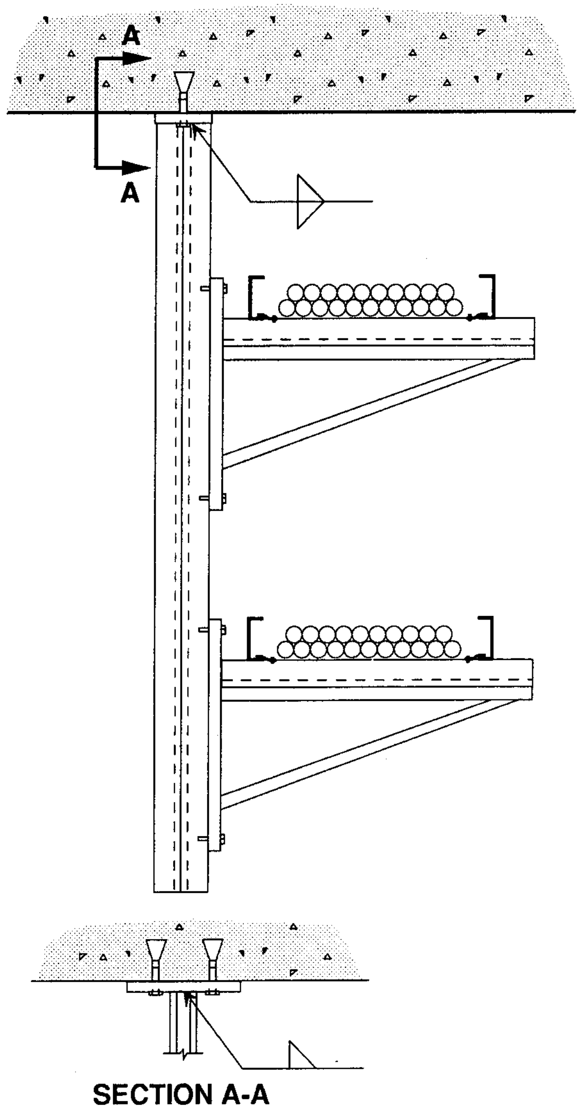
The support is seismically rugged if one of the following combinations of checks is satisfied:

- Checks 1 and 2.1 and 3
- Checks 1 and 2.2 and 4.1

If the support does not pass these checks, it is an outlier. Resolution of this outlier may be achieved if one of the following combination of checks is satisfied:

- Checks 1 and 3 and 5
- Checks 1 and 4.2

5.1.7 Cantilever Bracket Support Example 7



Check 1: Dead Load

1.1 Check all support members and connections for 1.0 Dead Load, including load eccentricity of the cable tray and using working stress allowable loads.

Check 2: Vertical Capacity

2.1 Check the overhead expansion anchors for 3.0 Dead Load, ignoring load eccentricity of the cable trays.

Check 3: Ductility Review

3.1 This support may be considered as ductile only if the expansion anchors and welded connection capacities are large enough to enable plastic hinge formation in the vertical support member. Note that it may be difficult for the welded connection to do this where the vertical member is light metal strut framing.

3.2 Check if the expansion anchors can develop the plastic moment capacity of the vertical member.

3.3 Check if the top welded connection can develop the plastic moment capacity of the vertical member.

5.1.7 Cantilever Bracket Support Example 7 (cont.)

Check 4: Lateral Load

4.1 Check the overhead expansion anchors and top welded connection for 1.0 Dead Load, plus equivalent static lateral loading.

4.2 This check may only be performed if the overhead expansion anchors are of the non-shell type and pass Check 2 and if the weld can develop the plastic flexural capacity of the vertical member. Determine the pendulum frequency of the support, using the length of the support to the center of mass of the cable trays, approximating it as a single-degree-of-freedom system. Obtain the 5% damped in-structure response spectral displacement for the anchor location of the support at this calculated lower-bound frequency.

Apply this deflection in the lateral direction at the center of mass point, considering the vertical support member and ceiling connection plate as rigid. Check if the resulting rotation at the ceiling connection plate (about a free edge of the plate) would cause less than 1/8-inch slip of the expansion (non-shell) anchor bolts.

Check 5: Limit State

5.1 Check the overhead expansion anchors for 1.0 Dead Load, plus the reaction from a plastic hinge moment in the vertical support member.

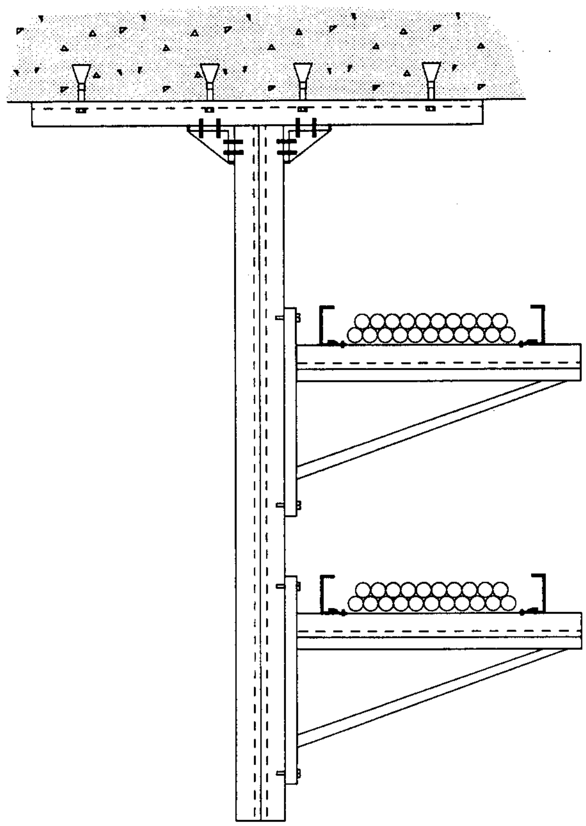
The support is seismically rugged if one of the following combinations of checks is satisfied:

- Checks 1 and 2 and 3
- Checks 1 and 2 and 4.1
- Checks 1 and 2 and 3.3 and 4.2

If the support does not pass these checks, it is an outlier. Resolution of this outlier may be achieved if one of the following combination of checks is satisfied:

- Checks 1 and 3 and 5
- Checks 1 and 4.1 or 4.2

5.1.8 Cantilever Bracket Support Example 8



Check 1: Dead Load

1.1 Check all support members and connections for 1.0 Dead Load, including load eccentricity of the cable tray and using working stress allowable loads.

Check 2: Vertical Capacity

2.1 Check the overhead expansion anchors for 3.0 Dead Load, ignoring load eccentricity of the cable trays. If credit is taken for all four anchor bolts, check if the bending strength and stiffness of the overhead channel section are sufficient to mobilize the outer anchor points.

2.2 Check the top connection bolts for 3.0 Dead Load, ignoring load eccentricity of the cable trays.

Check 3: Ductility Review

3.1 This support may be considered as inherently ductile. Lateral loading leads to bending of clip angles and slight slip of the bolts with channel nuts.

Check 4: Lateral Load

4.1 Check the overhead expansion anchors for 1.0 Dead Load, plus equivalent static lateral load. If the outer two expansion anchors are used, also check the overhead channel for bending strength and stiffness.

5.1.8 Cantilever Bracket Support Example 8 (cont.)

Check 5: Limit State

5.1 Check the overhead expansion anchors for 1.0 Dead Load, plus the reaction from plastic hinge moment capacity of the dual clip angle connection.

The support is seismically rugged if one of the following combinations of checks is satisfied:

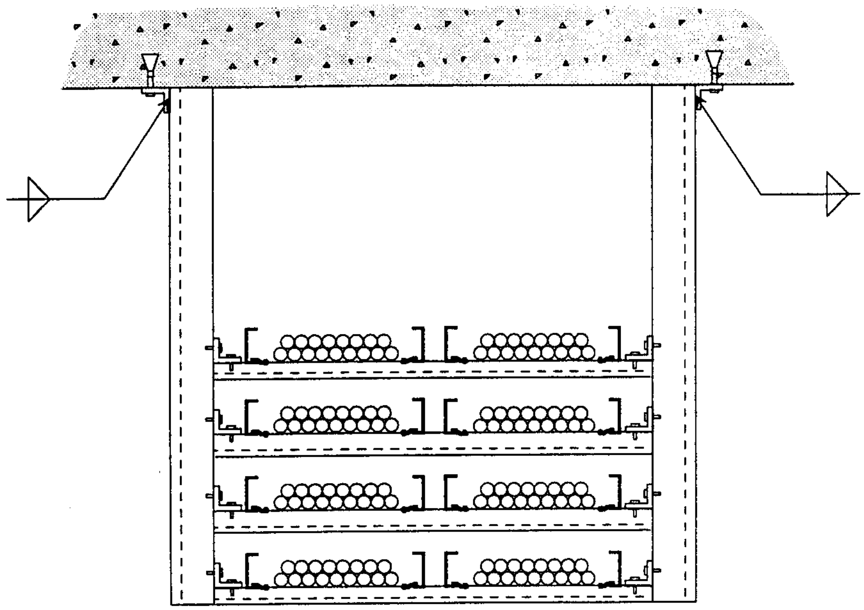
- Checks 1 and 2 and 3
- Checks 1 and 2 and 4

If the support does not pass these checks, it is an outlier. Resolution of this outlier may be achieved if the following combination of checks is satisfied:

- Checks 1 and 3 and 5
- Checks 1 and 4

5.2 EXAMPLE EVALUATION OF TRAPEZE FRAME RACEWAY SUPPORTS

5.2.1 Trapeze Frame Support Example 1



Check 1: Dead Load

1.1 Check all support members and connections for 1.0 Dead Load, using working stress allowable loads.

Check 2: Vertical Capacity

2.1 Check the overhead expansion anchors for 3.0 Dead Load.

2.2 Check the overhead welded connections for 3.0 Dead Load.

Check 3: Ductility Review

3.1 This support may be considered as inherently ductile. Lateral loading leads to bending of clip angles.

Check 4: Lateral Loads

4.1 Check the overhead expansion anchors for 1.0 Dead Load, plus reaction from equivalent static lateral loads.

4.2 Check the top welded connections for 1.0 Dead Load, plus reaction from equivalent static lateral load.

Check 5: Limit State

5.1 Check the overhead expansion anchors for 1.0 Dead Load, plus frame reaction due to formation of plastic hinge moments at all frame joints, plus reaction from local prying action due to the plastic hinge moment at the top connection.

5.2 Check the top welded connections for 1.0 Dead Load, plus frame reaction due to formation of plastic hinge moments at all frame joints.

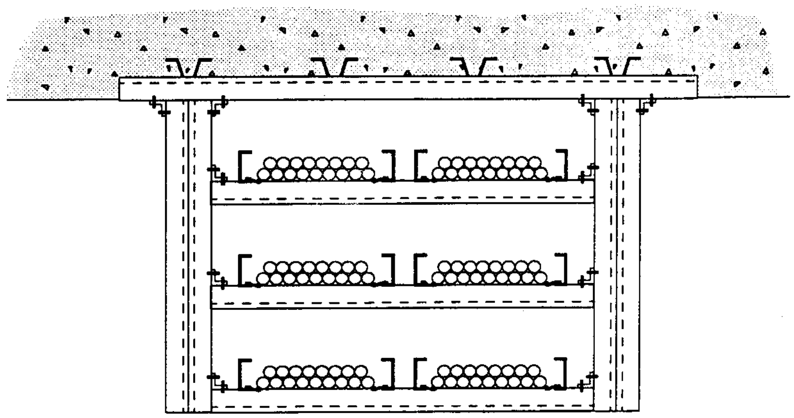
The support is seismically rugged if one of the following combinations of checks is satisfied:

- Checks 1 and 2 and 3
- Checks 1 and 2 and 4

If the support does not pass these checks, it is an outlier. Resolution of this outlier may be achieved if one of the following combination of checks is satisfied:

- Checks 1 and 3 and 5
- Checks 1 and 4

5.2.2 Trapeze Frame Support Example 2



Check 1: Dead Load

1.1 Check all support members and connections for 1.0 Dead Load, using working stress allowable loads.

Check 2: Vertical Capacity

2.1 Check the embedded channel for 3.0 Dead Load. Consider only an effective length of the embedded channel over each vertical support member for anchorage capacity. If credit is taken for long lengths of the embedded channel, check its bending strength and stiffness.

2.2 Check the bolts at the top connections for 3.0 Dead Load.

Check 3: Ductility Review

3.1 This support may be considered as inherently ductile. Lateral loads will cause bending of clip angles and slight slip of the bolts with channel nuts.

Check 4: Lateral Loads

4.1 Check the effective length of the embedded channel anchor for 1.0 Dead Load, plus reaction from equivalent static lateral loads.

4.2 Check the bolts at the top connection for 1.0 Dead Load, plus reaction from equivalent static lateral load.

Check 5: Limit State

5.1 Check the effective length of the embedded channel anchor and the top connection bolts for 1.0 Dead Load, plus frame reaction due to formation of plastic hinge moments at all frame joints, plus reaction from local prying action due to the plastic hinge moment at the top connection.

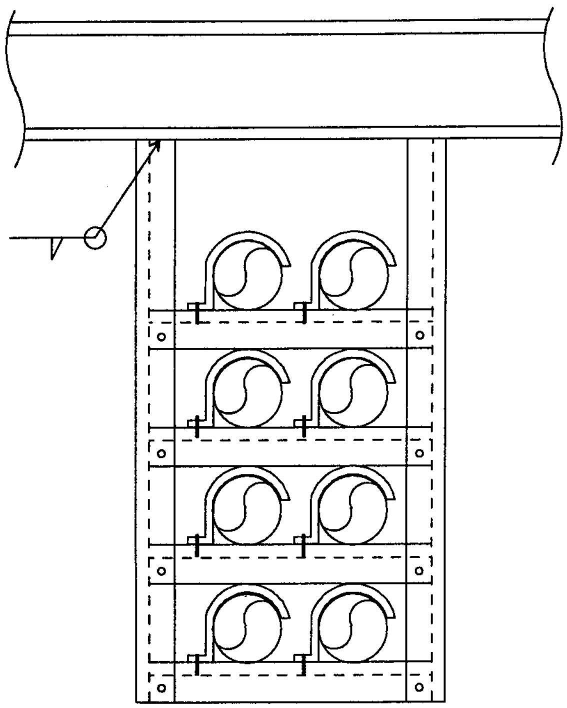
The support is seismically rugged if one of the following combinations of checks is satisfied:

- Checks 1 and 2 and 3
- Checks 1 and 2 and 4

If the support does not pass these checks, it is an outlier. Resolution of this outlier may be achieved if one of the following combination of checks is satisfied:

- Checks 1 and 3 and 5
- Checks 1 and 4

5.2.3 Trapeze Frame Support Example 3



Check 1: Dead Load

1.1 Check all support members and connections for 1.0 Dead Load, using working stress allowable loads.

Check 2: Vertical Capacity

2.1 Check the overhead weld for 3.0 Dead Load.

Check 3: Ductility Review

3.1 This support may be considered as ductile if the overhead welded connections can develop the plastic flexural capacity of the vertical support members. Anchor loads due to frame action are not a concern because all frame joints are pinned connections.

3.2 Check if the overhead welded connections can develop the plastic moment capacity of the vertical members.

Check 4: Lateral Load

4.1 Check the overhead welded connections for 1.0 Dead Load, plus reaction from equivalent static lateral load.

Check 5: Limit State

5.1 Check the overhead welded connections for 1.0 Dead Load, plus the reaction from formation of a plastic hinge in each vertical support member.

5.2.3 Trapeze Frame Support Example 3 (cont.)

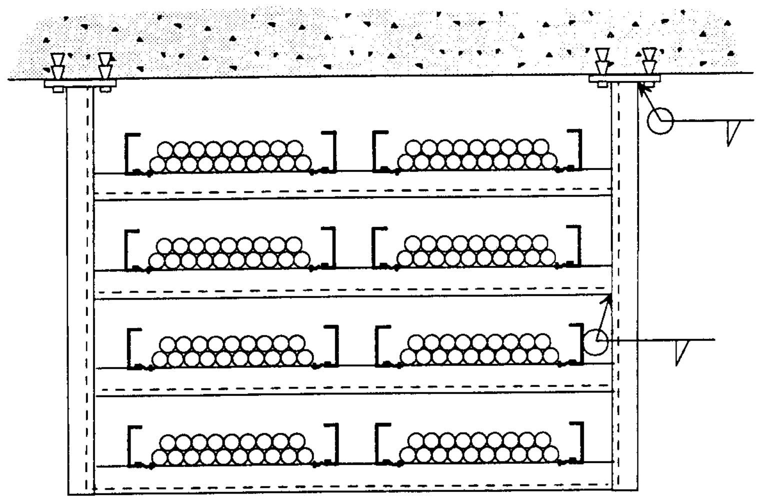
The support is seismically rugged if one of the following combinations of checks is satisfied:

- Checks 1 and 2 and 3
- Checks 1 and 2 and 4

If the support does not pass these checks, it is an outlier. Resolution of this outlier may be achieved if one of the following combination of checks is satisfied:

- Checks 1 and 3 and 5
- Checks 1 and 4

5.2.4 Trapeze Frame Support Example 4



Check 1: Dead Load

1.1 Check all support members and connections for 1.0 Dead Load, using working stress allowable loads.

Check 2: Vertical Capacity

2.1 Check the overhead expansion anchors for 3.0 Dead Load using realistic capacity.

2.2 Check the overhead weld for 3.0 Dead Load using realistic capacity.

Check 3: Ductility Review

3.1 This support is constructed as a rigid frame. It may be considered as ductile if the overhead connections and anchors can develop the plastic flexural capacity of the support members, and if the anchors can resist the rigid frame action forces.

3.2 Check if the overhead expansion anchors can develop the lesser of the plastic moment capacity of the vertical member or the ceiling connection plate, and also the reaction from frame action when plastic moment capacity is reached in all four cross beams.

3.3 Check if the top welded connections can develop the plastic moment capacity of the vertical support members.

5.2.4 Trapeze Frame Support Example 4 (cont.)

Check 4: Lateral Loads

4.1 Check the overhead expansion anchors for 3.0 Dead Load, plus reaction from equivalent static lateral loads.

4.2 Check the top welded connections for 1.0 Dead Load, plus reaction from equivalent static lateral load.

Check 5: Limit State

5.1 Check the overhead expansion anchors for 1.0 Dead Load, plus frame reaction due to formation of plastic hinge moment capacity in the cross beams at each cross beam to vertical member connection and in the top vertical member connection, plus reaction due to the local plastic hinge formation at the top connection. The plastic moment capacity of the top connection may be taken as the lesser of the plastic moment capacities of the vertical member or the ceiling connection plate behavior.

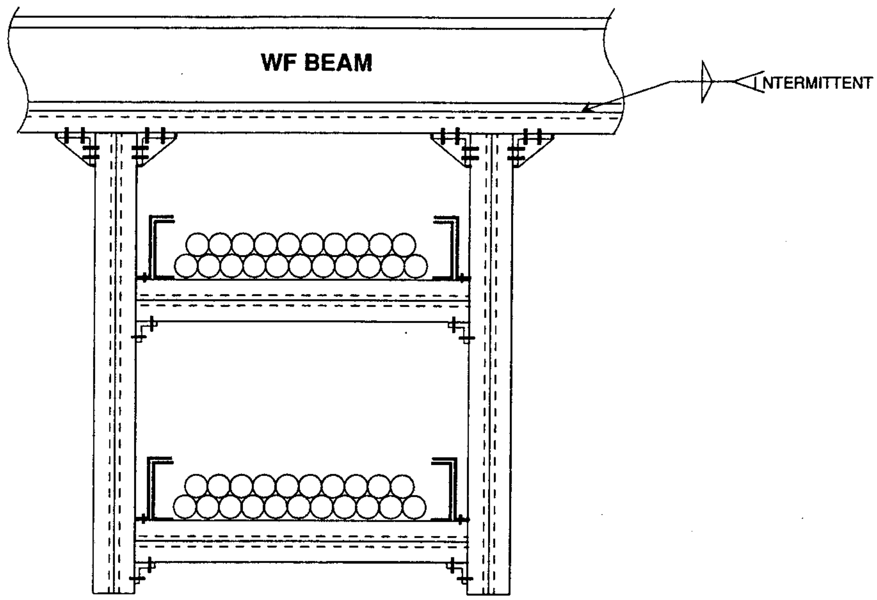
The support is seismically rugged if one of the following combinations of checks is satisfied:

- Checks 1 and 2 and 3
- Checks 1 and 2 and 4

If the support does not pass these checks, it is an outlier. Resolution of this outlier may be achieved if one of the following combination of checks is satisfied:

- Checks 1 and 3 and 5
- Checks 1 and 4

5.2.5 Trapeze Frame Support Example 5



Check 1: Dead Load

1.1 Check all support members, connections, and intermittent weld for 1.0 Dead Load, using working stress allowable loads.

Check 2: Vertical Capacity

2.1 Check the intermittent weld for 3.0 Dead Load. Consider only an effective length of the overhead channel. If credit is taken for welds that involve transfer of load across long spans of the overhead channel, check the channel bending capacity and stiffness.

2.2 Check the bolts at the top connection for 3.0 Dead Load.

Check 3: Ductility Review

3.1 This support may be considered as inherently ductile. Lateral loading leads to bending of clip angles and slight slip of the bolts with channel nuts.

5.2.5 Trapeze Frame Support Example 5 (cont.)

Check 4: Lateral Loads

4.1 Check the overhead welded connection (considering an effective length of the overhead channel) for 1.0 Dead Load, plus reaction from equivalent static lateral load.

4.2 Check the bolts of the top connections for 1.0 Dead Load, plus reaction from equivalent static lateral load.

Check 5: Limit State

5.1 Check the overhead welded connection (considering an effective length of the overhead channel) and the top connection bolts for 1.0 Dead Load, plus frame reaction due to formation of plastic hinge moments at all frame joints, plus reaction from local prying action due to the plastic hinge moment at the top connection.

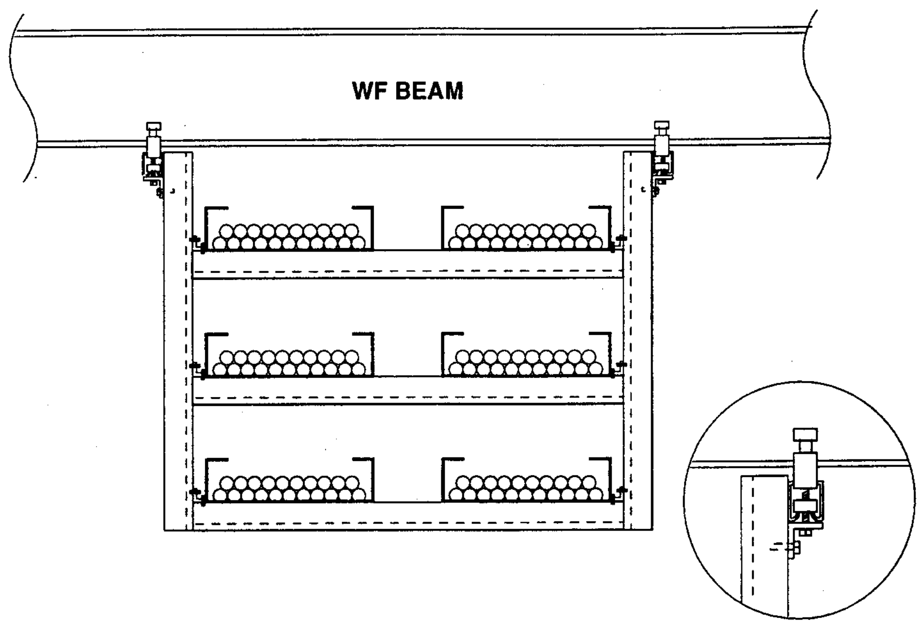
The support is seismically rugged if one of the following combinations of checks is satisfied:

- Checks 1 and 2 and 3
- Checks 1 and 2 and 4

If the support does not pass these checks, it is an outlier. Resolution of this outlier may be achieved if one of the following combination of checks is satisfied:

- Checks 1 and 3 and 5
- Checks 1 and 4

5.2.6 Trapeze Frame Support Example 6



Check 1: Dead Load

1.1 Check all support members and connections for 1.0 Dead Load, using working stress allowable loads.

Check 2: Vertical Capacity

2.1 Check the beam clamps at the overhead connection for 3.0 Dead Load.

2.2 Check the bolts at the overhead connection for 3.0 Dead Load.

Check 3: Ductility Review

3.1 This support may be considered as inherently ductile. Lateral loading leads to bending of clip angles and slight slip of the bolts with channel nuts.

Check 4: Lateral Loads

4.1 Check the overhead beam clamp connections for 1.0 Dead Load, plus reaction from equivalent static lateral load.

4.2 Check the top connection bolts for 1.0 Dead Load, plus reaction from equivalent static lateral load.

5.2.6 Trapeze Frame Support Example 6 (cont.)

Check 5: Limit State

5.1 Check the beam clamps and top connection bolts for 1.0 Dead Load, plus frame reaction due to formation of plastic hinge formation at all cross beam to vertical member connections. No prying need be considered as the beam clamps behave as pinned connections.

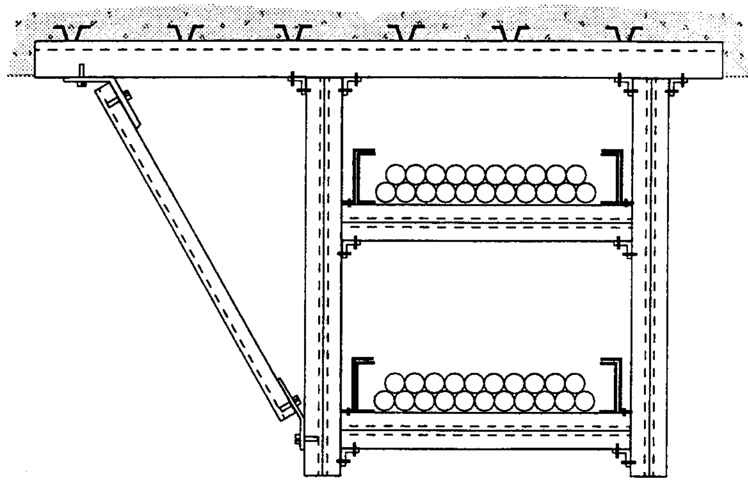
The support is seismically rugged if one of the following combinations of checks is satisfied:

- Checks 1 and 2 and 3
- Checks 1 and 2 and 4

If the support does not pass these checks, it is an outlier. Resolution of this outlier may be achieved if one of the following combination of checks is satisfied:

- Checks 1 and 3 and 5
- Checks 1 and 4

5.2.7 Trapeze Frame Support Example 7



Check 1: Dead Load

1.1 Check all support members and connections for 1.0 Dead Load, using working stress allowable loads.

Check 2: Vertical Capacity

2.1 Check the embedded channel for 3.0 Dead Load, considering an effective length of the embedded channel over each vertical support member.

2.2 Check the bolts at the top connections for 3.0 Dead Load. The brace connections should not be included.

Check 3: Ductility Review

3.1 This support may be considered as ductile if the bolts at the top connections and the effective length of the embedded channel over each vertical support member have capacities that exceed the reaction from 1.0 Dead Load, plus the vertical component of the compressive load capacity of the diagonal brace and its connections. If so, it is similar to the support of example 5.2.2.

Check 4: Lateral Loads

4.1 Check an effective length of the embedded channel over each vertical member, the top connection bolts, and the brace connections for 1.0 Dead Load, plus reaction from equivalent static lateral load.

Check 5: Limit State

5.1 Check the effective length of the embedded channel over each vertical support member and the top connection bolts for 1.0 Dead Load, plus reaction due to the vertical component of the brace compressive capacity equal to the lesser of the brace critical buckling load or connection capacity, plus frame reaction due to plastic hinge formation at all frame joints (cross beams to vertical members and top connections), plus reaction due to local plastic hinge moments at the top connection.

The support is seismically rugged if one of the following combinations of checks is satisfied:

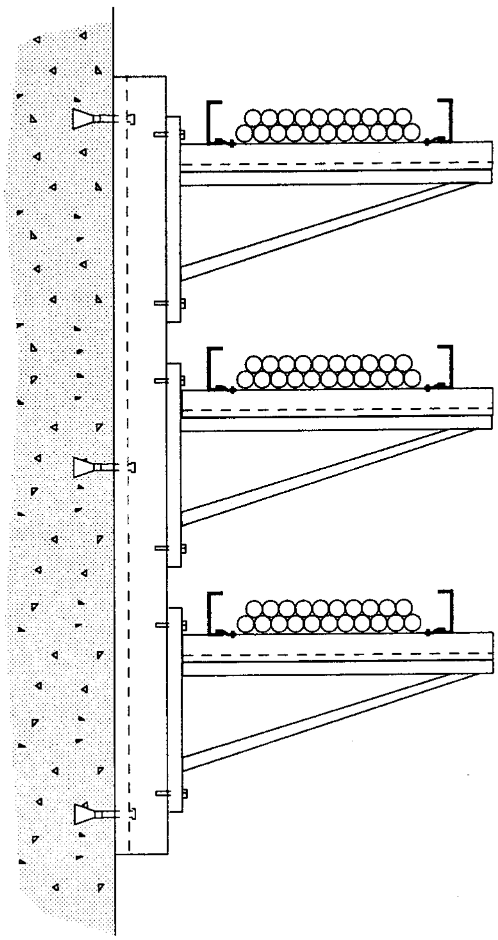
- Checks 1 and 2 and 3
- Checks 1 and 2 and 4

If the support does not pass these checks, it is an outlier. Resolution of this outlier may be achieved if one of the following combination of checks is satisfied:

- Checks 1 and 3 and 5
- Checks 1 and 4

5.3 EXAMPLE EVALUATIONS OF RIGID-MOUNTED RACEWAY SUPPORTS

5.3.1 Rigid Mount Support Example 1

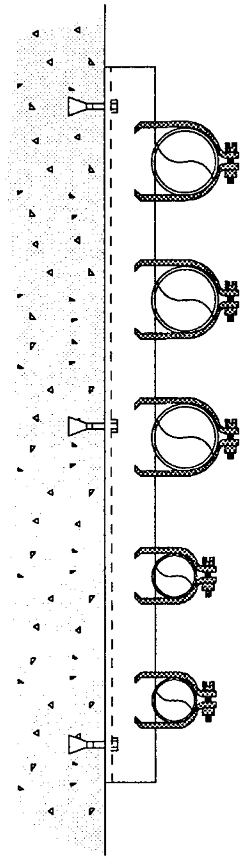


Check 1: Dead Load

1.1 Check all support members and connections for 1.0 Dead Load, including load eccentricity of the cable trays and using working stress allowable loads.

If Check 1 is satisfied, the support is seismically rugged.

5.3.2 Rigid Mount Support Example 2



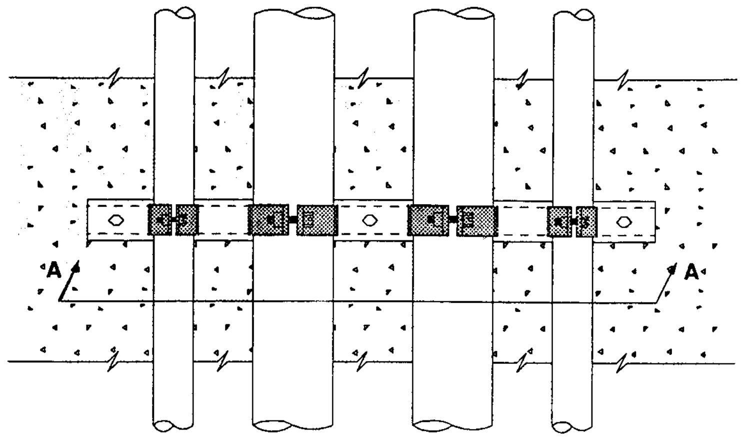
Check 1: Dead Load

1.1 Check all support members and connections for 1.0 Dead Load, including load eccentricity of the conduits and using working stress allowable loads.

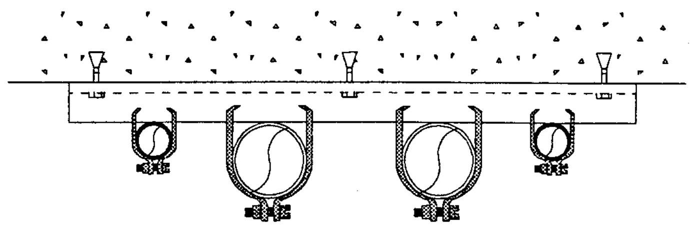
If Check 1 is satisfied, the support is seismically rugged.

If Check 1 is not satisfied, neglect the support, re-check resulting spans, and evaluate adjacent supports for ruggedness.

5.3.3 Rigid Mount Support Example 3



ELEVATION


SECTION A-A

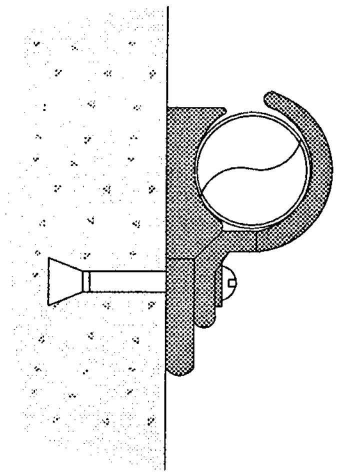
Check 1: Dead Load

1.1 Check all support members and connections (note that the conduit are running vertically) for 1.0 Dead Load (including the prying action on the anchor bolts).

If Check 1 is satisfied, the support is seismically rugged.

If Check 1 is not satisfied, neglect the support, re-recheck resulting spans, and evaluate the adjacent supports.

5.3.4 Rigid Mount Support Example 4



Check 1: Dead Load

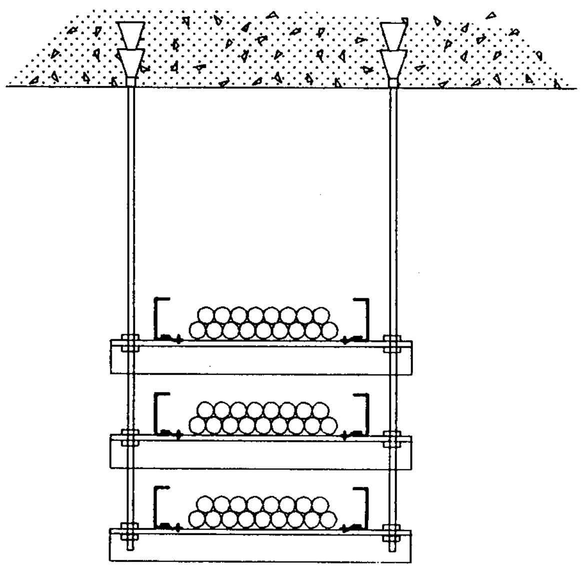
1.1 Check support anchorage for 1.0 Dead Load, including eccentricity of the conduit and prying action on the anchor bolt.

If Check 1 is satisfied, the support is seismically rugged.

If Check 1 is not satisfied, neglect the support, re-check resulting spans, and evaluate the adjacent supports.

5.4 EXAMPLE OF ROD-HUNG RACEWAY SUPPORTS

5.4.1 Rod Hanger Support Example 1



Check 1: Dead Load

1.1 Check all support members and connections for 1.0 Dead Load, using working stress allowable loads. Allowable rod stress should not exceed 6 ksi.

Check 2: Vertical Capacity

2.1 Check the overhead expansion anchors for 3.0 Dead Load.

Check 3: Ductility Review

3.1 This support may be considered as inherently ductile. Lateral loading leads to bending of the hanger rods. These bending strains may be very high because the rod hanger trapeze support has fixed-end connection details, so a fatigue check should be performed.

5.4.1 Rod Hanger Support Example 1 (cont.)

Check 4: Lateral Load

4.1 Check the fixed end rod hangers using the fatigue evaluation guidelines. Consider the total Dead Load as support weight and the rod hangers above the top tier for rod length. Use the rod fatigue screening chart corresponding to a rod fatigue bounding spectrum that envelopes that 5% damped in-structure response spectrum for the anchor location of the support, at the frequency of the support approximated as a single degree of freedom.

Check 5: Limit State

5.1 Check the overhead expansion anchors for 1.0 Dead Load, plus frame reaction due to formation of plastic hinge moment capacities in the rod hangers at all fixed-end connection details. If the lateral deflection corresponding to on-set of all these plastic hinges is excessive (i.e., greater than the in-structure spectral displacement at the pendulum frequency of the support), then determine a more realistic deflected shape limit state to perform this evaluation.

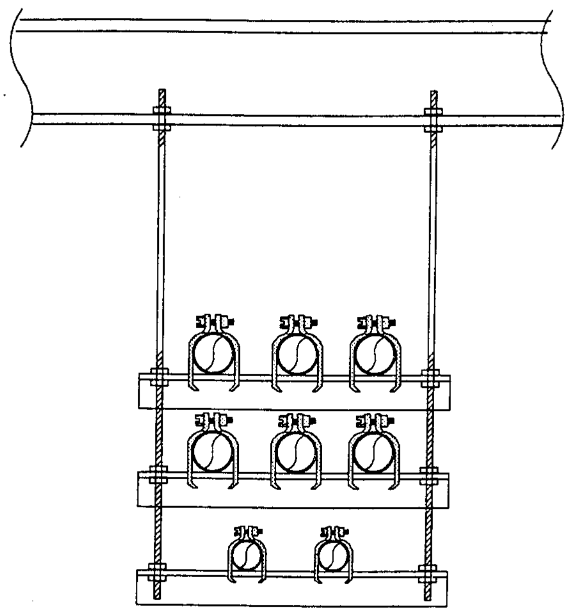
The support is seismically rugged if the following combination of checks is satisfied:

- Checks 1 and 2 and 3 and 4

If the support does not pass these checks, it is an outlier. Resolution of this outlier may be achieved if one of the following combination of checks is satisfied:

- Checks 1 and 3 and 4 and 5

5.4.2 Rod Hanger Support Example 2



Check 1: Dead Load

1.1 Check all the support members and connections for 1.0 Dead Load, using working stress allowable loads. Allowable rod stress should not exceed 6 ksi.

Check 2: Vertical Capacity

2.1 Check the overhead connection for 3.0 Dead Load.

Check 3: Ductility Review

3.1 This support may be considered as inherently ductile. Lateral loading leads to bending of the hanger rods. These bending strains may be very high because the rod hanger trapeze support has fixed-end connection details, so a fatigue check should be performed. Because the rods are not all-threaded, the evaluations should consider the rods as field-threaded, with reduced fatigue capacity.

Check 4: Lateral Load

4.1 Check the fixed end rod hangers using the fatigue evaluation guidelines. Because the hanger may be constructed of field threaded rods, consider the total dead load times 2.0 as equivalent support weight, and 2/3 the length of the rods above the top tier for equivalent rod length. Use the rod fatigue screening chart corresponding to the applicable rod fatigue bounding spectrum.

Check 5: Limit State

5.1 Check the overhead expansion anchors for 1.0 Dead Load, plus frame reaction due to formation of plastic hinge moment capacities in the rod hangers at all fixed-end connection details. If the lateral deflection corresponding to on-set of all these plastic hinges is excessive, then determine a more realistic deflected shape limit state to perform this evaluation.

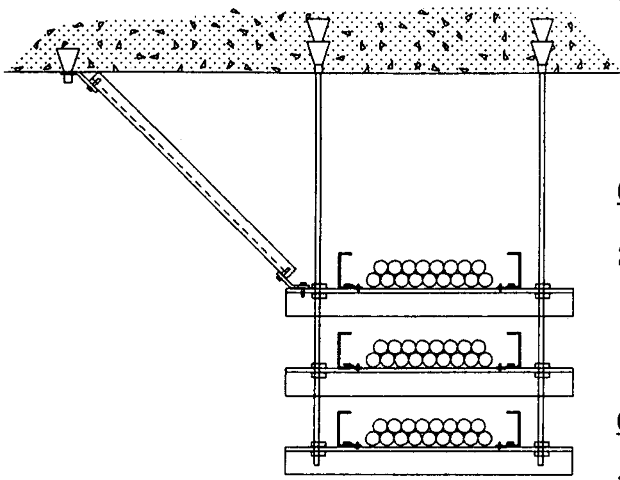
The support is seismically rugged if the following combination of checks is satisfied:

- Checks 1 and 2 and 3 and 4

If the support does not pass these checks, it is an outlier. Resolution of this outlier maybe be achieved if the following combination of checks is satisfied:

- Checks 1 and 3 and 4 and 5

5.4.3 Rod Hanger Support Example 3



Check 1: Dead Load

1.1 Check all support members and connections for 1.0 Dead Load, using working stress allowable loads. Allowable rod stress should not exceed 6 ksi.

Check 2: Vertical Capacity

2.1 Check the overhead expansion anchors for 3.0 Dead Load. The anchors of the brace should not be included in this check.

Check 3: Ductility Review

3.1 This support may be considered as ductile if the overhead expansion anchor capacity exceeds the reaction from 1.0 Dead Load, plus the vertical component of the compressive load in the diagonal brace and its connections. If so, it may then be evaluated as the support of example 5.4.1, with the brace neglected.

Check 4: Lateral Load

4.1 Check the overhead expansion anchors, and the brace and its connections for 1.0 Dead Load, plus equivalent static lateral load.

4.2 Check the rod hangers between the top and middle tiers using the fatigue evaluation guidelines. Consider the distance between the top and middle tiers for equivalent rod length, and total dead load from the lower two tiers as equivalent weight. Use the rod fatigue screening chart corresponding to the applicable rod fatigue bounding spectrum.

4.3 Check the fixed end rod hangers, neglecting the diagonal brace, using the fatigue evaluation guidelines. Consider the rod length above the top tier as effective length, and total dead load as effective weight. Use the rod fatigue screening chart corresponding to the applicable rod fatigue bounding spectrum.

Check 5: Limit State

5.1 Check the overhead expansion anchors for 1.0 Dead Load, plus frame reaction due to formation of plastic hinge moment capacities in the rod hangers at all fixed-end connection details of the lower two tiers, plus reaction from brace compressive load capacity. Limit the brace capacity to the lesser of the brace critical buckling strength or lowest brace connection capacity.

The support is seismically rugged if one of the following combinations of checks is satisfied:

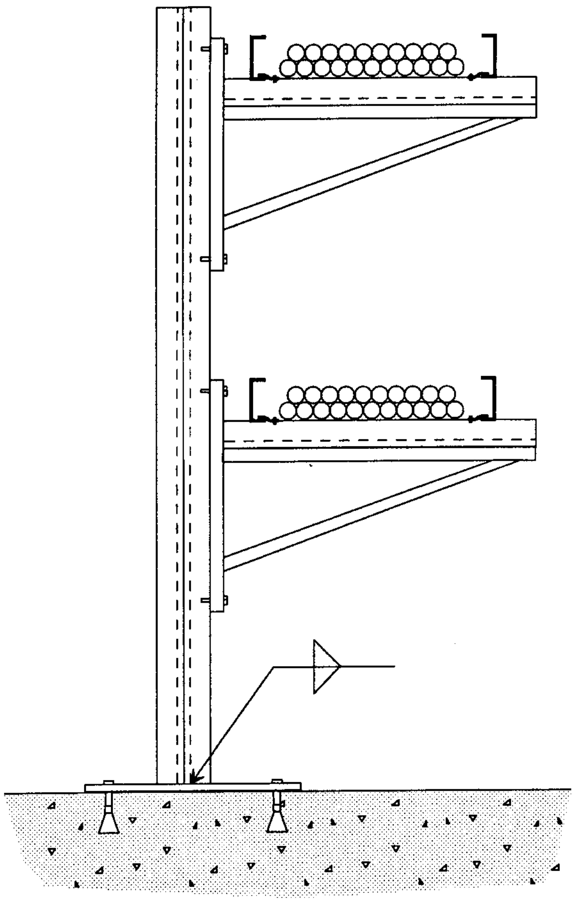
- Checks 1 and 2 and 3 and 4.3
- Checks 1 and 2 and 4.1 and 4.2

If the support does not pass these checks, it is an outlier. Resolution of this outlier may be achieved if one of the following combination of checks is satisfied:

- Checks 1 and 3 and 4.1 or 4.2 or 4.3 and 5, as applicable

5.5 FLOOR-MOUNTED SUPPORTS

5.5.1 Floor-mounted Support Example 1



Check 1: Dead Load

1.1 Check all support members and connections for 1.0 Dead Load, including load eccentricity of the cable trays and using working stress allowable loads.

Check 2: Vertical Capacity

2.1 There is no uncoupled vertical capacity check for base-mounted supports. The vertical check is conducted as part of the lateral loading check.

Check 3: Ductility Review

3.1 Base-mounted supports are not considered ductile. Plastic action of members and connections during lateral loading may lead to instability and collapse.

Check 4: Lateral Load

4.1 Check the expansion anchors for 1.0 Dead Load, plus equivalent static lateral load. Perform the check also (but not concurrently) for the equivalent static load applied in the longitudinal direction. Neglect any torsional load reactions that may result from the applied horizontal loads.

4.2 Check the bottom welded connections, the base plate, and the vertical post for 1.0 Dead Load, plus equivalent static lateral load. Perform the check non-concurrently for both orthogonal directions and neglect torsional moments.

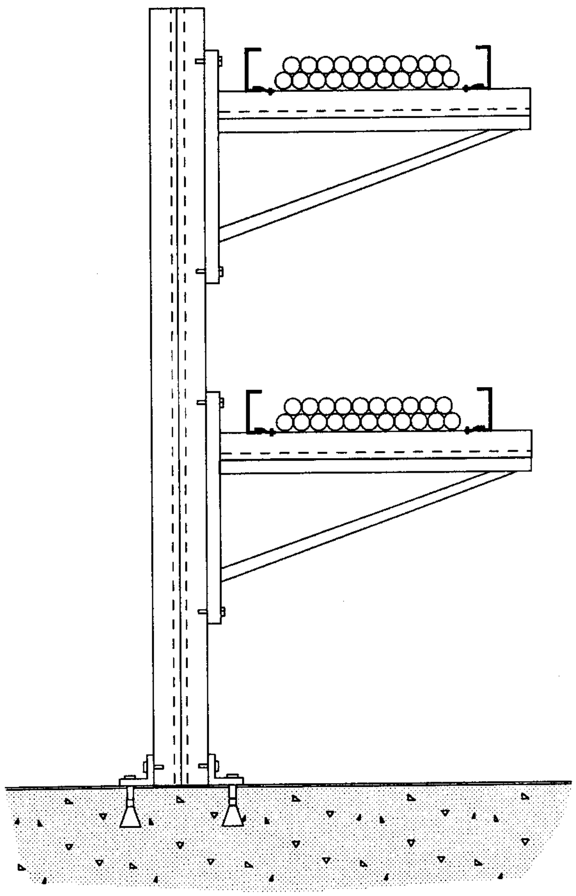
4.3 If non-shell anchors are used, and mean/3 capacities are considered, then also perform a P-delta evaluation as follows. In Checks 4.1 and 4.2, add an additional reaction force due to the P-delta effects caused by 1/8-inch anchor slip plus the displacement due to flexibility of the column and the plate.

Check 5: Limit State

5.1 Limit state evaluations only apply to suspended support systems.

The support is seismically rugged if Checks 1 and 4 are satisfied.

5.5.2 Floor-mounted Support Example 2



Check 1: Dead Load

1.1 Check all support members and connections (also clip angle bending) for 1.0 Dead Load, including load eccentricity of the cable trays and using working stress allowable loads.

Check 3: Vertical Capacity

None

Check 2: Ductility Review

None

Check 4: Lateral Load

4.1 Check the expansion anchors for 1.0 Dead Load, plus equivalent static lateral load. Perform the check non-concurrently in both orthogonal directions and neglect torsional moments.

4.2 Check the bolts at the bottom connection and the clip angles for bending and the vertical post for 1.0 Dead Load, plus equivalent static lateral load. Perform the check non-concurrently in both orthogonal directions and neglect torsional moments.

4.3 If non-shell anchors are used, and mean/3 capacities are considered, then add to Checks 4.1 and 4.2 the additional reaction from P-delta effects due to 1/8-inch anchor slip plus the displacement due to flexibility of the column.

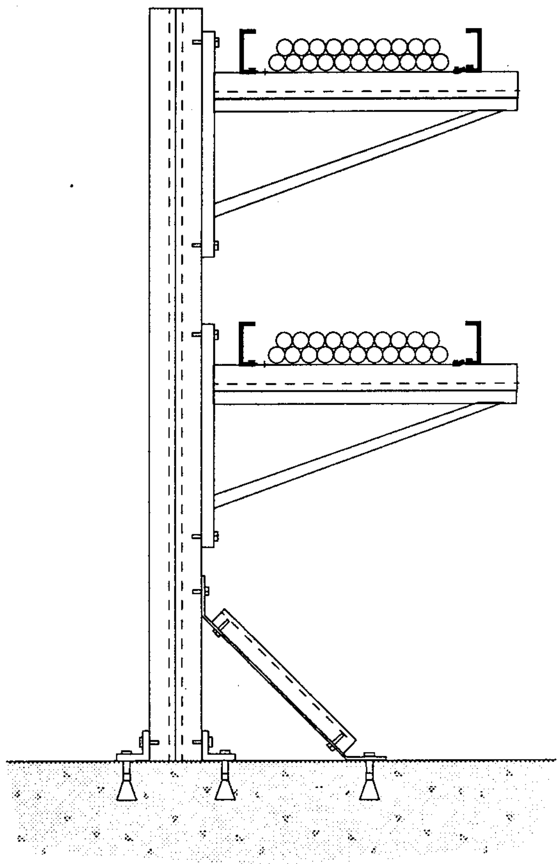
4.4 Add to Checks 4.1 and 4.2 the additional reaction from P-delta effects due to 1/16-inch slip of the bolts with channel nuts.

Check 5: Limit State

5.1 None

The support is seismically rugged if Checks 1 and 4 are satisfied.

5.5.3 Floor-mounted Support Example 3



Check 1: Dead Load

1.1 Check all support members and connections (also clip angle bending) for 1.0 Dead Load, including load eccentricity of the cable trays and using working stress allowable loads.

Check 2: Vertical Capacity

None

Check 3: Ductility Review

None

Check 4: Lateral Load

4.1 Check the expansion anchors, the channel nuts and clip angles, bending stress in the vertical post and clip angles, and buckling strength of the diagonal brace for 1.0 Dead Load, plus equivalent static load, applied non-concurrently in both orthogonal directions. Neglect torsional moments.

4.2 If the brace or any of its connections do not pass Check 4.1, then redistribute the percentage of the lateral load that cannot be resisted by the diagonal brace to the vertical post. Check the vertical post, its base connections and clip angles, and its expansion anchors for this redistributed load moment in addition to the loads of Check 4.1.

4.3 For both Checks 4.1 and 4.2, include P-delta effects due to anchor and channel nut slips as necessary plus the displacement due to flexibility of the column.

Check 5: Limit State

5.1 None

The support is seismically rugged if Checks 1 and 4 are satisfied.

SECTION 6

OUTLIERS

An outlier is defined as a raceway hardware feature that does not satisfy one of the following Inclusion Rules:

- 3.2.1 Cable Tray Span
- 3.2.2 Conduit Span
- 3.2.3 Raceway Member Tie-Downs
- 3.2.4 Channel Nuts
- 3.2.5 Rigid Boot Connection
- 3.2.6 Beam Clamps
- 3.2.7 Cast-iron Anchor Embedment

or does not satisfy the analytical guidelines as described in Section 4. In the following sections, acceptable methods for further evaluation of and resolution of outliers are described.

6.1 CABLE TRAY SPAN

Isolated outlier cable tray spans exceeding a length of about 10 feet may be shown to be acceptable as follows. If the isolated cable tray is of rugged construction and lightly loaded, it may be determined to be rugged. Trays meeting the NEMA standard (13) may be considered rugged and lightly loaded if their cable loading is no more than one-half of the tray's rated NEMA capacity (Table 3-1 of 13).

6.2 CONDUIT SPAN

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

6.3 RACEWAY MEMBER TIE-DOWNS

Tie-downs need to be installed until Inclusion Rule 3.2.3 is satisfied, or analyses or a static lateral pull test of the lateral load-carrying capacity of the as-built trays or conduit can be performed and the trays or conduit shown not to be capable of falling off (or significantly sliding along) the support. The amount of static lateral force should be consistent with one of the options in Section 4.4. It is preferable and usually not a difficult maintenance activity to add missing raceway member tie-downs.

6.4 CHANNEL NUTS

Channel nuts without teeth need to be replaced with nuts with teeth or an extensive plant-specific dynamic testing program can be performed to show the channel nuts without teeth are capable of carrying the anticipated seismic loads.

6.5 RIGID BOOT CONNECTION

Rigid boots are considered an outlier 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 so no gaps exist and the boot fits the member tightly, it is acceptable. One simple fix is to use through bolts as illustrated in Figure 3-2 of Section 3. The basis for the finding that there are no gaps should be thoroughly documented.

6.6 BEAM CLAMPS

The clamp needs to be replaced with a positive connection or oriented so 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 verified 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 resisting dead load only by clamping friction, then a sufficient amount of supports representative of the entire conduit run should be tugged to verify adequacy.

6.7 CAST-IRON ANCHOR EMBEDMENT

The cast-iron anchor embedment needs to be replaced with an acceptable anchorage or the support braced horizontally (similar to that in the example of Section 5.1.5) and the stress in the anchor kept very low.

6.8 ANALYTICAL OUTLIERS

Outliers that do not satisfy the analytical guidelines, as illustrated in Figure 4-1, can be evaluated further using more detailed analytical models of the raceway system. Also, in-plant testing may be used to demonstrate that the raceways are as rugged as required, or the raceways may be modified until they are in compliance with acceptable guidelines. Note 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 team may still find the support acceptable based on their professional judgement.

A limit state evaluation may be used as an alternative to the 3.0 times dead load check for outlier resolution. The limit state evaluation provides a check of anchorage and anchorage connection capacity. As anchor point demand, the limit state evaluation method considers 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 as possible.

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

For rod hanger trapeze supports with fixed-end connection details, the limit state evaluation is most 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 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 location of credible points of plastic hinge formation.

For threaded rods, the plastic hinge moment capacity should be consistent with those observed in the rod hanger fatigue tests (10). The plastic moment capacity may be calculated using the rod hanger's root section, a 1.7 shape factor, and the 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 evaluations may be calculated by assuming 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 midpoint 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 consider plastic hinges developing 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 should be based on test data. Reference 4 provides test information on several types and configurations of clip angle (gusseted and non-gusseted) connection details.

Care should be exercised as clip angle ultimate moment capacities vary with direction of loading. For example, consider manufacturer catalog standard light metal strut framing four-hole gusseted clip angles attached to double strut channel sections. The ultimate moment capacity is about 31,000 inch-pounds for bending towards the clip, about 6,000 inch-pounds for bending away from the clip, and about 48,000 inch-pounds for the case with clip angles on both sides of the member.

Example limit state checks are included with the example conceptual evaluations of Section 5. These should be reviewed as they illustrate application of the evaluation technique for several configurations of raceway supports. A detailed example limit state check for a multiple tier, rod hanger trapeze support system is included in Appendix A of this report.

The lateral load check of Section 4.4 may be used to evaluate outliers that do not meet the vertical capacity (3.0 times dead load) in Section 4.2. This is most applicable to supports characterized as non-ductile in Section 4.3, but may also be used for ductile supports.

6.9 REDUNDANCY AND CONSEQUENCE TEST

Isolated cases of a support not meeting the Section 4 analytical review guidelines may be accepted if the raceway support system has high redundancy, and if postulated support failure has no consequence to plant safety. High redundancy is demonstrated if the adjacent supports are suspended and meet the 3.0 times dead load vertical capacity check of Section 4.2, and either the ductility check of Section 4.3 or the lateral load strength check of Section 4.4.

"Isolated" means that it is not acceptable for as many as every other support to fail to meet the guidelines. In other words, there need to be at least two supports, each of which meets the guidelines of Section 4.2 and either Section 4.3 or Section 4.4, between each "isolated" support.

To assess safety consequence, the failure mode of the isolated support not meeting the analytical review guidelines must be determined by the review team engineers' judgement. 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 must be treated as a seismic interaction source. In this case, there is no safety consequence only if there are no fragile safety-related targets in the vicinity or below.

Acceptance of worst-case, boundary supports by the redundancy and consequence test does not provide considerable insight to the seismic ruggedness of the plant's raceway support systems. Rather, this option should be used during the walkdown to screen out isolated instances of marginal appearing supports, so as to exclude them from the bounding case sample.

SECTION 7

REFERENCES

1. EQE Engineering. March 1991. "The Performance of Raceway Systems in Strong Motion Earthquakes." EPRI NP-7150. Prepared for the Seismic Qualification Utility Group. San Francisco, CA.

2. Senior Seismic Review and Advisory Panel (SSRAP). March 1, 1991. "Review Procedure to Assess Seismic Ruggedness of Cantilever Bracket Cable Tray Supports." Revision 0. Prepared for the Seismic Qualification Utility Group.

3. URS/John A. Blume & Associates, Engineers. April 1983. "Shaking-Table Testing for Seismic Evaluation of Electrical Raceway Systems." Prepared for the Systematic Evaluation Program Owners Group. San Francisco, CA.

4. ANCO Engineers, Inc. December 15, 1978. "Cable Tray and Conduit Raceway Seismic Test Program." 1053-21.1-4. Vols. 1 and 2. Prepared for and in collaboration with Bechtel Power Corporation, Los Angeles, Power Division. Santa Monica, CA.

5. Senior Seismic Review and Advisory Panel (SSRAP). February 28, 1991. "Use of Seismic Experience Data to Show Ruggedness of Equipment in Nuclear Power Plants." Revision 4.0. Prepared for the Seismic Qualification Utility Group.

6. National Fire Protection Association. 1983. *National Electrical Code.* NFPA 70-1984. Quincy, MA.

7. EQE Engineering. March 1991. "Longitudinal Load Resistance in Seismic Experience Data Base Raceway Systems." EPRI NP-7153. Prepared for the Seismic Qualification Utility Group. San Francisco, CA.

8. URS Corporation/John A. Blume & Associates, Engineers. February 1991. "Seismic Verification of Nuclear Plant Equipment Anchorage." Volume 1: Revision 1. EPRI NP-5228. San Francisco, CA.

9. Horne, M. R. 1971. "Plastic Theory of Structures." Cambridge, MA.

10. EQE Engineering. March 1991. "Seismic Evaluation of Rod Hanger Supports for Electrical Raceway Systems." EPRI NP-7152. Prepared for the Seismic Qualification Utility Group. San Francisco, CA.

11. American Concrete Institute. June 1976. *Code Requirements for Nuclear Safety Related Concrete Structures.* ACI-349-76.

12. American Institute of Steel Construction, Inc. n.d. *Manual of Steel Construction.* Eighth edition. Chicago, IL.

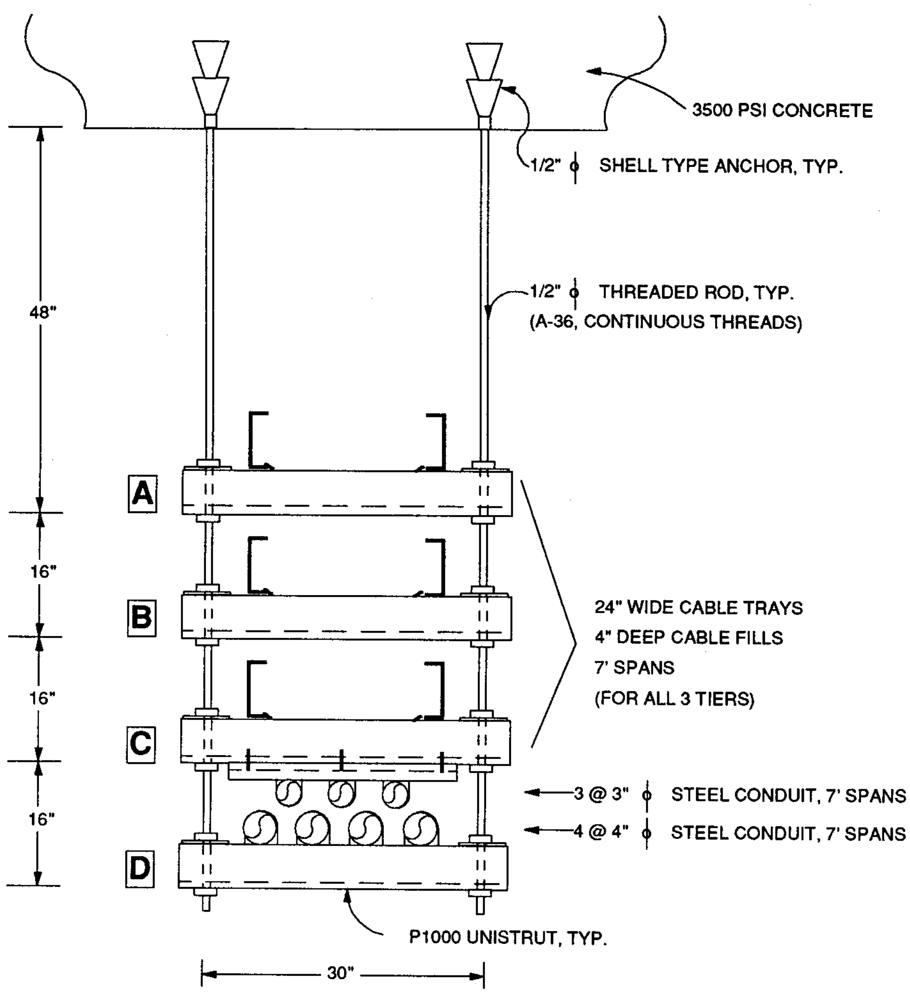
13. National Electrical Manufacturers Association. 1984. "Metallic Cable Tray Systems." Standards Publication/No. VE 1-1984. Washington, DC.

APPENDIX A

Example Limit State Evaluation for Resolution of Outliers of 3xDL Check

APPENDIX A

EXAMPLE EVALUATION - ROD HANGER TRAPEZE



Determine Weights:

$WA = (7')(50\#/ft) = 350\#$

$WB = WA = 350\#$

$WC = 350\# + (3)(7')(12.8\#/ft) = 619\#$

$WD = (4)(7')(16.5\#/ft) = 462\#$

$W_{TOTL} = 350 + 350 + 619 + 462 = 1781\#$

Section Properties:

1/2" ø Rod: $A_{NOM} = .196\ in^2$, $A_{ROOT} = .126\ in^2$, $S_{ROOT} = .00657\ in^3$

P1000: $S_{1-1} = .203\ in^3$

Check 1: Dead Load Design Check:

-Expansion anchors at ceiling:

$T/_{BOLT} = \frac{1}{2}\ (W_{TOTL}) = \frac{1}{2}\ (1781) = 891\#$

For T_{ALLOW} use EPRI Mean/4, $T_{ALLOW} = 1700\#$

$$\frac{891}{1700} = 0.52 < 1.0 \quad OK$$

-Trapeze cross members

(Approximate as uniform load, pin-ended)

AT "A" & "B", $M = 1/8\ (30")(.350^K) = 1.31$ in-k

AT "C", $M = 1/8\ (30")(.619^K) = 2.32$ in-k

AT "D", $M = 1/8\ (30")(.462^K) = 1.73$ in-k

Moment @ "C" controls, check bending stress

$$f_b = \frac{(2.32\ in\text{-}k)}{(.203\ in3\ )} = 11.4\ ksi$$

F_b (From unistrut catalog) = 25 ksi

$$\frac{11.4}{25} = 0.46 < 1.0 \quad OK$$

-Steel threaded rods (check for 19.1 ksi on nominal area):

$$\frac{891\#}{.196\ in^2} = 4.55\ ksi, \quad \frac{4.55}{19.1} = 0.24 < 1.0 \quad OK$$

-Machine bolts at "C" (3 @ 3/8" ø)

$T/_{BOLT} = 1/3\ (W_C) = 1/3\ (619\#) = 206\#$

For T_{ALLOW} use 20 ksi or Root Area

$T_{ALLOW} = (20\ ksi)(.068\ in^2) = 1360\#$

$$\frac{206}{1360} = 0.15 < 1.0 \quad OK$$

Therefore support meets dead load design check

Check 2: 3 X D.L. Vertical Capacity Check:

-Check only expansion anchors at ceiling

$3\ X\ D.L = 3(W_{TOTL}) = 3(1781\#) = 5343\#$

$T/_{BOLT} = \frac{1}{2}\ (5343) = 2672\#$

FOR T_{ALLOW} use EPRI Mean/4, $T_{ALLOW} = 1700\#$

$2672 > 1700$.

The support fails 3 X D.L. check is an outlier.

(Vertical capacity is only 1.91 X D.L)

Check 3: Ductility Check:

For lateral motion, this support will exhibit ductile response. Lateral motion will only cause yielding of the vertical rods in bending, and the support configuration is not susceptible to fatigue effects (based on the rod hanger screening charts).

Therefore a limit-state analysis may be performed to resolve this outlier.

Check 4: Limit State Evaluation:

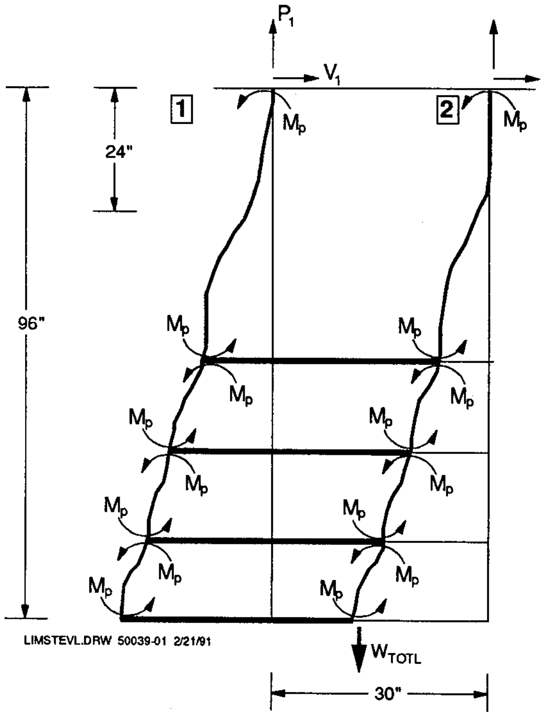
-Plastic hinge moment capacity of threaded rod can be determined based upon URS/Blume SEP test data methods.

Using root section, apparent yield of 90 ksi, and shape factor of 1.7:

$Mp = (90ksi)(1.7)(.00657in^3) = 1010$ in-lbs.

This is considered an upper-bound, conservative estimate.

-Determine maximum possible anchor load, using D.L. plus reaction from support going fully plastic. This is the most conservative approach.



$$\Sigma M_2 = 0$$

$$P_1\ (30") = W_{TOTL}\ (15") + 16\ M_p$$

$$P_1 = \frac{1}{30}\left[(1781)(15) + 16(1010)\right]$$

$$P_1 = 1429^{\#} = T_{BOLT}$$

For anchor shear, consider pt. of inflection above top tier

$$V_1 = \frac{1}{24"}(M_p) = \frac{1}{24}(1010)$$

$$V_1 = 42^{\#} = V_{BOLT}$$

-Compare D.L. + limit state anchor load with capacity

for V_{ALLOW} & T_{ALLOW} use EPRI MEAN/4, V_{ALLOW} = 1800#, P_{ALLOW} = 1700#

For interaction, $\frac{V_{Bolt}}{V_{Allow}} = \frac{42}{1800} = 0.02 < 0.30$

Therefore use $\frac{T_{Bolt}}{T_{Allow}} \leq 1.0 \qquad \frac{T_{Bolt}}{T_{Allow}} = \frac{1429}{1700} = 0.84 < 1.0$ OK

<u>Conclusion</u>:

Support is seismically rugged.

About EPRI

EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

EPRI. Electrify the World

Printed on recycled paper in the United States of America

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com