EQE INTERNATIONAL

WALKDOWN PROCEDURE
AND
ANALYTICAL EVALUATION CRITERIA
FOR THE
SEISMIC ADEQUACY REVIEW OF
HVAC DUCTS AT THE
OCONEE NUCLEAR STATION, UNITS 1, 2 & 3

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1. PURPOSE

This procedure provides guidelines for seismic evaluation of HVAC ducts at Duke Power Oconee Stations 1, 2 & 3. It is based on research and review of industry codes and standards, past earthquake performance data, and test results. Included are requirements for performing qualitative in-plant screening reviews and analytical evaluations. The objectives covered by this document are to assure structural stability as well as pressure boundary integrity, at a high level of confidence, for duct systems that require post event functionality.

The evaluation requirements provided are intended to result in margins of safety for seismic loading consistent with those achieved through use of the SQUG Generic Implementation Procedure (GIP, Reference 2) for the resolution of NRC Unresolved Safety Issue (USI) A-46.

2. SCOPE

These guidelines are applicable to all existing sheet metal heating, ventilation, and air-conditioning (HVAC) duct systems at the Duke Power Oconee Nuclear Stations 1, 2 & 3. Guidelines are provided for evaluating the effects of dead load, seismic load, and internal operating pressure on the ability to maintain HVAC duct function during and following the Safe Shutdown Earthquake (SSE) at Oconee. The seismic adequacy of other in-line equipment and components within the HVAC system such as fans are evaluated in accordance with the guidelines of the SQUG GIP (Reference 2).

3. RESPONSIBILITIES

The Project Manager shall be responsible for ensuring the implementation of this procedure and that the Walkdown Team members are trained in accordance with this procedure prior to performing the walkdowns.

The Project Manager shall be responsible for ensuring that the Walkdown Team members possess knowledge of the behavior and performance of equipment, systems, and structures during strong-motion earthquakes in industrial process and power plants.

The Project Manager shall be responsible for organizing and directing the walkdowns in accordance with this procedure.

The individual Walkdown Team members shall be responsible for the actual performance of the walkdowns and documentation of the results.

4. DEFINITIONS

4.1 ACRONYMS

SSE	Safe Shutdown Earthquake
HVAC	Heating, Ventilation, and Air Conditioning
SMACNA	Sheet Metal and Air Conditioning Contractors National Association
ZPA	Zero Period Acceleration

4.2 VARIABLES USED IN ANALYTICAL EXPRESSIONS

A = stiffener area

c = distance between neutral axis and extreme fiber of stiffener

d = maximum stiffener displacement

D = duct diameter

D_b = plate bending stiffness coefficient

E = Young's modulus

EQ_i = earthquake related stresses

- $i = h$ seismic load in horizontal directions; additional subscripts x and z refer to the two orthogonal transverse directions
- $i = v$ seismic load in vertical direction

f = maximum stiffener stress

$f1, f2$ = components of pressure stress in duct

f_b = bending stress

f_{DL}	=	stress in duct from dead load
f_p	=	computed pressure stress in duct
f_y	=	material yield stress of duct steel
f_s	=	frequency of support
F1, F2	=	allowable pressure stress in duct
F_b	=	allowable bending stress for duct
F_p	=	allowable pressure stress in duct
g	=	gravitational constant
H	=	duct height
I	=	moment of inertia for stiffener or hanger rod
K	=	empirical coefficient for estimating M_{max}
K_s	=	equivalent stiffness of trapeze support
l	=	duct span in determining M
L	=	duct stiffener spacing or hanger rod length
L_D	=	spacing between duct anchors
M	=	bending moment in duct
M_s	=	mass supported by trapeze assembly
p	=	pressure in duct
q	=	pressure load on stiffener

S	=	greater of H or W
t	=	duct wall thickness
T	=	axial tensile reaction resisting increase in duct span length that occurs with bending of the duct
u	=	variable in equation for total pressure stress
U_1	=	variable for obtaining u
w	=	linearly applied loading
W	=	duct width
W_{equiv}	=	equivalent weight of duct on trapeze support
Z	=	duct section modulus
π	=	Pi (3.1416)
ν	=	Poisson's ratio

5. HVAC DUCT IN-PLANT SCREENING REVIEW REQUIREMENTS

This section presents requirements for performing the in-plant screening review of HVAC duct systems for structural integrity, support review, seismic interaction, and pressure boundary integrity. Requirements are also provided for the selection of bounding/sample configurations for subsequent analytical evaluation. Analytical evaluation criteria are covered in Section 6. Screening and evaluation worksheets (SEWS) for recording information from the in-plant screening review are provided in Appendix A.

The HVAC duct system seismic evaluation consists of two phases, (1) an in-plant screening review of field conditions to evaluate as-installed configurations for seismic deficiencies and (2) the analytical evaluation of selected duct and/or support configurations and outliers.

The in-plant screening review of HVAC duct systems encompasses the following:

- Review duct system structural features that may lead to poor performance as illustrated by the seismic experience and test data (Section 5.1).

- Support system review for undesirable conditions that may lead to poor performance (Section 5.2).

- Review potential seismic interaction hazards (Section 5.3).

- Review duct system features to provide a high confidence level that pressure boundary integrity is assured. These requirements are based on seismic experience and test data (Section 5.4).

- Identify bounding configurations/samples for analytical evaluations (Section 5.5).

The walkdown teams performing these in-plant screening reviews shall consist of engineers knowledgeable of the technical criteria contained in this procedure and familiar with duct design and construction practices. Items not meeting the in-plant screening review are identified as outliers and, with the exception of maintenance items (such as damaged or missing hardware), will require an analytical evaluation.

An analytical evaluation will also be conducted for bounding configurations/samples of duct and/or supports selected during the in-plant review.

5.1 STRUCTURAL INTEGRITY REVIEW

This section describes HVAC duct attributes for review during the in-plant screening review walkdowns. These attributes have led to poor seismic performance based on past earthquakes and testing.

5.1.1 Duct Span

As a first screen, the HVAC duct runs should be checked for conformance with the SMACNA (References 5, 6 & 7) standards for span guidelines. The seismic experience data have shown that HVAC systems conforming to these standards have performed well in earthquakes. This is considered to be a conservative screening level because the experience data also has many examples of systems not meeting the SMACNA standards yet performing well. By enforcing the SMACNA standards, survivability of the HVAC systems is then assured. To further validate this approach, "worst case" bounding systems will be identified during walkdowns and subject to analytical evaluations for duct stresses and support adequacy.

5.1.2 Duct Tie-downs

HVAC ducts should be secured to their supports to preclude the possibility of sliding off during a seismic event. Most importantly, duct must be securely attached to the last hanger support in any run. Similarly, supports configured to limit the lateral movement of the HVAC duct system must also be attached to the duct. Seismic experience data

indicate that a mode of failure for HVAC duct systems subject to earthquake loading is the duct falling off of end supports. An example of this occurred at the Fertimex plant during the 1985 Mexico City earthquake.

5.1.3 Duct Joints

HVAC joints should be visually inspected to verify their structural integrity. Joints (including connected tees and elbows) that are observed to be loose, incomplete, corroded, or otherwise suspect (such as those repaired with duct tape or fiberglass, or missing rivets, screws, etc.) should be reviewed in detail. Seismic experience data have shown that such joints are often the point of failure of HVAC systems in an earthquake. A corroded riveted duct joint failed at the Caxton Paper Mill as a result of the 1987 New Zealand earthquake.

5.1.4 Riveted Lap Joints

Round HVAC duct with light gage riveted lap joint construction should be considered outliers and subjected to more detailed investigation. The seismic experience data base contains isolated cases of damage occurring to this kind of duct construction, such as the failure at the Wiltron Electronics Plant during the 1984 Morgan Hill earthquake. More detailed investigation should be performed to assure the seismic adequacy of this type of duct.

5.1.5 Appurtenances

Equipment attached to HVAC ducts must be checked to assure they will not fall in the event of an earthquake. This equipment includes items such as dampers, louvers, and air diffusers. Earthquake experience data have shown that intake and discharge screens and vanes that are inadequately attached to the duct (i.e. only slipped into place and not fastened with screws or rivets) have fallen during seismic events. Appurtenances not positively attached to the duct and appear to be at risk of falling during an earthquake should be evaluated to determine if failure will affect the functioning of the HVAC system and whether they will become an interaction hazard

with other nearby safety related equipment. All in-line equipment should be integral with the duct and equipment projecting from the duct (cantilevered) should be reviewed to assure connections are seismically adequate.

5.1.6 Flexibly Mounted Heavy Equipment

HVAC systems often have heavy pieces of mechanical equipment mounted in-line with the duct. Examples include fans, coolers, dryers, dampers with motor operators, and blowers. Earthquake experience data have shown that large pieces of equipment mounted in-line on flexible supports (e.g., without lateral and longitudinal bracing) can damage the duct from excessive displacement during an earthquake. This occurred at the Watkins-Johnson Plant during the 1989 Loma Prieta earthquake.

Mechanical equipment should be investigated to determine if the joints connecting the equipment to the duct are sufficiently flexible to accommodate any expected swinging of the equipment during a seismic event. Potential interactions between swinging mechanical equipment and the HVAC duct or other safety related equipment should also be investigated.

Heavy in-line equipment connected to HVAC duct may be floor-mounted on vibration isolation pads. Earthquake experience data have shown examples of failures of such HVAC systems due to insufficient restraint of the in-line equipment. Failures have been caused by floor-mounted equipment falling off their isolation pads and damaging attached ducts in the process. Heavy equipment that is flexibly supported or on vibration isolation pads should be identified as outliers for further evaluation.

5.1.7 Branch Flexibility

Earthquake experience data have indicated that "hard points" are prone to seismic damage. Examples of hard points include locations such as wall penetrations and rigid supports on short stiff branches which are attached to the otherwise flexibly supported duct. Such a failure occurred at the Wiltron Electronics Plant during the 1984 Morgan Hill earthquake. Short, stiff branches on a flexibly supported header should be

identified as outliers and checked for adequate flexibility to accommodate the expected header motion during a seismic event.

5.1.8 Cantilevered Duct

Earthquake experience data include isolated cases of cantilevered duct section damaged by jumping off their end hanger support. Long, flexibly supported duct runs must be attached to the final support. Unrestrained short cantilever ducts require positive attachment to the supporting headers. An example of inadequate attachment is given by the failure at the Pacific Bell Watsonville facility during the 1989 Loma Prieta earthquake.

5.2 SUPPORT SYSTEM REVIEW

This section describes support attributes for review during the in-plant screening review walkdowns. These attributes have led to poor seismic performance in similar distributive type systems, such as piping, cable tray and conduit systems (References 2 and 3). Existing duct systems judged to have similar, potentially poor seismic performance attributes, shall be documented as outliers.

5.2.1 Beam Clamps

Beam clamps should not be oriented in such a way that gravity loads are resisted only by the frictional forces developed by the clamps. Beam clamps oriented this way might loosen and slip off in an earthquake and possibly cause a collapse of the system.

5.2.2 Channel Nuts

Channel nuts used with light metal strut framing systems should have teeth or ridges stamped into the nut where it bears on the lip of the channel when slip resistance is relied upon to maintain structural integrity. Laboratory tests have shown that in a seismic environment, channel nuts without these teeth or ridges have significantly lower slip resistance capacity than those with the teeth or ridges. Excessive galvanization or

loose and flaking galvanization on the strut channel may also lead to reduced bolt resistance to slippage. Channel nuts should be randomly sampled to provide reasonable assurance that teeth or ridges are present when required for structural integrity, and that the nuts are properly engaged on the frame sections.

5.2.3 Cast-Iron Anchor Embedment

Threaded rod hanger anchor embedments constructed of cast iron should be evaluated because of potential brittle failure modes. Plant documentation should be consulted to determine whether anchor embedments are cast iron. The earthquake experience data base includes examples where heavily loaded rod hangers threaded into cast-iron inserts have failed (Reference 8). Failure modes include anchor pullout and anchor fracture where rods are only partially threaded into the anchor.

5.2.4 Broken Hardware

Any observed missing or broken hardware for HVAC duct and supports should be noted so that repair or replacement may be provided. HVAC related hardware that is missing or broken should be evaluated to determine the consequences that this would have on the HVAC system. In particular, it should be determined if the integrity of the HVAC pressure boundary could be affected.

5.2.5 Corrosion

Excessive corrosion of HVAC ducts, connections, or supports (including anchorage) should be evaluated for its effect on structural integrity. Light surface corrosion is generally not a concern but heavy flaking or pitting might be. Seismic experience data have shown that significant corrosion may lead to poor seismic performance for many plant items. Corrosion reviews are especially important in damp areas of a plant such as pump houses. Evaluations should consider an estimated strength reduction due to corrosion. Significant corrosion should generally be identified for repair.

5.2.6 Concrete Quality

Gross defects or large cracks in the concrete to which the duct supports are attached should be evaluated for their potential effects on seismic performance. Visibly large cracks, significant spalled concrete, and serious honeycombing in the vicinity of HVAC duct support anchors should be considered as gross defects. The walkdown team should consider grossly defective concrete as outliers and include supports anchored to marginally defective concrete in the sample selected for the limited analytical review.

5.2.7 Welded Attachments

Support anchorage connections containing obviously undersized welds, incomplete welds, or welds of poor quality (i.e., with significant burn-through) require analytical review incorporating reduced capacities. Seismic experience data and shake table tests have shown that welds not capable of developing the strength of connected members may be subject to a brittle-type failure mode during seismic loading.

5.2.8 Rod Hanger Fatigue

Although no specific instance of fatigue failure has been identified for HVAC duct rod hangers, raceway shake table tests have shown that short, fixed ended, heavily loaded rod hangers may be subject to low cycle, high strain fatigue failures during seismic events (Reference 8). Rod hangers that may be subject to high strain low cycle fatigue effects should be investigated in greater detail. The rod fatigue evaluation requirements outlined in Section 6.4.2 should be used to address rod fatigue concerns. Rods to be evaluated are characterized as follows:

- rods double nutted to flanges of steel members
- rods threaded into shell-type concrete expansion anchors
- rods connected by rod couplers to non-shell type concrete expansion anchors

- rods threaded into rod couplers which are welded to overhead steel embedments.

5.3 SEISMIC INTERACTION REVIEW

Requirements for the evaluation of seismic interaction are as follows:

5.3.1 Proximity and Falling Hazards

The walkdown team should be aware of issues associated with seismic interaction and be alert for potential seismic interaction hazards. Duct systems attached to or in the vicinity of unanchored components or unrestrained block walls should be noted and evaluated. Only credible and significant interaction sources should be considered as outliers. Damage that may occur to the duct itself as well as to any safety related equipment that the duct may interact with should be considered.

If an isolated support with questionable structural adequacy is found, the walkdown team should perform further evaluation of its adequacy or exercise judgment regarding the likely consequences of failure. If the adjacent spans are not excessive, and if adjacent supports have a sufficiently high factor of safety, 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 fragile components in proximity.

5.3.2 Differential Displacement Hazards

Ducts spanning from one structure to another should be checked to assure that they can accommodate any relative movement of the structures. Experience data indicate failures for duct systems without sufficient flexibility at spans experiencing differential displacement (Reference 3). Stress criteria established in Section 6 of this procedure should be used if this condition is identified.

5.4 PRESSURE BOUNDARY INTEGRITY REVIEW

This section applies to HVAC duct systems where a high confidence level of pressure boundary integrity is required for functional considerations. The following are in-plant screening requirements to achieve this level of pressure boundary integrity.

5.4.1 Duct Joints and Stiffener Spacing

Stiffeners prevent bulging of the duct panels due to internal pressure. Lateral joints such as companion angles, and lateral reinforcements, typically of steel angles, are considered as stiffeners. Earthquake experience and test data have demonstrated that duct systems which met the SMACNA guidelines performed well during earthquakes. Items to be checked for the given system operating pressure requirements include sheet metal gage, stiffener size and spacing, and panel dimensions. For bolted duct connections, it is also necessary to check minimum flange height, number of bolts, maximum hole spacing, and ring size where segments of round duct are bolted together. Applicable sections from the SMACNA standards include Section 7 of Reference 6; Sections 4 and 5 of Reference 7; and Sections 1 and 3 of Reference 5.

5.4.2 Round Duct Supports

Round HVAC duct runs supported such that the duct is point loaded should be considered outliers unless the duct is reinforced at the point of support. An example of this situation is a round duct supported by a rod hanger without a saddle.

5.4.3 Flexible Bellows

Flexible bellows connecting HVAC duct to in-line equipment may become damaged if they do not have enough slack to accommodate differential motion between the equipment and the duct. Bellows are typically not designed to resist any large differential motions imposed by the earthquake. If reasonable estimates of bellows flexibility cannot be determined by judging the available slack in the as-installed configuration, then manufacturers data should be reviewed.

5.5 SELECTION OF BOUNDING CONFIGURATIONS

As part of the in-plant screening review, representative, worst-case HVAC duct and duct supports are selected as bounding configurations. These selected configurations are then subjected to the analytical evaluations of Section 6. Detailed evaluation of bounding, worst-case configurations assures the seismic adequacy of the entire population. When selected configurations do not pass the analytical review, the selected population must be expanded to identify the population of HVAC system configurations that meet the required seismic criteria.

The walkdown team needs to understand the analytical review requirements presented in Section 6 prior to performing in-plant screening reviews and selection of bounding configurations. The goal is to establish a biased, worse-case sampling, representative of and bounding the major different HVAC configurations in the scope. This bounding of worse-case samples will be subject to analytical review.

Notes should be taken describing the basis for selection of each configuration. The location of the selected configuration should be noted, and detailed sketches of the as-installed condition should be made. As-built sketches should include the duct and support configuration, dimensions, connection details, anchorage attributes, member sizes, and loading. Any additional information that may be considered relevant to the seismic ruggedness of the selected configuration should be noted in detail.

Building elevation should be taken into account when choosing HVAC duct configurations as bounding samples. Identical systems at two different elevations in the plant experience different seismic environments. The higher the building elevation, the greater the seismic demand. Therefore, it is possible that a system appearing to have few seismic vulnerabilities which is located at an upper elevation in a building may actually have a greater probability of failure than a system located at a lower elevation with a worse configuration. The walkdown team members should acquaint themselves with the differing seismic demand environments in the buildings being inspected by reviewing the floor response spectra before selecting the bounding sample.

5.5.1 Selecting Bounding Duct Support Configurations

The most heavily loaded support for each duct configuration should be selected as a bounding case. Long spans, insulated duct, supports carrying multiple ducts, top supports of vertical runs, heavy in-line components and isolated "stiff" supports on rod hung systems are indicators of heavy load. Duct support configurations to consider are long HVAC runs with few supports providing lateral or longitudinal restraint, long vertical runs, runs with seemingly weak curved sections, and runs with large, flexibly mounted in-line equipment. Of particular importance are duct supports that appear to have more load than originally designed for. Heavily loaded supports can be identified by the presence of other plant components attached to the supports, such as supports for pipe, cable trays, and conduit.

Selection of a bounding duct support should consider conditions where anchorage appears to be the weak link in the load path. Duct supports with anchorage that appears marginal for the supported weight should be investigated. Anchorage with undersized welds, incomplete welds, or welds of poor quality should also be evaluated. Overhead support steel, such as steel angle, used specifically as an anchor point to support the duct system should have its anchorage to the building structure evaluated.

5.5.2 Selection of Bounding Duct Configurations

When appropriate, the selection should include duct systems with evidence of extreme or over-pressure loads, and/or duct systems that appear to be deteriorated but require pressure boundary integrity. Examples include buckled or deformed sheet metal, leaking joints, corroded joints, and suspect flexible joints.

6. ANALYTICAL REVIEW

Analytical evaluations shall be performed on the selected bounding or sample HVAC duct and support configurations required to achieve duct system function following a seismic event. The selection of duct and/or support configurations shall be consistent with the requirements of Section 5.5. The duct evaluation criteria are based primarily on the design approach utilized in SMACNA's construction standards for round and rectangular industrial duct (References 6 and 7). Equations for computing pressure stresses in duct and stiffeners are taken directly from SMACNA standards. Use of this procedure results in a conservative estimate of the duct capacity and is compatible with data obtained from various test programs listed as References 9 through 13.

The pressure boundary integrity review of HVAC duct considers the combined effects of dead weight and seismic loads on the duct, as well as the effects of pressure on the duct and stiffener. The combined dead load and seismic stress is checked against a factored allowable working stress for acceptance. The general stress combination equations are given below:

Horizontal Duct

$$f_{DL} + [(EQ_v)^2 + (EQ_{hx})^2 + (EQ_{hz})^2]^{1/2} < F_b$$

Vertical Duct

$$[(EQ_{hx})^2 + (EQ_{hz})^2]^{1/2} < F_b$$

The effects of longitudinal seismic loading on the ducts is typically not a concern. However, if duct configurations are found which may experience significant longitudinal loading, these effects should be combined with transverse and vertical seismic loading by the Square Root of the Sum of the Squares (SRSS) method in the stress calculations.

6.1 DEAD LOAD AND SEISMIC STRESSES

Analysis for dead and seismic loads may be performed using either the equivalent static load method or the response spectrum method.

The equivalent static load method follows a tributary length approach using the spectral acceleration at the applicable frequency (use peak floor spectral acceleration if frequency is unknown). An equivalent static coefficient of 1.0 times the spectral acceleration is used which is similar to the static coefficient used for equipment items addressed in Reference 2. For this method, the bending moment for a simply supported span is approximated by (References 6 and 7):

$$M = (w*l^2) / 10 \quad (1)$$

Other configuration anomalies, such as cantilevered duct sections, shall be considered on a case-by-case basis.

Bending stresses due to axial response of a duct system may result if the axial run of duct is not braced in the longitudinal direction along the run of duct. If the axial restraint is provided by the first lateral restraint around a bend in the system, then the bending stress in the duct at the lateral restraint should be checked also for longitudinal motion of a tributary span of the axial run.

Alternatively, longitudinal load resistance along an axial run may be provided by framing action between the duct itself and the supports, if the duct is adequately attached to the supports. In this case, the additional bending moment in the duct (about the transverse horizontal axis) must be checked.

The response spectrum method requires modeling of sufficient ducting to analytically represent the expected dynamic response of the system. In general, this includes duct up to anchor points or equivalent adequate restraint. Modal combinations are performed using the Square Root of the Sum of the Squares (SRSS) method. The analyses should consider all modes up to 33 Hz and include a minimum 90% mass participation.

For both methods, a critical damping ratio of 7% is appropriate for determining the seismic loads. This damping ratio is a conservative estimate of derived damping ratios from actual shake table tests (References 9 through 13).

Bending stresses for dead weight and seismic loads are derived using the duct section modulus as follows:

$$f_b = \frac{M}{Z} \tag{2}$$

Allowable bending stresses differ for rectangular and round ducts.

For rectangular ducts, Reference 6 limits the effective area of sheet metal for calculation of the duct section modulus to a 2-inch by 2-inch region at the four corners of the duct. A reduced section modulus is thus calculated by assuming only these corners are effective in resisting bending. For round ducts, the full section is available for resisting the bending moment on the duct (Reference 7).

In addition, frequency correction factors of 0.59 and 0.87 for pocket lock (or equivalent) and companion angle (or equivalent) constructions, respectively, must be applied to adjust the calculated rectangular duct frequency based on analytical correlation of test results (Reference 4).

For the normal operating condition, the allowable bending stress due to dead weight for rectangular and round steel duct, as specified by SMACNA, is 8 ksi and 10 ksi, respectively. This allowable stress limit is increased by a factor of 1.5 for SSE effects. The 1.5 factor results in a minimum factor of safety of about 1.5 with respect to the duct bending stress capacity. This is based on analytical correlation of test results with respect to bending stresses at failure (References 8, 9, 10).

$$F_b \text{ (rectangular)} = 1.5 * 8.0 = 12.0 \text{ ksi}$$

$$F_b \text{ (round)} = 1.5 * 10.0 = 15.0 \text{ ksi}$$

The above allowables apply to the pocket lock and companion angle (or equivalent) ducts (i.e. joints types T-17 through T-24 of Figure 1), since all duct testings

(References 8, 9, 10) were performed on these types of duct joints. For potentially weaker steel ducts, such as the types T-1 through T-16 of Figure 1, the SMACNA allowables of 8.0 ksi (rectangular duct) and 10.0 ksi (round duct) should be used without the increase factor of 1.5. SMACNA allowables may also be used for slip joints which do not fit any of the Figure 1 duct joint types but can be shown to behave similarly to one of them. Those slip joints which do not fit any of the Figure 1 duct joint types and can not be shown to behave in a manner equivalent to one of them should be evaluated separately.

6.2 PRESSURE STRESS IN DUCTS

The effect of stress in HVAC duct material from internal pressure shall be accounted for in the analytical evaluation of HVAC duct requiring pressure boundary integrity. These pressure stresses are checked against pressure stress allowables established in the SMACNA guidelines.

6.2.1 Pressure Stresses in Rectangular Ducts

The SMACNA design of rectangular ducts is based on simplifying assumptions which permit the reduction of the analysis from a three-dimensional to a two-dimensional problem. Each of the four sides of the duct is assumed to act as an independent two-dimensional panel. Duct panel stresses are computed based on thin plate bending equations found in Reference 15.

For a given rectangular duct, the largest cross-sectional dimension (i.e. width or height) is used for stress analysis (see Figure 2). The applicable plate bending equations are dependent on the ratio of this maximum duct dimension, S, to the duct stiffener spacing, L.

Two simplified models used to calculate duct pressure stresses are shown below:

<u>If $L \le S$:</u>

The duct panel is idealized as one-way plate bending over a fixed-ended span, L, with axial in-plane tensile reactions resisting the increase in panel length due to bending curvature.

Let:

T = Axial tensile reaction resisting the increase in length due to bending curvature

$D_b = E*t^3/(12(1-v^2))$ (plate bending stiffness coefficient) (3)

$u = 0.5L(T/D)^{0.5}$ (4)

To obtain u, use Figure 3 taken from Reference 15. To use this chart, the variable U_1 is first calculated as:

$U_1 = (E^2*t^8) / ((1-v^2)^2*p^2*L^8)$ (5)

The quantity $\log_{10}(10^4*U_1^{0.5})$ then gives the ordinate of the curve in Figure 3, and the corresponding abscissa gives the required value of u. After determining U, the maximum stresses in the plate are calculated as follows:

The maximum tensile stress is (Reference 15):

$f1 = (E*u^2)*(t/L)^2/(3(1-v^2))$ (6)

The maximum bending stress is (Reference 15):

$f2 = (p/2)*(L/t)^2 * 3(u-\tanh(u))/(u^2 * \tanh(u))$ (7)

Maximum total pressure stress is:

$f_p = f1 + f2$ (8)

If L > S:

As the stiffener spacing exceeds the width of the critical duct section, the restraining effect of the panel side edges increasingly influences the stress distribution within the panel, requiring the use of a second set of stress equations.

The panel is modeled as a uniformly loaded rectangular two-way plate fixed on the two opposite edges at the stiffeners and hinged on the edges along the sides. The maximum bending moment occurs at the mid-points of the fixed edges and is given by (Reference 15):

$$M_{max} = K*p*S^2 \qquad (9)$$

A list of K values for various L/S ratios, is given in Table 1.

The resulting stress is:

$$f_p = 6*K*p*S^2/t^2 \qquad (10)$$

Through the use of equations (9) and (10), the panel pressure stresses can be calculated for any combination of system pressure and duct dimensions.

The allowable pressure stresses for rectangular and round steel ducts are taken per Reference 6 as:

$$F_p = 24 \text{ ksi}$$

6.2.2 Pressure Stresses in Round Ducts

The pressure capacity of circular ducting is controlled by either buckling of the duct 'skin' or buckling (or yielding) of the duct stiffeners assuming negative duct pressure. Duct skin buckling is influenced by the duct end conditions.

The critical duct pressure is given per Reference 7 by two equations developed to envelop conditions for which the duct length is short enough for end conditions to be important.

$$F_p = \text{Min}(F1, F2) \tag{11}$$

where:

$$F1 = 31.92*E*(D/L)*(t/D)^{2.5}/((1-v^2)^{0.75}*(52+D)) \tag{12}$$

$$F2 = (28*E*(t/D)^3)/((1-v^2)*(52+D)) \tag{13}$$

This critical duct pressure should be used as the pressure stress allowable, F_p.

6.3 PRESSURE STRESSES IN STIFFENERS

6.3.1 Stiffener Evaluation for Rectangular Ducts

Following analysis of the panels, the duct stiffeners are checked for two conditions:

- Maximum deflection $\leq$ S/360
- Maximum bending stress in the stiffener $\leq$ 24 ksi

The load transmitted to the stiffener from the duct panel is dependent on the ratio of L/S. The tributary load to the stiffener, q, is calculated as follows:

For L/S $\leq$ 2.0,

$$q = p*L \tag{14}$$

For 2.0 < L/S $\leq$ 10.0,

$$q = p(1.25 - 0.125*L/S)*L \tag{15}$$

For $L/S \geq 10.0$,

q = tributary load resulting from pressure p being applied on an area bounded by lines radiating at 45° from the ends of the stiffener (see Figure 4).

$$= p(S/2) \tag{16}$$

The stiffener stress evaluation for the above loading conditions is dependent upon whether the stiffener ends are fixed or pinned.

Stiffeners welded at their ends to stiffeners from the adjacent side of the duct provide bending moment transition and are considered fixed. Such stiffeners should be analyzed as follows:

$$f = q*S^2*c/(I*10) \leq 24 \text{ ksi} \tag{17}$$

$$d = 3q*S^4/(384*E*I) \leq S/360 \tag{18}$$

Stiffeners are considered pinned regardless of whether they are bolted at their ends, tack welded, or not connected at their ends. Such stiffeners should be evaluated as follows:

$$f = q*S^2*c/(I*8) \leq 24 \text{ ksi} \tag{19}$$

$$d = 5q*S^4/(384*E*I) \leq S/360 \tag{20}$$

Inadequate stiffeners will need to be supplemented. Stiffeners placed on only two opposite sides of a rectangular duct and meeting the above criteria are adequate as long as the panel width is less than 72 inches. For panels of longer size, stress concentration becomes excessive and additional stiffeners are required.

6.3.2 Stiffener Evaluation for Round Ducts

The capacity of round duct stiffeners is controlled by buckling or yielding, where the theoretical buckling strength is proportional to the moment of inertia of the stiffener, and the yield strength is proportional to the area. Both of the following equations must therefore be satisfied (Reference 7):

$$I > I_{min} = 0.917*p*L*D^3/E \quad (21)$$

$$A > A_{min} = (52+D)*p*L*D/(14*f_y) \quad (22)$$

6.4 DUCT SUPPORT EVALUATION

6.4.1 Rod Hanger Supports

A fatigue evaluation should be conducted for rod hanger supports that have rods with fixed end connection details. For rod hung HVAC duct systems with rods of uniform length, the fatigue evaluation is conducted as follows:

(a) Obtain the 5% damped floor response spectrum for the location of the support attachment point.

(b) Compare the Bounding Rod Fatigue Spectra of Figure 5 with the damped floor response spectra.

For a given ZPA, if a Rod Fatigue Spectrum entirely envelops the floor response spectrum, proceed to step (c). If the Rod Fatigue Spectrum does not entirely envelop the floor response spectrum, then compare the Rod Fatigue Spectrum with the floor response spectrum (unbroadened) at the frequency of the support. Support frequency may be estimated as follows:

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

where:

M_S = W_{equiv}/g (lbs-sec^2/in)

K_S = $24EI/L^3 + W_{equiv}/L$ (trapeze support, lbs/in)

W_{equiv} = total dead weight on the pair of rod supports (lbs)

g = gravitational constant (386.4 in/sec^2)

E = Young's modulus of rod hanger material (psi)

I = moment of inertia of rod root section (in^4)

L = length of rod above top tier (in)

If the bounding Rod Fatigue Spectrum does not envelop the floor response spectrum at the frequency of interest, then a more detailed evaluation should be conducted (by requirements other than the screening evaluation requirements presented herein).

(c) Figure 6 provides an example of a typical rod hanger fatigue evaluation screening chart for a trapeze support. If hanger length is greater than minimum acceptable length, and support dead weight is less than maximum acceptable weight, then the support is acceptable. This chart is applicable for all continuously threaded rods. For field threaded rods see (d) below. The rod shown in Figure 6 is for 3/8-inch-diameter rod. Charts for other rod sizes may be obtained from Figures 8-10 through 8-14 of Reference 1.

(d) If field threaded rods are to be evaluated, then the screening chart may be used for modified rod lengths and weights. For field threaded rods, double the weight and decrease rod length by 1/3 before using the chart.

If isolated, short fixed-end rod hangers are used in a system with predominantly longer, more flexible hangers, a special evaluation should be conducted if the isolated support does not meet the redundancy and consequence test as outlined in Section 7.4.4. The special evaluation proceeds as follows:

(a) Estimate the frequency of the system, neglecting the isolated, short rod support. The frequency estimation formula given above may be used, providing that the length of the longer rods is considered.

(b) Assure that the rod fatigue bounding spectrum envelops the applicable floor response spectrum at this frequency of interest.

(c) Back-calculate an equivalent weight for the evaluation of an isolated short rod, using the frequency of the long rods as follows:

$$W_{equiv} = \frac{24\,EIg}{(2\pi f_s)^2 L^3 - gL^2} \qquad \text{(trapeze support)}$$

(d) Check the short rod length for this equivalent weight, using the screening chart of Figure 6.

6.4.2 Other Support Types

Other support types such as cantilever bracket, trapeze frame, and light metal strut channels, should be evaluated using equivalent static method for the combined effects of dead weight and seismic loads. Steel components, such as bracket members, support members, and internal support framing connections should be checked against the allowables specified in Reference 2.

6.4.3 Anchorage Evaluation

Capacity values for anchors should be taken from Reference 2. The provisions of these anchorage guidelines should be followed, including edge distance, bolt spacing, and inspection procedures. For overhead- and wall-mounted supports, tightness

checks do not need to be conducted for these expansion anchor bolts which are normally subjected to tensile forces due to dead weight.

6.4.4 Redundancy and Consequence Test

Isolated cases of a support not meeting the analytical review guidelines may be accepted if the HVAC support system has redundancy so that postulated support failure would have no consequence to overall system performance. Adequate redundancy is demonstrated if the adjacent supports are capable of sustaining the additional weight resulting from the postulated support failure.

6.5 RESOLUTION OF OUTLIERS

Outliers identified during the evaluation should be documented and resolved following the guidelines provided in Sections 6.1 through 6.4 or other analytical methods based on industry-standard practices and sound engineering mechanics principles.

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TABLE 1

VALUE OF K FOR RECTANGULAR DUCTS

(From Reference 15)

Values of Parameter K	
L/S	**K**
1.0	-0.0697
1.1	-0.0787
1.3	-0.0868
1.4	-0.0938
1.5	-0.0998
1.6	-0.1049
1.7	-0.1090
1.8	-0.1122
1.9	-0.1152
2.0	-0.1174
3.0	-0.1191
---	-0.1250

L = Stiffener spacing (in)
S = Max (height, width in inches)
K = Dimensionless coefficient

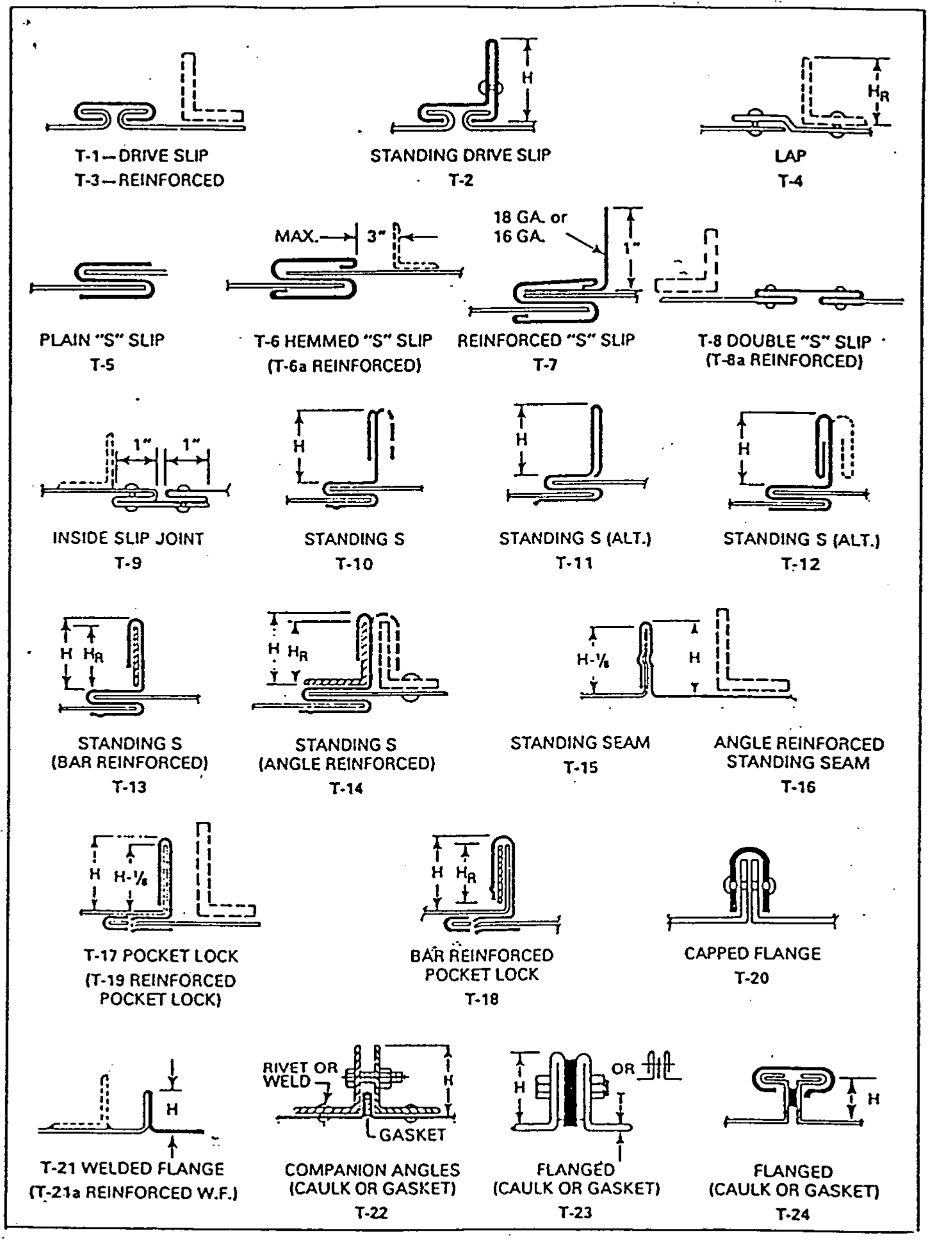
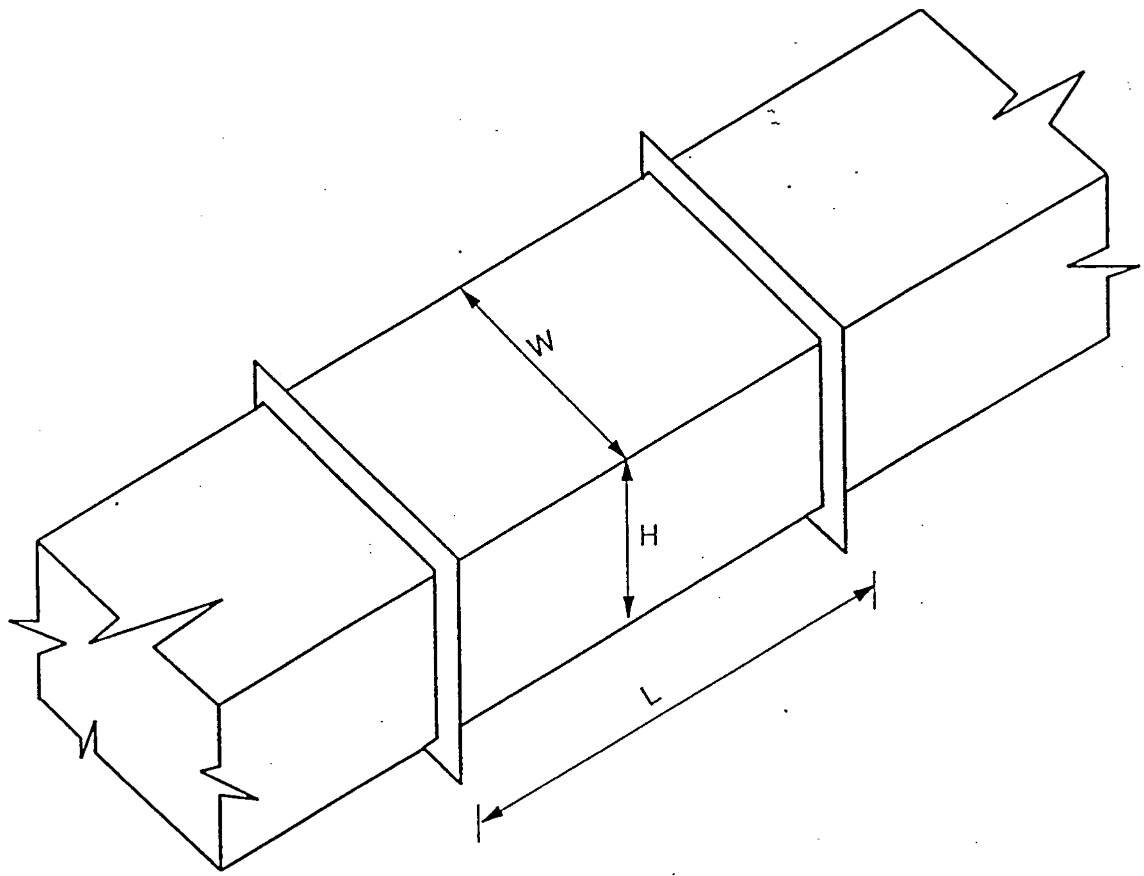


Figure 1: SMACNA Duct Joints



S = Max (H, W)

Figure 2: Rectangular Duct Configuration

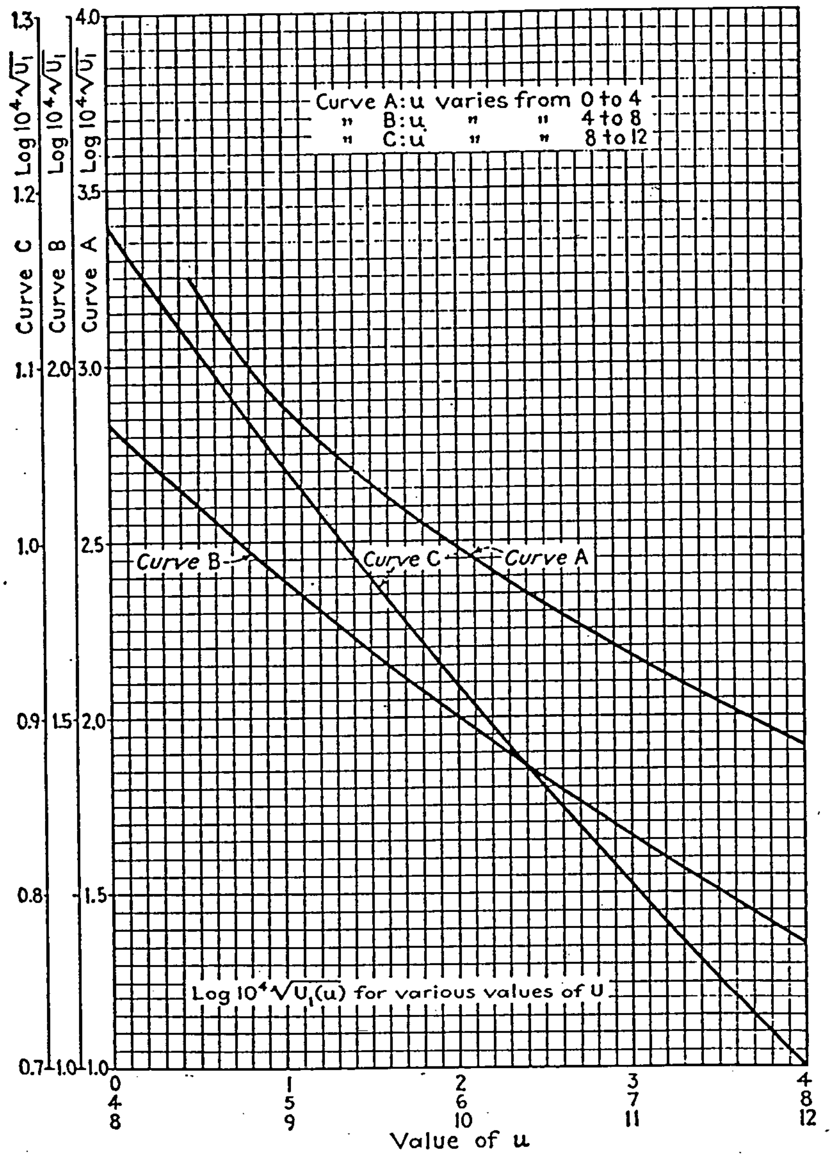


Figure 3: Value of u for Rectangular Ducts (From Reference 15)

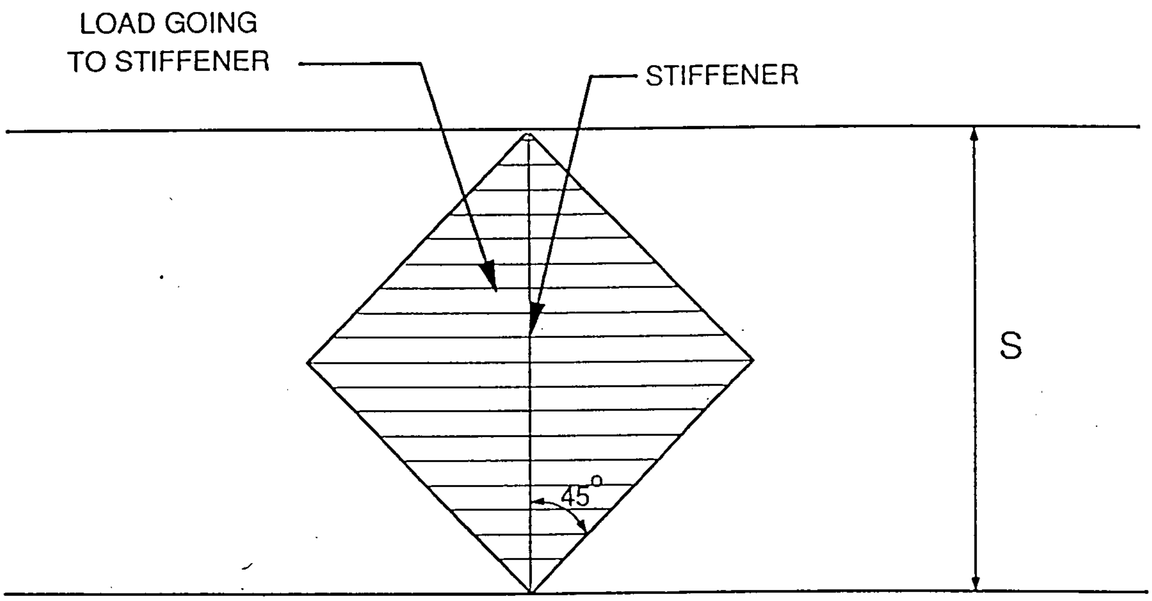


Figure 4: Load Going to Stiffener on a Rectangular Duct When $L/S \geq 10.0$ (Reference 6)

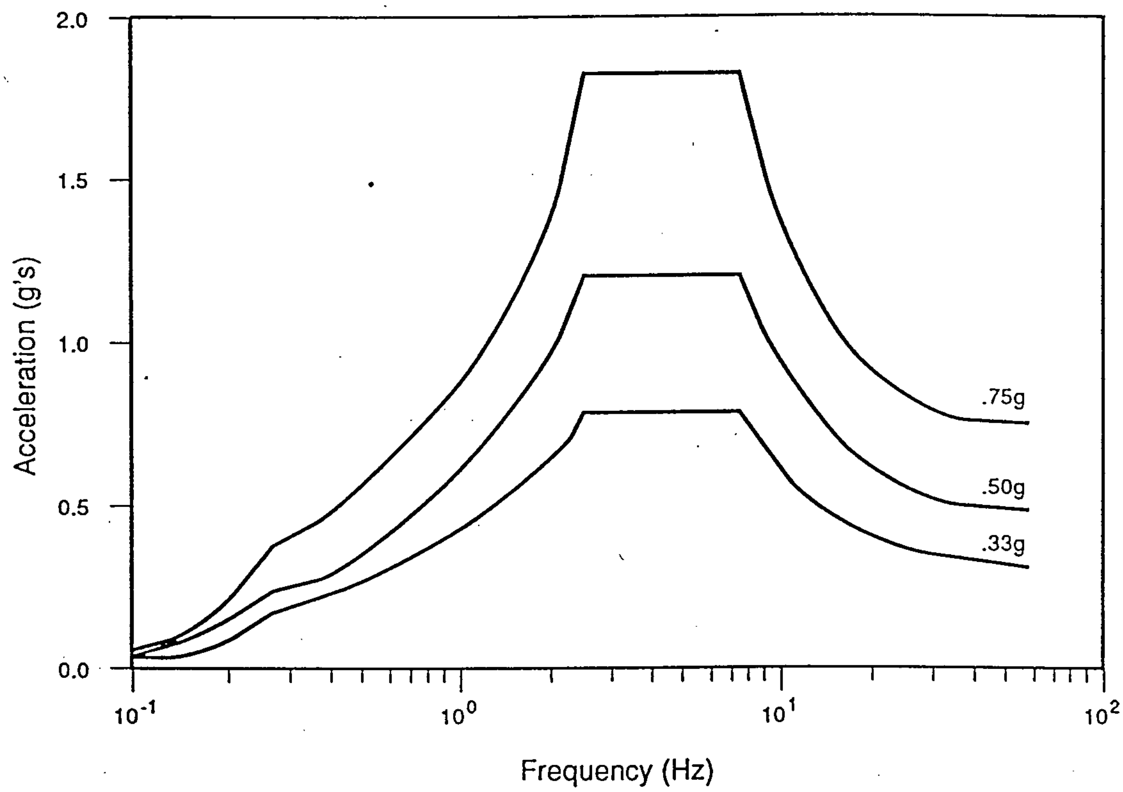


Figure 5: Bounding Rod Fatigue Spectra (5% damping)

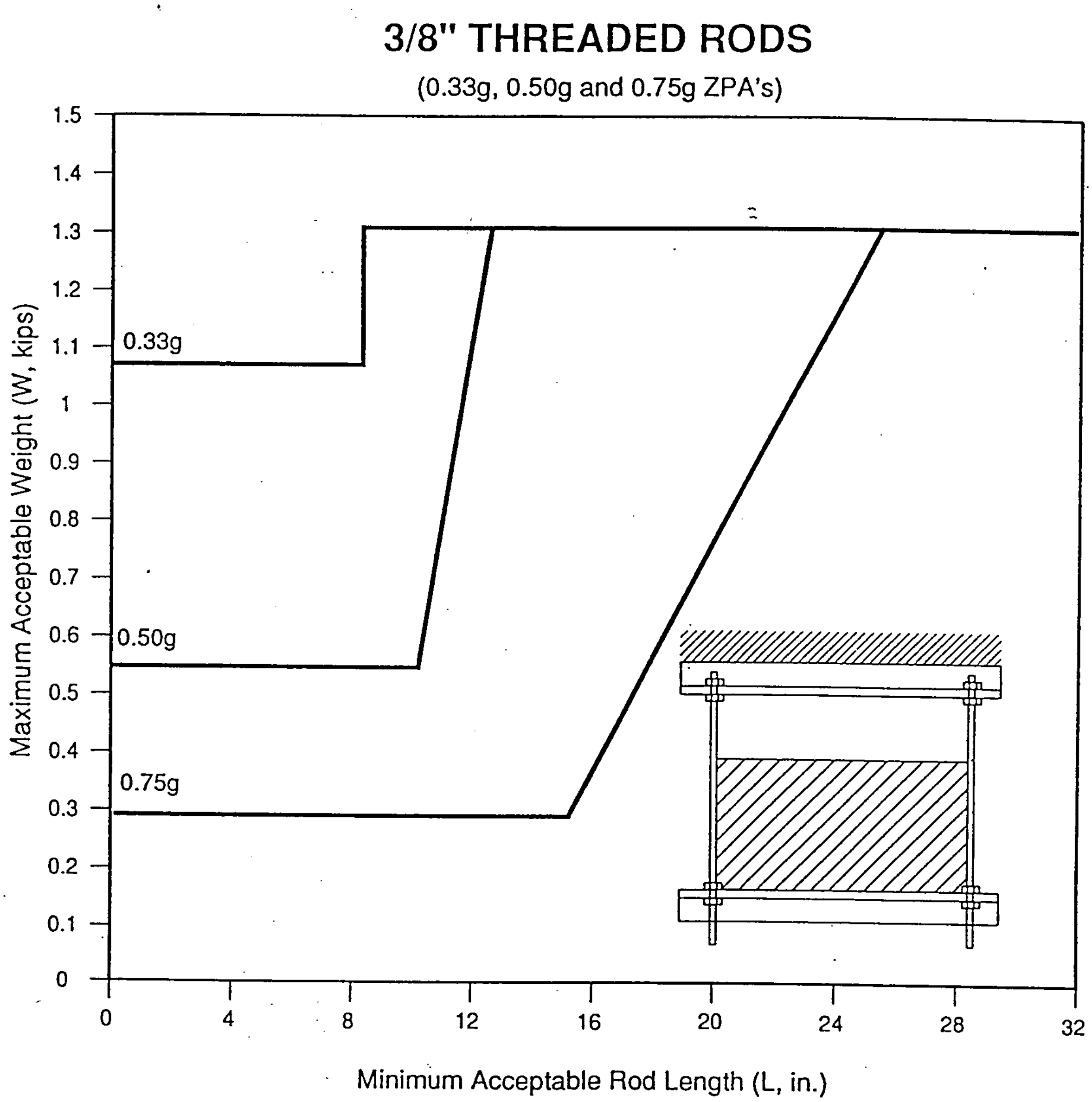


Figure 6: Rod Fatigue Screening Chart

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Recommended Approaches for Resolving Anchorage Outliers

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Outlier No. 5 - Prying Action

Introduction

Prying forces result from eccentricity between the points of load application and resistance, and their magnitude depends upon the flexibility of the connection pieces. A typical case where the effects of prying may be significant is illustrated in **Figure 5.1**. This connection consists of a clip angle which is attached to an equipment cabinet and bolted to a concrete slab via an expansion bolt.

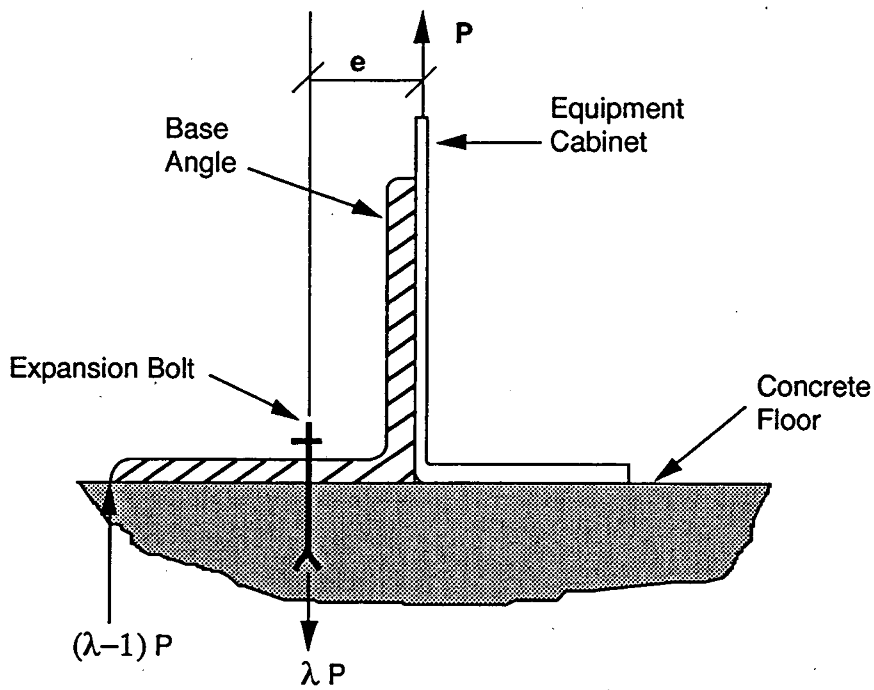


Figure 5.1 – Typical Base Anchorage with Prying on Clip Angle

A seismic analysis of the cabinet may indicate a vertical load, P, transferred to the vertical leg of the angle due to overturning of the cabinet. Due to the eccentricity, e, and the continuous beam action in the base member (i.e., angle, channel, or plate), the load resisted by the bolt will be amplified by a factor λ. Thus, the evaluation of the anchor bolt needs to consider forces that are greater than those which result from a simplified analysis of the cabinet.

The GIP Rev. 2 and the supporting EPRI anchorage report include cautionary language regarding the possible effects of prying. However, these documents do not provide specific guidance regarding methods and criteria for evaluating prying. The following development suggests a method for evaluating prying and presents example analyses to illustrate the effect of variations in the flexibility of the connecting pieces on the magnitude of the prying force developed in the anchor bolt.

nalysis Approach for Cabinets with Clip Angle

A mathematical computer model used to evaluate prying is illustrated in **Figure 5.2**.

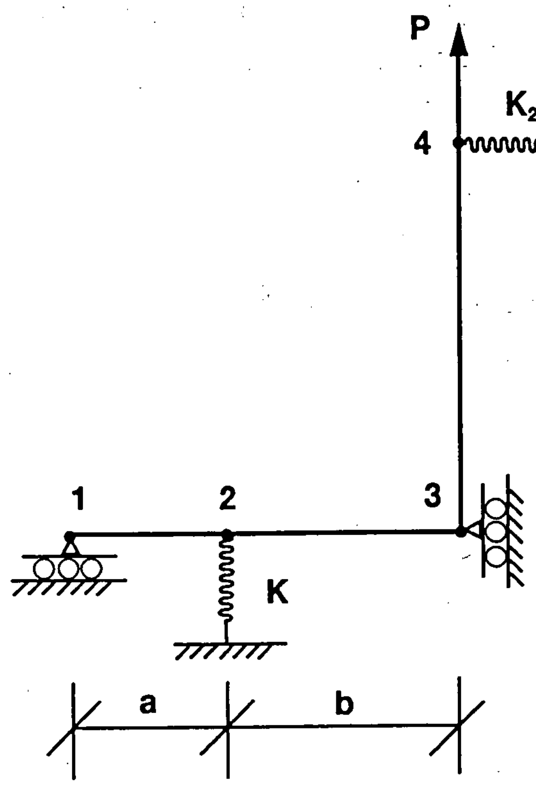


Figure 5.2 – Structural Model Used to Evaluate Prying

The angle is modeled as a series of beam elements, and the expansion bolt is modeled at node 2 as a spring with stiffness K. In the following example evaluations, the spring stiffness was taken from expansion anchor bolt tests conducted by URS for EPRI (Reference 6). Bolt stiffness data are presented in **Table 5.1**. The vertical leg of the angle is laterally restrained in two places but is free to displace in the vertical direction. The restraint at node 3 represents the combined effect of the lateral stiffness of the anchor bolt and the concrete slab, and it is assumed as rigid for this study. The spring at node 4 (K_2) represents the local translational stiffness of the cabinet wall at the top of the base angle. Variation of stiffness in this lateral restraint significantly affects the prying load in the anchor bolt. To demonstrate the impact of this restraint on the prying, the model of **Figure 5.2** was used with a 4"x4"x1/2" clip angle. The stiffness K_2 was increased y a factor of 10 in consecutive analyses, and the prying load on the bolt was noted. The results are summarized in **Table 5.2**.

TABLE 5.1

Bolt Stiffness Data

Bolt Diameter Inch	**Bolt Stiffness ($\overline{X} + \sigma$) kips/inch**
3/8	159
1/2	530
5/8	645
3/4	1,098
7/8	1,022
1	1,942

TABLE 5.2

Variation of Prying Force with Lateral Stiffness K_2

K_2 (Kip/inch)	λ
0.000	2.67
0.345*	2.61
3.450	2.26
34.500	1.46
345.000	1.16
3,450.000	1.12
Rigid	1.12

*equivalent to lateral stiffness of a 90" tall, 10" wide, and 0.15" thick simply supported plate calculated 3" above the base. K_2 may be higher for bolts located closer to the cabinet corners.

For design, accurate quantification of the lateral stiffness of the cabinet wall may be time-consuming. Therefore, it is recommended that the prying initially be estimated based on the assumption of no lateral support at node 4. If this assumption leads to prying loads that cannot be accommodated, a more refined analysis, including the actual flexibility at node 4, should be used.

Other key parameters of the model in **Figure 5.2** are the axial stiffness of the spring (K) and the bending stiffness of both the horizontal and vertical legs of the angle. If the spring representing the bolt is flexible and the angle is stiff, relatively small prying forces will be created. An extremely flexible bolt combined with a rigid angle will result in separation between the concrete surface and the entire horizontal leg of the angle. This behavior precludes the development of any prying forces. In this configuration, the flexural stiffness of the base members (i.e., members 1-2 and 2-3) and the vertical member (3-4) depends on the member

length (perpendicular to the plane of paper) assumed to be effective in resisting prying forces. For this study, unit length of the clip angle equal to the width of the leg was considered as effectively participating in the development of prying force on the anchor bolt.

In contrast, a relatively stiff spring and a rigid angle will result in significant prying forces. An extreme case of an infinitely rigid spring could lead to a force in the spring that is larger than the applied load by a factor of (a+b)/a. When a and b are approximately equal, this factor implies an upperbound prying amplification of 2. If the clip angle is extremely flexible (such as a rubber band), there is no prying in the bolt. As the base flexural stiffness increases, the prying becomes a function of axial stiffness of the bolt.

A parametric study was performed to determine the impact of bolt stiffness on the prying factor. Two models - the first, a 3"x3"x3/8" clip angle with a 1" Ø bolt and the second, a 4"x4"x1/4" clip angle with 1/2" Ø bolt - were utilized as shown in **Figure 5.2**. The bolt stiffness was reduced by a factor of 10 in consecutive analyses, and the prying load on the bolt was computed. The results are summarized in **Table 5.3**.

TABLE 5.3

Variation of Prying Load with Anchor Bolt Stiffness K

Section	Bolt Size	Stiffness (K/in)	λ
3"x3"x3/8"	1"Ø	1942.000	2.57
		194.200	2.54
		19.420	2.32
		1.942	1.23
4"x4"x1/4"	1/2"Ø	530.00	2.56
		53.00	2.47
		5.30	1.84

The above results confirm that the prying load increases for a given clip angle as the bolt stiffness increases. Also, the above data indicate that the typical bolts used in the industry have a large enough actual axial stiffness to preclude the base from lifting.

The cabinet, and the attachment between the cabinet and the angle are assumed to be capable of resisting the applied loads. This load transfer should be checked as part of the prying evaluation.

[illegible]nal consideration is the relative dimensions a and b. The prying loads in the bolts are relatively sensitive to small changes in the bolt location. As the dimension "a" in **Figure 5.2** reduces, the prying load on the

bolt increases. The example evaluation discussed below considers the bolt to be located at b=g, where g is the gage length of the angle. This bolt location conforms to the American Institute of Steel Construction (AISC) fabrication specifications (Reference 8). If the bolt is moved farther toward the angle heel such that a=b, the prying factor will reduce.

Example Evaluations

The model illustrated in **Figure 5.2** was used to evaluate the effects of prying for several typical anchorage configurations. The PC-based structural analysis program RISA-2D (Reference 9) was used for these evaluations. The following angle sizes were considered:

L 3x3x ¼, ⅜, ½	Width = 3"
L 4x4x ¼, ⅜, ½, ⅝, ¾	Width = 4"
L 6x6x ⅜, ½, ⅝, ¾, ⅞, 1	Width = 6"

As previously mentioned, the bolt was assumed to be located at b=g, where g is the gage length per AISC for a given size of angle. Bolt diameters ranging from ⅜" to 1" were considered with bolt stiffnesses taken from Reference 6 at the mean plus one standard deviation level. Bolt stiffness data are summarized in **Table 5.1**.

The results of the evaluation are summarized in **Table 5.5**. The prying factor, λ, presented in the table is the ratio of the load resisted by the anchor bolt and the load applied to the vertical leg of the angle. Thus, for the first entry in the table (Angle 3x3x1/4 with 3/8" diameter bolt) the force in the expansion anchor is 2.33 times the applied load for the bolt located at gage.

The results shown in **Table 5.5** support the trends previously discussed. Specifically, for a given angle size, prying loads in the bolt tend to increase with anchor stiffness. For a given bolt diameter, the prying loads tend to increase as the flexural stiffness of the angle leg increases. For each bolt diameter, the maximum prying factors are associated with the 4x4x3/4 angle, and these values range from 2.62 to 2.66, with the bolt at gage.

It should be noted that when the anchor bolts are located at gage as it is given in AISC, the 4x4 angle produces the largest prying factors, considering all bolt sizes and angle thicknesses. This is anticipated as the gage dimension given by AISC are such that the ratio (a+b)/a is the largest for this angle as shown on **Table 5.4**.

TABLE 5.4 - Comparison of Predicted and Computed Prying Loads

Section (inches)	Gage=b (inches)	a (inches)	$\lambda = \frac{a+b}{a}$	computed λ
3x3	1.75	1.25	2.40	2.37
4x4	2.50	1.50	2.67	2.64
6x6	3.50	2.50	2.40	2.37

The actual prying factor determined by computer is slightly lower than the approximate prying factor calculated based on the assumption of a rigid clip angle and a relatively rigid bolt. The difference takes into account the actual stiffnesses of the clip angle and the anchor bolts; also, the computer model accounted for the lateral stiffness of the cabinet wall, which tends to lower the prying load on the bolt.

For all practical configurations, prying factors in excess of unity occur in all cases.

These example evaluations are for expansion anchor bolts which are considerably less stiff than other types of fasteners (e.g., cast-in-place bolts, J-bolts, grout-in-place bolts, epoxy anchors). Because of their higher axial stiffness, more significant prying forces could be expected for fasteners in the latter group.

It is important to also note that the values in **Table 5.5** represent a conservative case, specifically a short clip angle in the middle of a flexible cabinet. A cabinet with a continuous base frame on all four sides may have lower prying factors, principally due to the increase in the parameter K_2 which would apply in this case. K_2 would also be greater for a single clip angle located near the corner of cabinet (with solid sidewall in the perpendicular direction) as compared to the K_2 used to develop **Table 5.5**. Thus, the prying factor for a continuous base angle or a clip angle located near a solid cabinet side wall would be less than the values given in **Table 5.5**.

In summary, the data presented in **Table 5.5** can be used to assess the significance of prying for the range of examples included in the table for expansion anchor bolts. The model illustrated in **Figure 5.2** can be modified to evaluate prying for other cases involving the anchorage of equipment to concrete using other structural members and concrete expansion anchor bolt sizes.

The results of the above analyses are not intended to set hard and fast rules for prying behavior in angle connections. Rather, a method of evaluating prying and the corresponding results are presented to show that prying factors are highly variable and cannot be represented accurately by a single amplification factor. The method illustrated could be used to qualify an anchor that might otherwise fail when analyzed with a

general prying factor calculated based on the assumption of rigid base and relatively rigid bolt. It is the seismic qualification engineer's responsibility to apply these modelling techniques accurately to more closely assess the true prying in a given connection detail.

Analysis Approach for Cabinets with Clip Channel

Another common anchorage detail susceptible to significant prying is one in which the equipment cabinet is bolted to a clip channel, and the channel is then anchored to the floor using an expansion anchor. This connection detail is typically used to support equipment on floors that are prone to flooding. The detail is illustrated in **Figure 5.3**. Although the cabinet is bolted to the channel at the midwidth of the top flange, the cabinet could alternatively be welded to the channel at the outer face of the cabinet, or less likely, at the toe of the top flange.

The computer model used to evaluate prying in this case is shown in **Figure 5.4**. On this figure, the load is applied at node 5, however, load P could alternatively be applied at node 4, or less frequently at node 6. This model ignores the prying developed due to eccentricity of load P and the channel top flange bolt, and also the flexibility of the equipment cabinet.

Both standard channels (C) and miscellaneous channels (MC) were used in the analyses. There are no gage distances for channels specified by the AISC manual; consequently, the expansion anchors were located at the midlength of the bottom flange. The vertical load P resulting from seismic input was applied independently to nodes 4, 5, and 6.

The results of the prying evaluations obtained from computer runs using the structural analysis computer program RISA-2D are shown in **Table 5.6**. For the most probable configuration in which the load is applied at node 5, there is no prying factor (i.e., there is no amplification on the anchor bolt). For the less likely configurations in which P is applied at node 4 or 6, λ reaches a peak value of 2.0.

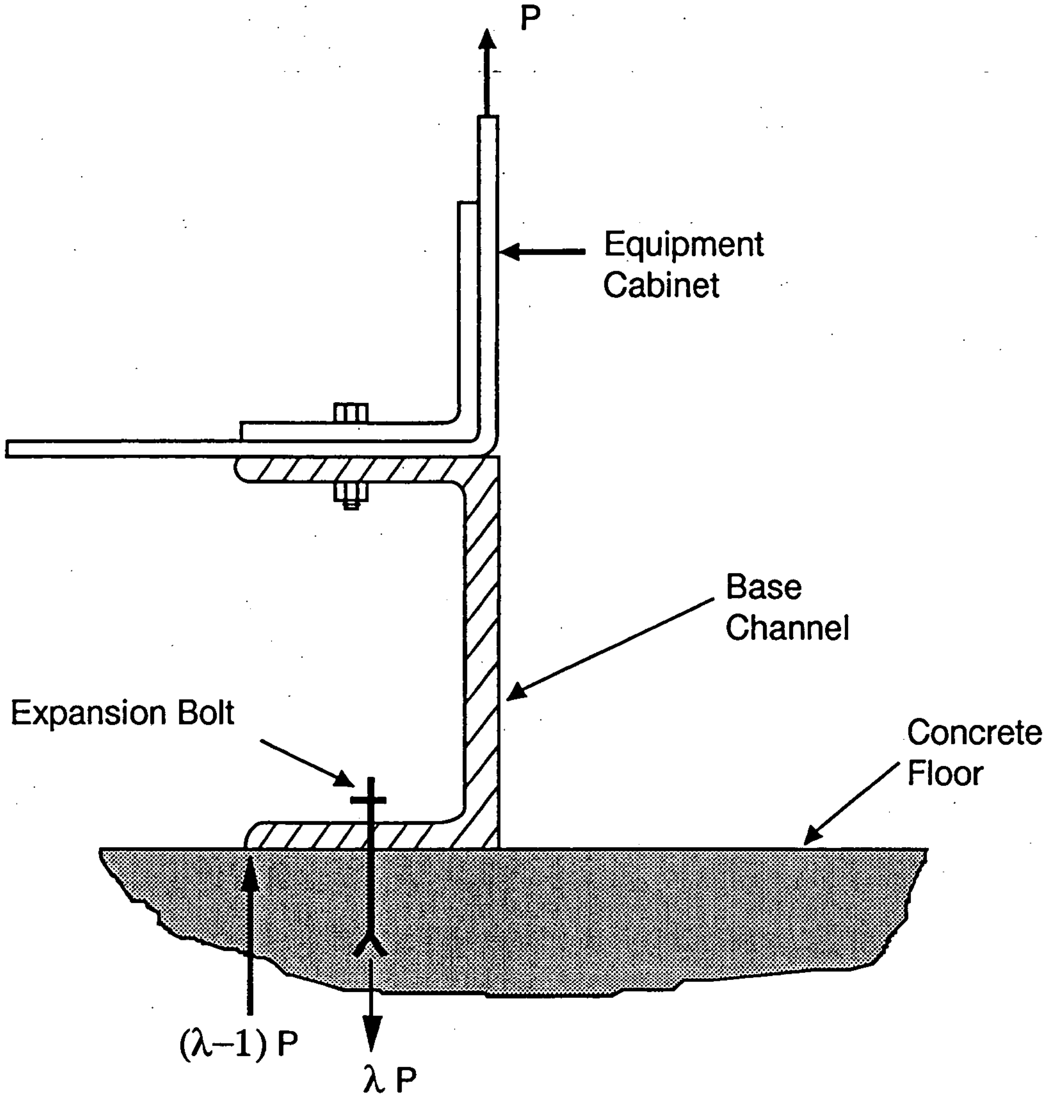


Figure 5.3 - Typical Base Anchorage with Prying on Base Channel

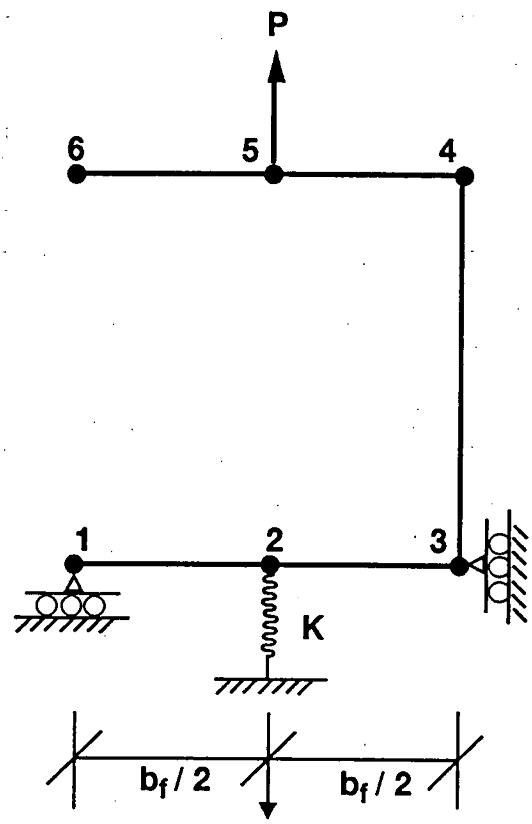


Figure 5.4 - Structural Mode Used to Evaluate Prying on Channel

TABLE 5.5
Results of Prying Evaluation in Angle Sections

Angle	Bolt Diameter (inches)	Prying Factor λ (1)	Angle	Bolt Diameter (inches)	Prying Factor λ (1)	Angle	Bolt Diameter (inches)	Prying Factor λ (1)
3 x 3 x 1/4	3/8	2.33	4 x 4 x 1/4	3/8	2.54	6 x 6 x 3/8	3/8	2.32
	1/2	2.35		1/2	2.56		1/2	2.34
	5/8	2.35		5/8	2.56		5/8	2.34
	3/4	2.35		3/4	2.57		3/4	2.34
	7/8	2.35		7/8	2.57		7/8	2.34
	1	2.35		1	2.57		1	2.34
3 x 3 x 3/8	3/8	2.36	4 x 4 x 3/8	3/8	2.60	6 x 6 x 1/2	3/8	2.35
	1/2	2.38		1/2	2.63		1/2	2.37
	5/8	2.38		5/8	2.63		5/8	2.37
	3/4	2.38		3/4	2.63		3/4	2.37
	7/8	2.38		7/8	2.63		7/8	2.37
	1	2.38		1	2.63		1	2.37
3 x 3 x 1/2	3/8	2.36	4 x 4 x 1/2	3/8	2.61	6 x 6 x 5/8	3/8	2.36
	1/2	2.38		1/2	2.64		1/2	2.38
	5/8	2.39		5/8	2.64		5/8	2.38
	3/4	2.39		3/4	2.65		3/4	2.38
	7/8	2.39		7/8	2.65		7/8	2.38
	1	2.39		1	2.65		1	2.39
			4 x 4 x 5/8	3/8	2.62	6 x 6 x 3/4	3/8	2.36
				1/2	2.65		1/2	2.38
				5/8	2.65		5/8	2.39
				3/4	2.65		3/4	2.39
				7/8	2.65		7/8	2.39
				1	2.66		1	2.39
			4 x 4 x 3/4	3/8	2.62	6 x 6 x 7/8	3/8	2.37
				1/2	2.65		1/2	2.39
				5/8	2.65		5/8	2.39
				3/4	2.66		3/4	2.39
				7/8	2.66		7/8	2.39
				1	2.66		1	2.39
						6 x 6 x 1	3/8	2.37
							1/2	2.39
							5/8	2.39
							3/4	2.39
							7/8	2.39
							1	2.39
	Ave. $\lambda \cong 2.37$			Ave. $\lambda \cong 2.64$			Ave. $\lambda \cong 2.37$	

(1) Expansion Anchor @ Gage

TABLE 5.6
Results of Prying Evaluation in Channel Sections

Channel	Bolt Diameter (inches)	P @ Node 4 λ	P @ Node 5 λ	P @ Node 6 λ
C3 x 4.1	3/8	2.01	1.00	1.99
	1/2	2.01	1.00	1.99
	5/8	2.01	1.00	1.99
C3 x 5	3/8	2.00	1.00	2.00
	1/2	2.00	1.00	2.00
	5/8	2.00	1.00	2.00
C3 x 6	3/8	2.00	1.00	2.00
	1/2	2.00	1.00	2.00
	5/8	2.00	1.00	2.00
C4 x 5.4	3/8	2.00	1.00	2.00
	1/2	2.00	1.00	2.00
	5/8	2.00	1.00	2.00
C4 x 7.25	3/8	2.00	1.00	2.00
	1/2	2.00	1.00	2.00
	5/8	2.00	1.00	2.00
C5 x 6.7	3/8	2.00	1.00	2.00
	1/2	2.00	1.00	2.00
	5/8	2.00	1.00	2.00
C5 x 9	3/8	2.00	1.00	2.00
	1/2	2.00	1.00	2.00
	5/8	2.00	1.00	2.00
C6 x 8.2	3/8	2.00	1.00	2.00
	1/2	2.00	1.00	2.00
	5/8	2.00	1.00	2.00
C6 x 10.5	3/8	2.00	1.00	2.00
	1/2	2.00	1.00	2.00
	5/8	2.00	1.00	2.00
C6 x 13	3/8	2.00	1.00	2.00
	1/2	2.00	1.00	2.00
	5/8	2.00	1.00	2.00
MC6 x 12	3/8	2.00	1.00	2.00
	1/2	2.00	1.00	2.00
	5/8	2.00	1.00	2.00
MC6 x 15.1	3/8	2.00	1.00	2.00
	1/2	2.00	1.00	2.00
	5/8	2.00	1.00	2.00
	3/4	2.00	1.00	2.00
MC6 x 16.3	3/8	2.00	1.00	2.00
	1/2	2.00	1.00	2.00
	5/8	2.00	1.00	2.00
	3/4	2.00	1.00	2.00
MC6 x 18	3/8	2.00	1.00	2.00
	1/2	2.00	1.00	2.00
	5/8	2.00	1.00	2.00
	3/4	2.00	1.00	2.00
	7/8	2.00	1.00	2.00

Attachment RAI 16b.2

Station	Oconee	Unit 2	Rev. 04	File No.	OSC-6040		Sheet No.	of
Subject	Outlier Resolution: Anchorage calculation for MCC 2XP							
					Orig. By	R P Childs	Date	10/28/98
Equip. No.	MCC 2XP				Checked By	[signature]	Date	10/28/98

FOR INFORMATION ONLY

Purpose:

To verify the seismic adequacy of the revised anchorage of MCC 2XP for A-46 and IPEEE per ONOE-12902

Relationship to Nuclear Safety:

This calculation should be considered QA condition 4 under the Duke Power QA program. Although MCC 2XP is not safety related, all upgrades to equipment for the A-46/IPEEE program will be performed as QA-4 as a minimum.

Analytical Method Used:

Hand calculations and EBAC anchorage analysis

Assumptions:

All 1/2" self drill anchors are assumed to be located in the center of each bay. Actual field conditions differ slightly. However, this variance will not significant impact the analysis.
The MCC bays are bolted back to back and will be treated as a single unit. Reference the shear flow calculation on page 1224 of this calculation.
Other assumptions were stated within body of calculation.

References:

Gip Rev. 2
O-917
EPRI TR-103960 Sect. 1.4
Dynamic Reanalysis of Oconee" Plots 76,77 & 78

1290

Station Oconee Unit 2 Rev. 6 File No. OSC-6040		Sheet No.	of
Subject Outlier Resolution: Anchorage calculation for MCC 2XP			
	Orig. By R P Childs	Date 10/27/98	
Equip. No. MCC 2XP	Checked By [signature]	Date 10/27/98	

Calculation/Discussion

FOR INFORMATION ONLY

Equipment Characteristics:

Equipment type:	Motor Control Center
Number of Cabinets:	8
Estimated Cable Tray Weight:	N/A
Estimated Cabinet Weight:	600# (Ref. Clark AO Smith Bulletin 6200)
Total Weight at C.G.	600#x8=48000#
Center of Gravity:	Assume C.G. is at geometric center Height = 90" Length = 112" Depth = 14.5" Effective Depth = 29"
Natural Frequency:	<8Hz
Damping:	5%
Essential Relays:	Contains Motor Starters

Seismic Accelerations:

46

This cabinet is located in the Aux. Bldg. at Elev. 796'+6".
(Ref. OS-027B.00-00-0002)

Ref. SPECTRA software

Direction	5% Damped	Seismic Demand Acceleration
N-S	.37	.37x1.25=.46
E-W	.34	.34x1.25=.425
Vertical	.15	.15x1.25=.19

IPEEE (Ref. "Dynamic Reanalysis of Oconee" Plots 76,77 & 78)

Take peak acceleration for Elev. 796'+6":

Direction	Acceleration
N-S	.41
E-W	.43
Vertical	.17

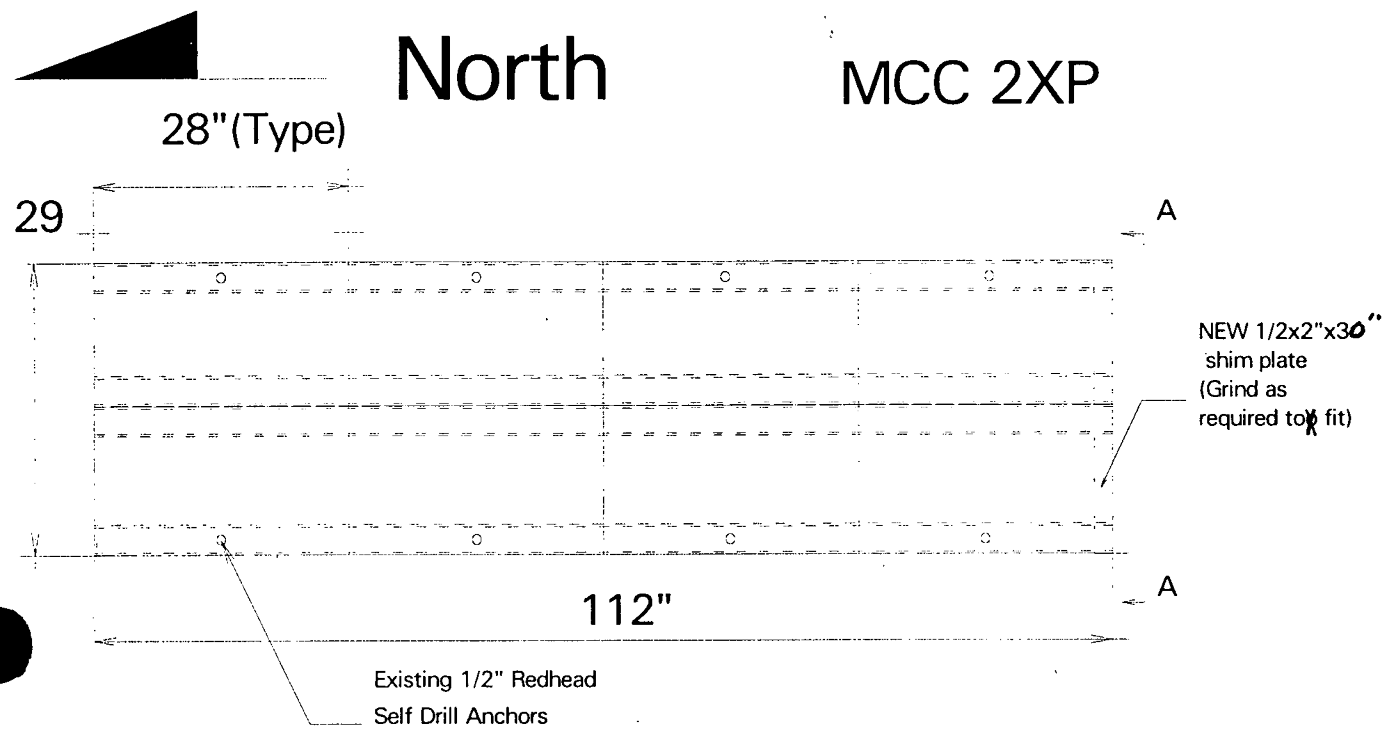
46 Accelerations Control

1291

Station: Oconee	Unit: 2	Rev. 6	File No. OSC-6040		Sheet No. ___	of ___
Subject: Outlier Resolution: Anchorage calculation for MCC 2XP						
			Orig. By	R P Childs	Date	10/27/98
Equip. No. MCC 2XP			Checked By	(signature)	Date	10/27/98

Bolt Pattern:

FOR INFORMATION ONLY



Bolt Analysis:

Anchor Type, Allowables, and Reductions

Anchor Type: Phillips 1/2" Self Drill Anchors (existing anchors)

Allowable and reduction values are taken from GIP sections C.2.2 to C.2.11.

Pnom = 2290#(FS = 3.0) Vnom = 2380# (FS = 3.0)

Reduction For:		
RTp = 1.0	RTs = 1.0	Type of Anchor
RLp = 1.0	RLs = 1.0	Short Embedment
RSp = 1.0	RSs = 1.0	Anchor Spacing
REp = 1.0	REs = 1.0	Edge Distance
RFp = 1.0	RFs = 1.0	Low f'c (<4000psi)

Station Oconee Unit 2 Rev. 61 File No. OSC-6040				Sheet No.	of
Subject Outlier Resolution: Anchorage calculation for MCC 2XP					
	Orig. By	R P Childs	Date	10/27/98	
Equip. No. MCC 2XP	Checked By	[signature]	Date	10/27/98	

RCp = 1.0 Cracked Concrete

RRp = 0.75 RRs = 0.75 Essential Relays

P_{all} = .75(2290) = 1718# V_{all} = .75(2380) = 1785#

FOR INFORMATION ONLY

Cabinet anchorage was evaluated using EBAC program (attached).

Per the attached EBACK evaluation, the F.S. =1.89

Anchors are acceptable for A-46

Check IPEEE (Ref page 1227.4 of this calculation)

UHS conversion factor @ 796' in the AB = .92

.92(1.89) =1.74 >1.67 ∴ O.K.

Gap Evaluation

There is a 3/16" gap between the bottom of the inverted channel and the top of concrete at the anchors in the South most bay of MCC 2XP on both the East and West side. Check bending in the anchor bolt using recommended approach in EPRI TR-103960, page 12.

V_T = Max. shear to develop plastic hinge at concrete surface = Z/e(Fy-P/A)

where: e =.1875"

Z = plastic modulus of bolt = $d^3/6 = (0.5)^3/6 = 0.0208\ in^3$

Fy = yield strength of bolt material = 36000.0 psi (assumed)

P = applied axial load in bolt (F.S. x axial load)

$$= 1.89x\left[\sqrt{(489^2)+(942^2)+(114^2)} - 600\right] = 884\#$$

A $= \pi d^2/4$

$= \pi(0.5)^2/4$

$= 0.196\ in^2$

V_T = (0.0208 /0.1875)(36000-(884/0.196)) = 3494#

V_B = Max. shear force required to develop plastic hinge in the embedded portion of anchor

$= [Z(F_Y-P/A) + M_c] / (e + 2d_b)$

where: $M_C = 5.4\ f'_c\ d_b^3 = 5.4(4000)(0.5)^3 = 2700$ in-lb

Station	Oconee	Unit	2	Rev. 61	File No.	OSC-6040		Sheet No.	of
Subject	Outlier Resolution: Anchorage calculation for MCC 2XP								
					Orig. By	R P Childs		Date	10/27/98
Equip. No.	MCC 2XP				Checked By	[signature]		Date	10/27/98

$V_B = [0.0208(36000-(884/0.196)) + 2700] / [0.1875+ 2(0.5)] = 2825\#$

$V_{max.}$ = The lesser of V_T and $V_B = 2825\#$

Using EBAC results

Applied shear, $V = 1.89\text{x} \sqrt{(276)^2 + (281)^2} = 744\#$

$V = 744 < V_{max} = 2825\#$

$\therefore$ Bending in the anchor does not significantly affect the anchorage evaluation. The 3/16" gap at the anchor is acceptable as described.

Embedded Steel Qualification:

N/A

Conclusion:

Anchorage is acceptable for A-46 and IPEEE loads. Per ONOE-12902, a shim plate will be added to the South end of the MCC.

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****************************
*** EBAC    VERSION 0.0 ***
****************************

2XP

DEAD LOAD IS IN THE -Z DIRECTION

ACCELERATION IN X DIRECTION:     .46
ACCELERATION IN Y DIRECTION:     .46
ACCELERATION IN Z DIRECTION:     .19

DIMENSIONS OF EQUIPMENT
LENGTH IN X DIRECTION: 112.00
LENGTH IN Y DIRECTION:  29.00
CG COORDINATES:      X:  56.00
                     Y:  14.50
                     Z:  46.00

WEIGHT OF ITEM: .480E+04

OVERTURNING AXES
FOR FORCE IN +X DIR.:  56.00
FOR FORCE IN +Y DIR.:  14.50

INTERACTION EQUATION:     1
      EQ.0 EXPONENTIAL
      EQ.1 BI-LINEAR
```

Calc. No. [illegible] -6040
Sheet No. 1294
Rev 6
By: [signature] Date 10/27/98
Ck: [signature] Date 10/27/98

FOR INFORMATION ONLY

FASTENER PROPERTIES

ID NO	X	Y	FACTOR	VALL	PALL
1	14.50	1.50	1.00	1785.0	1718.0
2	42.50	1.50	1.00	1785.0	1718.0
3	70.50	1.50	1.00	1785.0	1718.0
4	98.50	1.50	1.00	1785.0	1718.0
5	14.50	27.50	1.00	1785.0	1718.0
6	42.50	27.50	1.00	1785.0	1718.0
7	70.50	27.50	1.00	1785.0	1718.0
8	98.50	27.50	1.00	1785.0	1718.0

Calc. No. OSC-6040
Rev. 6 Sheet No. 1295
By: [signature] Date 10/27/98
Ck: [signature] Date 10/27/98

FOR INFORMATION ONLY

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****************************
*** EBAC    VERSION 0.0 ***
****************************
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2XP

POSITIVE INPUT INERTIAL FORCES

DIRECTION OF INPUT	X			Y			Z
DIRECTION OF RESULTANT	X	Y	Z	X	Y	Z	Z
FASTENER ID NO.							
1	276.0	.0	489.2	-1.6	281.0	942.3	114.0
2	276.0	.0	159.1	-1.6	277.7	942.3	114.0
3	276.0	.0	.0	-1.6	274.3	942.3	114.0
4	276.0	.0	.0	-1.6	271.0	942.3	114.0
5	276.0	.0	489.2	1.6	281.0	.0	114.0
6	276.0	.0	159.1	1.6	277.7	.0	114.0
7	276.0	.0	.0	1.6	274.3	.0	114.0
8	276.0	.0	.0	1.6	271.0	.0	114.0

NEGATIVE INPUT INERTIAL FORCES

DIRECTION OF INPUT	X			Y			Z
DIRECTION OF RESULTANT	X	Y	Z	X	Y	Z	Z
FASTENER ID NO.							
1	-276.0	.0	.0	1.6	-281.0	.0	.0
2	-276.0	.0	.0	1.6	-277.7	.0	.0
3	-276.0	.0	163.4	1.6	-274.3	.0	.0
4	-276.0	.0	478.8	1.6	-271.0	.0	.0
5	-276.0	.0	.0	-1.6	-281.0	942.3	.0
6	-276.0	.0	.0	-1.6	-277.7	942.3	.0
7	-276.0	.0	163.4	-1.6	-274.3	942.3	.0
8	-276.0	.0	478.8	-1.6	-271.0	942.3	.0

Calc. No. OSC-6040
Rev. 6 Sheet No. 1296
By: R. Ynd Date 10/27/98
Ck. L Bdl Date 10/27/98

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***************************
*** EBAC    VERSION 0.0 ***
***************************
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2XP

AN ACCEPTABLE EARTHQUAKE FACTOR FOR EACH FASTENER
USING FOUR EARTHQUAKE DIRECTIONAL COMBINATIONS
AND USING THE SRSS METHOD HAS BEEN CALCULATED

+X+Y+Z

ID 1	2	3	4	5	6	7	8
1.9	2.0	2.1	2.1	2.9	4.2	4.6	4.6

+X-Y+Z

ID 1	2	3	4	5	6	7	8
2.9	4.2	4.6	4.6	1.9	2.0	2.1	2.1

-X+Y+Z

ID 1	2	3	4	5	6	7	8
2.0	2.0	2.0	1.9	4.5	4.6	4.2	3.0

-X-Y+Z

ID 1	2	3	4	5	6	7	8
4.5	4.6	4.2	3.0	2.0	2.0	2.0	1.9

***** THE SMALLEST ACCEPTABLE FACTOR (APPLIED TO THE INPUT G LEVELS)
FOR THIS CASE IS 1.89 *****

FOR INFORMATION ONLY

Attachment 16b.3

Duke Power Company

FOR INFORMATION ONLY

OSC-6040

Station Oconee Unit 3 Rev. File No. Sheet 47 Of

Subject Anchorage for 600/208 VAC MCC 3XS3

By R. W. McAuley Date 09/22/94

Equip No. Checked By [signature] Date 9/28/94

The following information and assumptions were used to evaluate the subject equipment's anchorage capacity.

EQUIPMENT CHARACTERISTICS

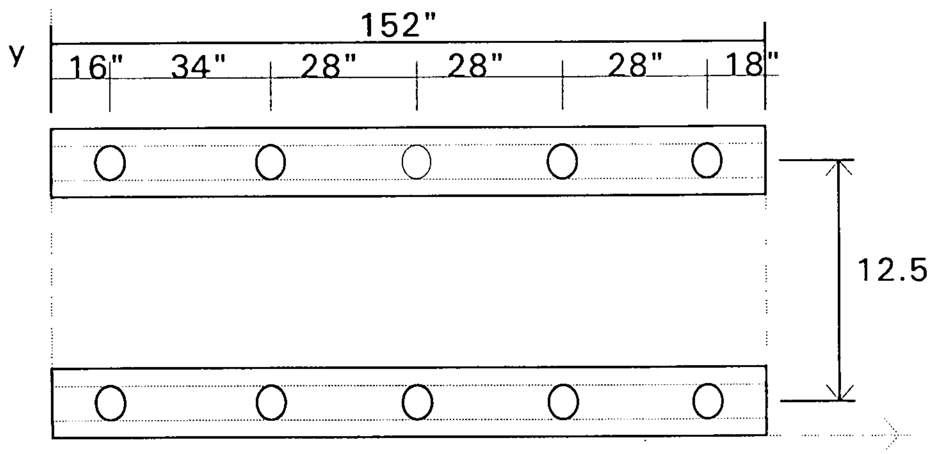
Equipment type:	Motor Control Center
Number of Cabinets:	5
Weight:	5 cabinets x 800# = 4000#
Center of Gravity:	Assume CG is at the geometric centerlines
	Height - 92 inches
	Length - 152 inches
	Width - 14.75 inches
	Xbar = 76"
	Ybar = 7.38"
	Zbar = 46"
Natural Frequency:	Flexible (GIP Table C.1-1)

Duke Power Company FOR INFORMATION ONLY OSC-6040

Station Oconee	Unit 3 Rev.	File No.	Sheet 218 Of
Subject Anchorage for 600/208 VAC MCC 3XS3			
	By R. W. McAuley		Date 09/22/94
Equip No.	Checked By RV Hart		Date 7/28/94

Anchorage Pattern

Motor Control Center is mounted on inverted 3" channels. See drawings OM 2308-44 for details.



Anchorage Pattern

USI - A46 Evaluation

Damping: 5% (GIP Table C.1-1)
Essential Relays: Assume MCC contains essential relays

SEISMIC ACCELERATIONS

MCC's are located in Equipment Room, Elevation 796' + 6". We have in-structure response spectra for .5% and 2% damping, but not 5%. GIP section 4.4.3 gives formula for approximation of accelerations for unanalyzed levels of damping. (Ref. OS-027B.00-00-0002)

Direction	2% damping	ZPA
N-S	0.67g	0.14g
E-W	0.73g	0.14g

Use formula in GIP section 4.4.3 to estimate seismic accelerations at 5% damping.

Station Oconee	Unit 3 Rev.	File No.	Sheet 49 Of
Subject Anchorage for 600/208 VAC MCC 3XS3			
		By R. W. McAuley	Date 09/22/94
Equip No.		Checked By RV Hart	Date 9/28/94

$Sa_{iD} = Sa_{iA}[\beta_A/\beta_D]^{1/2}$

N-S: $Sa_5 = .67(2/5)^{1/2} = 0.42g$

E-W: $Sa_5 = .73(2/5)^{1/2} = 0.46g$

Use largest horizontal acceleration for seismic demand in both directions and use 2/3 of the horizontal acceleration (per GIP 4.4.3) for the vertical seismic acceleration. A factor of conservatism of 1.25 (GiP Table 4-3) must also be applied to the accelerations.

Direction	Seismic Demand Acceleration	
Horizontal	0.46(1.25) = 0.58g	
Vertical	2/3(0.58) = 0.39g	(Conservative -see GIP 4.4.3)
Horizontal	0.58g	
Vertical	0.39g	

Anchor Type, Allowables, and Reductions

Anchor Type: Redhead 1/2" Self Drill Expansion Anchors

Allowable and reduction values are taken from GIP sections C.2.2 to C.2.11.

Pnom = 2290# (FS = 3.0)	Vnom = 2380# (FS = 3.0)	Reduction For:
RTp = 1.0	RTs = 1.0	Type of Anchor
RLp = 1.0	RLs = 1.0	Short Embedment
RSp = 1.0	RSs = 1.0	Anchor Spacing
REp = 1.0	REs = 1.0	Edge Distance
RFp = 1.0	RFs = 1.0	Low f'c (<4000psi)
RCp = 1.0		Cracked Concrete
RRp = 0.75	RRs = 0.75	Essential Relays (Assumed)

Pall = Pnom x RTp x RLp x RSp x REp x RFp x RCp x RRp
Pall = 0.75 x 2290 = 1718#

Vall = Vnom x RTs x RLs x RSs x REs x RFs x RCs x RRs
Vall = 0.75 x 2380 = 1785#

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Station Oconee Unit 3 Rev. File No. Sheet 210 Of

Subject Anchorage for 600/208 VAC MCC 3XS3

By R. W. McAuley Date 09/22/94

Equip No. Checked By RV Hurt Date 9/28/94

Method of Analysis

Analysis was performed using the EBAC computer program. Per GIP, electrical cabinets equipment bases should be considered flexible. Therefore, base assumed flexible in EBAC program. See attached EBAC program output.

Results of Analysis

Maximum allowed seismic acceleration from EBAC = 0.75g

Acceleration demand on equipment = 0.58g

0.58 < 0.75 1/2" Self Drill Expansion Anchors OK for A-46

OTHER SEWS FORM CONCERNS

There is a 5/8" gap between the base and the concrete under part of 3XS3. Since gap is greater than 1/4", this is an outlier. Evaluate problem using recommended approach in EPRI TR-103960, page 12.

$V_T = Z/e(F_y - P/A)$

where: Z = plastic modulus of bolt = $d^3/6 = (0.5)^3/6 = 0.021$ in^3
Fy = yield strength of bolt material = 50000psi (assumed)
P = applied axial load in bolt = (using EBAC results in fastener #1 using SRSS of inertial forces minus dead load)
$P = [(614.2)^2 + (2724.6)^2 + (268)^2]^{1/2}$ (0.58g/1.0g) - 4000/10 = 1227#
$A = \pi d^2/4 = \pi(0.5)^2/4 = 0.196$ in^2

$V_T = 0.021/0.625(50000 - 1227/0.196) = 1470$#

$V_B = [Z(F_y - P/A) + M_c] / (e + 2d_b)$

where: $M_c = 5.4 f'c\, d_b^3 = 5.4\,(4000)\,(0.5)^3 = 2700$ in-lb

$V_B = [0.021(50000 - 1227/0.196) + 2700] / [0.625 + 2(0.5)] = 2227$#

Using SRSS method on EBAC results for fastener #1,
Applied Shear $V = [(400)^2 + (411)^2]^{1/2} (0.58) = 333$#

V= 333# < Vall = lesser of V_T and V_B = 1470#.   OK

CONCLUSION

MCC 3XS3 OK for A-46

FOR INFORMATION ONLY

OSC-6040

Calc. No. OSC-
Rev. Sheet No. 222
By: R.W. McCauley Date 9/22/94
Ck: R V Wests Date 9/28/94

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****************************
*** EBAC    VERSION 0.0 ***
****************************

MCC3XS3 (ASSUMING FLEXIBLE BASE)

DEAD LOAD IS IN THE -Z DIRECTION

ACCELERATION IN X DIRECTION:   1.00
ACCELERATION IN Y DIRECTION:   1.00
ACCELERATION IN Z DIRECTION:    .67

DIMENSIONS OF EQUIPMENT
LENGTH IN X DIRECTION: 152.00
LENGTH IN Y DIRECTION:  14.75
CG COORDINATES:      X:  76.00
                     Y:   7.38
                     Z:  46.00

WEIGHT OF ITEM: .400E+04

OVERTURNING AXES
FOR FORCE IN +X DIR.:  76.00
FOR FORCE IN +Y DIR.:   7.38

INTERACTION EQUATION:     1
     EQ.0 EXPONENTIAL
     EQ.1 BI-LINEAR
```

FASTENER PROPERTIES

ID NO	X	Y	FACTOR	VALL	PALL
1	16.00	1.13	1.00	1785.0	1718.0
2	50.00	1.13	1.00	1785.0	1718.0
3	78.00	1.13	1.00	1785.0	1718.0
4	106.00	1.13	1.00	1785.0	1718.0
5	134.00	1.13	1.00	1785.0	1718.0
6	16.00	13.63	1.00	1785.0	1718.0
7	50.00	13.63	1.00	1785.0	1718.0
8	78.00	13.63	1.00	1785.0	1718.0
9	106.00	13.63	1.00	1785.0	1718.0
10	134.00	13.63	1.00	1785.0	1718.0

FOR INFORMATION ONLY

Calc. No. OSC-6040

Rev.____ Sheet No. 223

By: R.W. McCauley Date 9/22/94

Ck: RV Hester Date 9/28/94

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*** EBAC VERSION 0.0 ***

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MCC3XS3 (ASSUMING FLEXIBLE BASE)

POSITIVE INPUT INERTIAL FORCES

DIRECTION OF INPUT	X			Y			Z
DIRECTION OF RESULTANT	X	Y	Z	X	Y	Z	Z
FASTENER ID NO.							
1	400.0	.0	614.2	-1.1	411.1	2724.6	268.0
2	400.0	.0	266.1	-1.1	404.9	2724.6	268.0
3	400.0	.0	.0	-1.1	399.8	2724.6	268.0
4	400.0	.0	.0	-1.1	394.7	2724.6	268.0
5	400.0	.0	.0	-1.1	389.5	2724.6	268.0
6	400.0	.0	614.2	1.1	411.1	.0	268.0
7	400.0	.0	266.1	1.1	404.9	.0	268.0
8	400.0	.0	.0	1.1	399.8	.0	268.0
9	400.0	.0	.0	1.1	394.7	.0	268.0
10	400.0	.0	.0	1.1	389.5	.0	268.0

FOR INFORMATION ONLY

OSC-6040

Calc. No. OSC-

Rev. Sheet No. 224

By: R.W. McCauley Date 9/22/94

Ck: R V Hesst Date 9/28/94

*** EBAC VERSION 0.0 ***

MCC3XS3 (ASSUMING FLEXIBLE BASE)

NEGATIVE INPUT INERTIAL FORCES

DIRECTION OF INPUT	X			Y			Z
DIRECTION OF RESULTANT	X	Y	Z	X	Y	Z	Z
FASTENER ID NO.							
1	-400.0	.0	.0	1.1	-411.1	.0	.0
2	-400.0	.0	.0	1.1	-404.9	.0	.0
3	-400.0	.0	20.0	1.1	-399.8	.0	.0
4	-400.0	.0	300.0	1.1	-394.7	.0	.0
5	-400.0	.0	580.1	1.1	-389.5	.0	.0
6	-400.0	.0	.0	-1.1	-411.1	2722.6	.0
7	-400.0	.0	.0	-1.1	-404.9	2722.6	.0
8	-400.0	.0	20.0	-1.1	-399.8	2722.6	.0
9	-400.0	.0	300.0	-1.1	-394.7	2722.6	.0
10	-400.0	.0	580.1	-1.1	-389.5	2722.6	.0

FOR INFORMATION ONLY
OSC-6040

Calc. No. OSC-

Rev. Sheet No. 225

By: R.W. McAuley Date 9/20/94

Ck: R V Hester Date 9/28/94

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*** EBAC VERSION 0.0 ***

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MCC3XS3 (ASSUMING FLEXIBLE BASE)

AN ACCEPTABLE EARTHQUAKE FACTOR FOR EACH FASTENER
USING FOUR EARTHQUAKE DIRECTIONAL COMBINATIONS
AND USING THE SRSS METHOD HAS BEEN CALCULATED

+X+Y+Z

ID 1	2	3	4	5	6	7	8	9	10
.8	.8	.8	.8	.8	2.0	2.5	2.7	2.7	2.8

+X-Y+Z

ID 1	2	3	4	5	6	7	8	9	10
2.0	2.5	2.7	2.7	2.8	.8	.8	.8	.8	.8

-X+Y+Z

ID 1	2	3	4	5	6	7	8	9	10
.8	.8	.8	.8	.8	2.7	2.7	2.7	2.4	2.0

-X-Y+Z

ID 1	2	3	4	5	6	7	8	9	10
2.7	2.7	2.7	2.4	2.0	.8	.8	.8	.8	.8

***** THE SMALLEST ACCEPTABLE FACTOR (APPLIED TO THE INPUT G LEVELS)
FOR THIS CASE IS .75 *****

IPEEE

Anchor Type, Allowables, and Reductions

Anchor Type: Redhead 1/2" Self Drill Expansion Anchors

Allowable and reduction values are taken from GIP sections C.2.2 to C.2.11.

Pnom = 2290#(FS = 3.0) Vnom = 2380# (FS = 2.0) Ref NP 6041 App O for FS

Take peak accelerations from enveloped response spectra (5% damping) at Elev. 796' + 0".

Direction	Acceleration
N-S	0.40g
E-W	0.44g
Vertical	0.40g

Ref: Dynamic Reanalysis of the Oconee Nuclear Station Auxiliary Buildings, Units 1,2, & 3 Volume II.

Method of Analysis

Analysis was performed using the EBAC computer program. Per GIP, electrical cabinets equipment bases should be considered flexible. Therefore, base assumed flexible in EBAC program. See attached EBAC program output.

FS=2.18 1/2" Self Drill Expansion Anchors OK for IPEEE

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	By R. V. Hester		Date 1/29/96
Equip No.	Checked By R.W. McCauley		Date 1/29/96

OTHER SEWS FORM CONCERNS

There is a 5/8" gap between the base and the concrete under part of 3XS3. Since gap is greater than 1/4", this is an outlier. Evaluate problem using recommended approach in EPRI TR-103960, page 12.

$V_T = Z/e(F_y - P/A)$

where: Z = plastic modulus of bolt = $d^3/6 = (0.5)^3/6 = 0.021\ in^3$
Fy = yield strength of bolt material = 50000psi (assumed)
P = applied axial load in bolt = (using EBAC results in fastener #1 using SRSS of inertial forces minus dead load)
$P = [(246)^2 + (1199)^2 + (160)^2]^{1/2} - 4000/10 = 834\#$
$A = \pi d^2/4 = \pi(0.5)^2/4 = 0.196\ in^2$

$V_T = 0.021/0.625(50000 - 834/0.196) = 1537.0\#$

$V_B = [Z(F_y - P/A) + M_c] / (e + 2d_b)$

where: $M_c = 5.4\ f'c\ d_b^3 = 5.4\ (4000)\ (0.5)^3 = 2700$ in-lb

$V_B = [0.021(50000 - 834.0/0.196) + 2700] / [0.625 + 2(0.5)] = 2252\#$

Using SRSS method on EBAC results for fastener #1,
Applied Shear $V = [(160)^2 + (180)^2]^{1/2} = 240.8\#$

$V = 240.8\# < V_{all}$ = lesser of V_T and $V_B = 1537\#$.

CONCLUSION
FS=1537/240.8=6.4> 2.18 Use 2.18

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By R. V. Hester Date 1/29/96

Equip No. Checked By Rwm Date 1/29/96

IPEEE Evaluation

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MCC 3XS3

DEAD LOAD IS IN THE -Z DIRECTION

ACCELERATION IN X DIRECTION:    .40
ACCELERATION IN Y DIRECTION:    .44
ACCELERATION IN Z DIRECTION:    .40

DIMENSIONS OF EQUIPMENT
LENGTH IN X DIRECTION: 152.00
LENGTH IN Y DIRECTION:  14.75
CG COORDINATES:      X:  76.00
                     Y:   7.38
                     Z:  46.00

WEIGHT OF ITEM: .400E+04

OVERTURNING AXES
FOR FORCE IN +X DIR.:  76.00
FOR FORCE IN +Y DIR.:   7.38

INTERACTION EQUATION:    1
      EQ.0 EXPONENTIAL
      EQ.1 BI-LINEAR
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FASTENER PROPERTIES

ID NO	X	Y	FACTOR	VALL	PALL
1	16.00	1.13	1.00	3570.0	2290.0
2	50.00	1.13	1.00	3570.0	2290.0
3	78.00	1.13	1.00	3570.0	2290.0
4	106.00	1.13	1.00	3570.0	2290.0
5	134.00	1.13	1.00	3570.0	2290.0
6	16.00	13.63	1.00	3570.0	2290.0
7	50.00	13.63	1.00	3570.0	2290.0
8	78.00	13.63	1.00	3570.0	2290.0
9	106.00	13.63	1.00	3570.0	2290.0
10	134.00	13.63	1.00	3570.0	2290.0

FOR INFORMATION ONLY

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By R. V. Hester Date 1/29/96

Equip No.______ Checked By RWM Date 1/29/96

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MCC 3XS3

POSITIVE INPUT INERTIAL FORCES

DIRECTION OF INPUT	X			Y			Z
DIRECTION OF RESULTANT	X	Y	Z	X	Y	Z	Z
FASTENER ID NO.							
1	160.0	.0	245.7	-.5	180.9	1198.8	160.0
2	160.0	.0	106.5	-.5	178.2	1198.8	160.0
3	160.0	.0	.0	-.5	175.9	1198.8	160.0
4	160.0	.0	.0	-.5	173.6	1198.8	160.0
5	160.0	.0	.0	-.5	171.4	1198.8	160.0
6	160.0	.0	245.7	.5	180.9	.0	160.0
7	160.0	.0	106.5	.5	178.2	.0	160.0
8	160.0	.0	.0	.5	175.9	.0	160.0
9	160.0	.0	.0	.5	173.6	.0	160.0
10	160.0	.0	.0	.5	171.4	.0	160.0

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By R. V. Hester Date 1/29/96

Equip No. Checked By RWM Date 1/29/96

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MCC 3XS3

NEGATIVE INPUT INERTIAL FORCES

DIRECTION OF INPUT	X			Y			Z
DIRECTION OF RESULTANT	X	Y	Z	X	Y	Z	Z
FASTENER ID NO.							
1	-160.0	.0	.0	.5	-180.9	.0	.0
2	-160.0	.0	.0	.5	-178.2	.0	.0
3	-160.0	.0	8.0	.5	-175.9	.0	.0
4	-160.0	.0	120.0	.5	-173.6	.0	.0
5	-160.0	.0	232.0	.5	-171.4	.0	.0
6	-160.0	.0	.0	-.5	-180.9	1198.0	.0
7	-160.0	.0	.0	-.5	-178.2	1198.0	.0
8	-160.0	.0	8.0	-.5	-175.9	1198.0	.0
9	-160.0	.0	120.0	-.5	-173.6	1198.0	.0
10	-160.0	.0	232.0	-.5	-171.4	1198.0	.0

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****************************
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MCC 3XS3

AN ACCEPTABLE EARTHQUAKE FACTOR FOR EACH FASTENER
USING FOUR EARTHQUAKE DIRECTIONAL COMBINATIONS
AND USING THE SRSS METHOD HAS BEEN CALCULATED

+X+Y+Z
ID 1    2    3    4    5    6    7    8    9    10
 2.2  2.2  2.2  2.2  2.2  7.1  8.9  9.7  9.8  9.8

+X-Y+Z
ID 1    2    3    4    5    6    7    8    9    10
 7.1  8.9  9.7  9.8  9.8  2.2  2.2  2.2  2.2  2.2

-X+Y+Z
ID 1    2    3    4    5    6    7    8    9    10
 2.2  2.2  2.2  2.2  2.2  9.6  9.7  9.7  8.8  7.4

-X-Y+Z
ID 1    2    3    4    5    6    7    8    9    10
 9.6  9.7  9.7  8.8  7.4  2.2  2.2  2.2  2.2  2.2

***** THE SMALLEST ACCEPTABLE FACTOR (APPLIED TO THE INPUT G LEVELS)
      FOR THIS CASE IS 2.18 *****
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