UNITED STATES
NUCLEAR REGULATORY COMMISSION
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MEMORANDUM FOR: R. L. Spessard, Director
Division of Engineering
Region III

FROM: D. G. Eisenhut, Director
Division of Licensing

SUBJECT: REVIEW OF STRUCTURAL DESIGN ADEQUACY OF THE MIDLAND HVAC SYSTEMS

REFERENCES:
a. "Summary of October 4-7, 1983 Audit and Meeting on the Midland Heating, Ventilation and Air Conditioning Systems", Memorandum by D. Hood dated February 14 , 1984.
b. "Summary of October 27, 1983 Meeting on Midland Heating, Ventilation and Air Conditioning Systems", Memorandum by D. Hood dated February 14 , 1984

Your memorandum of August 4, 1983 requested NRR technical support in order that the combination of our respective efforts and those of Franklin Institute will address the adequacy of the safety-related HVAC systems as they are constructed and allegations of former Zack employees. To this end, NRR and Region III conducted a design audit on October 4 - 7, 1983 which is summarized by Reference a. A follow-up audit (Reference b) was also conducted on October 27, 1983.

The technical evaluations by NRR resulting from this effort are presented in Enclosures 1, 2 and 3. Enclosure 1 addresses the structural design adequacy of the Midland HVAC systems and is based upon the evaluation by Mr. D. Terao of our Mechanical Engineering Branch. In support of Enclosure 1, Enclosure 2 updates the staff's review of relevant functional aspects of the HVAC design as reported in the Midland SER in May 1982. Enclosure 2 is based upon the evaluation by Mr. W. LeFave of our Auxiliary Systems Branch. Enclosure 3 addresses results of the review of the Midland HVAC materials specification and materials records, and comments on the results of materials testing by Franklin Institute. Enclosure 3 is based upon the evaluation of Mr. C. D. Sellers of our Materials Engineering Branch.

Should you require our further assistance in this matter, please do not hesitate to contact us.

Darrell Eisenhut

Darrell Eisenhut, Director
Division of Licensing

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Enclosures:
As stated

ENCLOSURE 1

EVALUATION OF STRUCTURAL DESIGN ADEQUACY
OF MIDLAND HVAC SYSTEMS

I. Applicable Codes and Standards for HVAC Ductwork and Support

Presently, there are no national codes or standards which provide specific requirements for the overall design, fabrication, and installation of HVAC systems in nuclear facilities. The only national standard which addresses the design and construction of duct systems in a limited manner is ANSI-N509, "Nuclear Power Plant Air Cleaning Units and Components." ANSI-N510 covers the functional system testing aspects. The ANSI-N509 standard does not require specific material documentation.

Typically, the HVAC systems of nuclear facilities have been designed according to the guidelines shown in Sheet Metal and Air Conditioning Contractors National Association (SMACNA) publications, "Low Velocity Duct Construction Standards," which is applicable to duct pressures up to 2 inches water gauge and, "High Velocity Duct Construction Standards," which is applicable to duct pressure up to 10 inches water gauge. These design standards are based on performance only and are not based on the stress and deflection considerations associated with seismic Category I structures.

The American Iron and Steel Institute (AISI) code was adopted by the applicant for the Midland facility to govern the design of seismic Category I ductwork because of its applicability to thin gauge sheet metal.

The American Institute of Steel Construction (AISC) Code, "Specification for the Design, Fabrication and Erection of Structural Steel for Buildings," was used for the design of the HVAC ductwork supports.

The supports and ductwork were welded in accordance with the American Welding Society (AWS) Structural Welding Code (AWS D1.1), Specification for Welding Sheet Steel in Structures (AWS D1.3), and Specification for Welding of Sheet Metal (AWS D9.1).

II. Documentation

Because there are no national codes nor standards which specify the documentation required, the documentation requirements become the responsibility of the Utility (or its architect-engineer) to define.

For Midland Plant Units 1 & 2, the architect-engineer, Bechtel Power Corporation provided a technical specification for HVAC Work (Spec. No. 7220-M-151A[1]) which specifies the documentation requirements. The technical specification requires that a certificate of conformance is necessary for all requirements of the technical specification. A certificate of conformance is a written statement signed by a qualified party certifying that the items or services comply with the technical specification requirements.

A material certificate of compliance is required by the technical specification to be provided for subcontractor-supplied (Zack) construction materials including dampers, diffusers, grilles, registers, air flow measuring units, ductwork, hangers, supports, and miscellaneous materials specifically identified by the technical specification. A material certificate of compliance is a written statement signed by a qualified party certifying that the materials are in accordance with a particular material specification.

When required by the referenced codes or material specifications, the material certificate of compliance is required to be accompanied by a certified material test report (CMTR). When the requirements of the technical specification are more stringent than the referenced code or material specification, the material certificate of compliance is required to be accompanied by a CMTR which demonstrates compliance with the more stringent criterion. For example, ASTM specification A526 does not require a mechanical strength test for the sheet steel and, thus, no minimum yield strength is specified. However, the technical specification [1]M-151A requires a minimum yield strength of 30 ksi for A526 and A527 sheet steel. The CMTR includes all chemical, physical, mechanical, and electrical property test data required by the material specification, applicable codes, and procurement documents. The CMTR includes a statement of conformance that the material meets the technical specification requirements.

III. Materials

The technical specification (M-151) for HVAC ductwork specifies the materials for the HVAC ducting, stiffeners, fasteners, and supports. For the typical duct details, the materials used are standard commercial grade materials. The sheet steel is typically galvanized carbon sheet steel conforming to ASTM A526-71 or ASTM A-527 with a coating designation G-90 and a minimum yield strength of 30 ksi. Carbon steel sheet includes ASTM A366-72 (minimum yield strength of 30 ksi) and ASTM A607-75, Grade 50. An austenitic stainless steel sheet or plate (Type 304-2B, ASTM A240-75A) with a minimum yield strength of 30 ksi is also specified.

For support steel, the technical specification requires that carbon steel structural shapes, bar sizes, and plate conform to ASTM A36-75, ASTM A572-77A, (Grade 50), and ASTM A284 (Grade A) with minimum yield strength of 36 ksi. Structural tubing conforms to ASTM A500-77 (Grade B) and angles 2½ inches by 2½ inches by ¼ inch and smaller conform to ASTM A575 (Grade 1020) with a minimum yield strength of 36 ksi.

Carbon steel fasteners (including Huck bolts and sheet metal screws) conform to ASTM A325 galvanized and ASTM A307-74 galvanized. The only acceptable substitute permitted by the Midland technical specification for ASTM A325 is ASTM A490-76a. Acceptable substitutes for ASTM A307 are ASTM A193-76, ASTM A354-766, ASTM A449-76c, ASTM A490-76a, ANSI B18.2.1-65 with CMTR, or ASTM A325.

IV. Structural Design Margins

In order to determine the structural adequacy of the HVAC system (supports, stiffeners, and ducting), it is necessary to ask ourselves the following question, "Is the structural design of the HVAC system adequate if the materials used are questionable?" It logically follows that if the design margin to failure is large and if the range or possible variation in material properties in question (e.g., mechanical strength) is small, then we can reasonably conclude that the design is adequate. The adequacy or design margin can be expressed in the form:

$$\text{design margin} = \frac{\text{allowable stress}}{\text{calculated stress}}$$

For the components to be acceptable the design margin must be greater than 1.0. The larger the value, the more design margin is available. If the design margin is less than 1.0, then the question arises, "Will the component fail?" In order to answer the question, it is necessary to define what is meant by "failure". It is also important to understand what the basis is for the allowable stress.

In the following sections, we will be comparing the potential reduction in material strength due to substitute materials with the typical design margin for the various structural components in the HVAC system. The structural components that will be covered include the following:

A. Structural Steel Supports and Welds
B. Ductwork and Stiffeners
C. Ducting Companion Flange Bolts
D. Concrete Expansion Anchor Bolts

A. Structural Steel Supports and Welds

For the Midland HVAC supports, the design specification[1] requires the use of carbon steel structural shapes, bar sizes, and plate to conform to ASTM A-36, A-572 Grade 50, and A-284 Grade A, structural tubing to conform to A-500 Grade B, and angles to conform to A575 Grade M-1020. The material minimum yield strengths and minimum tensile strengths of the HVAC support steel are provided in Table 1.

The structural steel used for the Midland HVAC support member is designed in accordance with the AISC, "Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings."

The applicant specified in its design guide[2] the allowable stresses for the structural steel and tube sections as follows:

Allowable stress in accident conditions:
bending and torsion = 0.9 Fy
shear = 0.5 Fy

where Fy is the material yield strength.

In the calculations reviewed by the staff, it was found that the material yield strength used for the support steel was assumed to be 36 ksi. It was noted by the staff that the applicant prudently used a 36 ksi yield strength for a structural tube steel (A500) which actually had a minimum yield strength of 46 ksi. Typically, the applicant used 36 ksi yield strength for all structural steel in the support calculations. It should be noted that because the tube steel is welded in construction, the use of 36 ksi is prudent since its higher tensile strength resulting from coldwork will be annealled out in welding.

For the A284 Grade A plate material, the minimum yield strength is only 25 ksi. Although, the staff did not review specific calculations for the A284 material, it was concluded by the staff that the design margin for plates is large, thus, if the applicant had used 36 ksi instead of 25 ksi for the plate material, it is unlikely that the actual stresses would be near yield. The design margin to the allowable stress in accident conditions for a plate was found to be 7.7. The design margin to failure is greater than 10.0.

For A575 (M1020) material used as angles in the Midland HVAC supports, the ASTM specification does not require mechanical tensile tests. However, the Midland technical specification[1] does require a minimum yield stress of 36 ksi for A575 material. Because several grades of A575 are available with lesser carbon content (and thus lesser strength) than Grade M1020, the strength properties of the lesser grades needed to be determined to evaluate whether the design adequacy could have been compromised. The staff obtained typical test results from Northwestern Steel and Wire Company for various grades of A575 material. The values are shown in Table 2. Thus, it appears that the lowest grade (M1008) of A575 material could exhibit strength properties approximately 10% less than that required by the design specification.

The typical design margins for HVAC supports are provided in Table 3 of this report. As can be seen, the support steel (wide flanges, angles, plates, and tube steel) exhibit substantial design margin to the allowable stress at accident conditions.

It should be noted that the staff found other conservatisms in the HVAC support design. One conservatism is the damping values specified for the seismic building response spectra used in the HVAC support analyses. The supports (welded structures) are designed using a damping value of 2% for both OBE and SSE loads. Regulatory Guide 1.61 allows for welded steel structures 2% for OBE and 4% for SSE. The ratio of the maximum peak acceleration for the SSE at 2% to the maximum peak acceleration for the SSE at 4% is approximately 1.4. Thus, at the maximum peak acceleration, the use of the 2% damping results in an additional design margin of approximately 1.4 for welded steel structures.

It should be noted that the HVAC duct is more rigid than the HVAC supports because of the conservative 8-ft span criterion. Typically, the HVAC duct fundamental beam bending frequency between support spans of 8 ft is approximately 150 hertz (with the lowest frequency approximately 55 hertz) whereas the fundamental frequency of HVAC supports are typically less than 33 hertz.

The welds for HVAC supports are governed by AWS D1.1-72. Weld tensile strength is assumed to be 60 ksi for E60 electrode. For a 3/16" fillet weld the allowable weld strength is :

$= (\text{effective area of weld})(.3\,\sigma_u)$

where σ_u = ultimate weld tensile strength

$= (3/16 \cos 45°)(0.3)(60{,}000)$

$= 2386$ lbs/inch

For accident conditions, a 50% increase in the design allowable is used resulting in an allowable strength of 1.5 x 2386 = 3579 lbs/inch. The design margin to ultimate breaking strength is, 48,060/27,000*= 1.78 at the accident condition allowable weld strength.

As shown in Table 3, the design margin to the allowable weld strength at accident condition varies from 1.3 to 33.3 and is in addition to the 1.78 margin described above. Thus, the staff concludes that welds have a substantial design margin to failure.

B. HVAC Ductwork and Stiffeners

For HVAC ductwork, the staff found that typically A526 or A527 sheet steel is used. However, the design specification[1] also stipulates the use of carbon steel sheet material A366 and A607 Grade 50 and austenitic stainless steel sheet (or plate) Type 304-2B, ASTM A240. The material minimum yield strengths and minimum tensile strengths of the HVAC ductwork are shown in Table 4.

In order to understand the design margins in the HVAC ductwork, it is important to clarify the analytical and testing methods used by the applicant in qualifying the ductwork.

The applicant does not follow the design guidelines of the SMACNA standards but rather uses the generic design guidelines as depicted in their HVAC drawings C-842 through C-849. The staff has compared the differences between the SMACNA standard and the Midland HVAC drawings and has found that the Midland sheet metal thicknesses and stiffener sizes tend to be larger than those specified by SMACNA for the corresponding duct sizes and is, thus, conservative. The SMACNA stiffener spacing tends to be closer than the spacing used at Midland. However, because the stiffener is primarily used to prevent buckling of the sheet metal, the additional thickness of the sheet metal compensates for the increased stiffener spacing.

In 1977, the architect-engineer for the Midland facility (Bechtel Power Corporation) sponsored testing of the HVAC duct specimens for the Limerick plant.

The test results were used to develop a Bechtel generic HVAC duct design guide[3] which was used for the Midland plant. The main goals of the Duct Test Program[4] were:

a) To substantiate the use of width to thickness (w/t) and height to thickness (h/t) ratios of up to 1500 while maintaining the AISI specification as the basis for design.

b) To justify stiffener design.

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* The AWS D1.1 allowable weld stress is 18,000 psi and the corresponding weld stress for the accident condition is 1.5 x 18,000 or 27,000 psi. AWS D1.1 also states that the ultimate breaking strength of fillet welds and partial joint penetration groove welds shall be computed at 2.67 times the basic allowable stress for 60 ksi tensile strength . Accordingly, 2.67 x 18,000 = 48,060 psi.

c) To obtain a rational design method for the structural design of HVAC ducts by correlation between theoretical prediction and experimental results.

d) To assure that the duct details and materials used would not cause any fabrication problems when full scale production began.

The testing was performed by Hales Testing Laboratories of Oakland, California. The testing was based on A526 and A527 ductwork material with a minimum yield strength of 36 ksi. The significant conclusions of the testing included the following results.

- Failure modes of the ducts were not catastrophic and there was a great reserve strength after failure.
- Pressure loading was the most important loading. Live load and seismic loads were less important.
- Effect of seismic loads can be simulated by pressure loads.
- The primary failure modes of rectangular ducts were by corner crippling of sheet and by stiffener buckling.
- Live load stresses in the sheet and stiffeners were low.

The Bechtel generic HVAC duct design guide was used to qualify the ductwork spans in the Midland plant. The calculations assumed a minimum yield strength of the duct material to be 30 ksi. Thus, the ductwork materials specified in the design specification all meet or exceed the 30 ksi value. It should be noted that the ASTM Specification for A526 and A527 material does not require mechanical tensile strength tests. The Midland design specification[1] does require that the sheet metal (where there are no ASTM tensile test requirements) be purchased with a minimum of 30 ksi yield stress. The staff reviewed several purchase orders and confirmed that for the A526 and A527 material, the yield strength and ultimate tensile strengths were specified by the supplementary test requirements. All purchase orders reviewed showed that the yield strengths for safety-related duct material were greater than 30 ksi. With regard to material substitution, the staff has found that drawing quality sheet steel can have a yield stress as low as 25 ksi. However, the staff concluded that approximately 20% decrease in yield stress (25 ksi vs. 30 ksi) is not a significant concern because of the adequate design margins in the HVAC ductwork. The HVAC ductwork design margins are shown in Table 5 of this report.

C. HVAC Ductwork Companion Flange Bolts

The standard bolts used in the HVAC ductwork companion flanges are 3/8 inch diameter and made of A307 low carbon steel. The generic design detail is shown on Midland Dwg No. C-844 (Q) and specifies a 6-inch maximum spacing between the bolts in the companion angle flange connections. The calculation[5] of the 3/8-inch bolt loads was performed for the worst case loadings and included many conservatisms. The calculation was based on A307 bolt material with an allowable design stress of 20 ksi (per AISC Manual of Steel Construction). A307 bolts (Grades A and B) are required by the ASTM specification to have a minimum tensile strength of 60 ksi. The allowable tension was calculated as follows:

Allowable tension load = (20 ksi)(0.078 in^2)(1.5)
(accident condition) = 2340 lbs.

The ASTM (A307) tensile strength requirement for 3/8 inch diameter bolts is 4650 lbs. Thus, there is a design margin of 2 to failure at the allowable tension load at accident conditions. The staff found that assuming one bolt is effective in each corner of the flange, the bolt has adequate strength to accommodate the applicable loads and load combinations. The staff found the bolt calculation to be based on conservative assumptions and the results show an adequate design margin. It should be noted that prying action (steel-to-steel) was considered in the calculation per AISC (8th Edition). A summary of the bolt design margin from the calculated load to the allowable bolt load at accident condition (2340 lbs) for several duct sizes are shown in Table 6.

D. Concrete Expansion Anchor Bolts

The HVAC ductwork supports are generally anchored to reinforced concrete foundations with expansion anchor bolts. The drilled-in concrete expansion anchor bolts are supplied by Hilti Fastening System for all sizes except for 7/8 inch nominal diameter bolts. The 7/8 inch bolts are supplied by Phillips Drill Company. The material properties are shown in Table 7.

In reviewing the design margins in Table 3 of this report, it can be seen that the anchor bolt tends to be the controlling component in the HVAC support design (i.e., the anchor bolts have the least design margin). Anchor bolts are designed with a margin of safety of four to its ultimate tensile load capacity as published in manufacturers' catalogs. The ultimate tensile load capacity is based on the failure of the anchor bolt in concrete due to static loadings. IE Bulletin 79-02 also accounts for bolt slippage in its safety factor of four. Thus, the staff concludes that although the expansion anchor bolts have the least design margin to the allowable design load, there is a design margin of at least 4.0 to the anchor bolt failure due to static loads.

To provide additional verification of the accuracy of the catalog data presented by the anchor bolt manufacturers, Teledyne Engineering Services (TES) has performed both experimental and analytical work on anchor bolts made by different manufacturers including Hilti and Phillips[6]. This work was done for a group of 14 utilities, in response to IE Bulletin 79-02. The TES report is discussed in detail in Appendix B of NUREG/CR-2137. The TES test data for Hilti and Phillips wedge anchors showed relatively close correlation with the catalog loads. The maximum ratio of catalog loads to TES average test loads for Hilti and Phillips was 1.3.

The available test data(6) indicates that by using a safety factor of four to the average strength of the expansion bolt, the probability of failure at the design load is less than 0.001. The probability of failure at two times the design load is about 0.023(7).

The ultimate strength of drilled-in concrete expansion anchor bolts for dynamic and vibratory loadings was investigated by the staff. The safety factor of four as recommended by anchor bolts manufacturers is applicable to static loadings. The design margin to failure for seismic loadings which are dynamic and vibratory in nature is a function of both load magnitude and the number of cycles. A report on an investigation by Bechtel Power Corporation to justify the use of expansion anchor bolts in the Fast Flux Test Facility (Richland, Washington) was prepared for the Hanford Engineering Development Laboratory in January 1975.[8] The objective of this investigation was to establish the allowable design loads (tension, shear, and combined load) for expansion bolts to be installed in various mixes of concrete. The test loads included static loads and alternating loads which simulated the dynamic earthquake loads. The expansion bolts included the stud type wedge anchors manufactured by Hilti Fastening Systems. The seismic loading was simulated by about 6000 cycles of a sine wave which varied from zero to 0.2S (where S is the static load capacity of the anchor bolt). The test found that all expansion bolts which were tested successfully withstood 6000 cycles of 0 to 0.2 S alternating load as designated for seismic qualification. The dynamic load capacities of the expansion bolts were found to be the same as their corresponding static load capacity. It was further discovered that at 6000 to 7800 load cycles when the dynamic test load sequence was increased to 0.6 S subsequent alternating loading caused appreciable wedge movement (or "walking"). If the bolt did not fail in a brittle mode due to pull-out or in some other premature failure mode (e.g., poor installation), the "walking" ceased after a certain number of load cycles.

Extensive dynamic testing of expansion anchor bolts was also discussed in NUREG/CR-2999(9) by Hanford Engineering Development Laboratory under contract with the NRC. Prior to the testing, a survey was performed to determine the adequacy of existing concrete expansion anchor test data. Based on the survey findings, it was concluded that there was a lack of testing to assess the effect of bolt preload under dynamic loadings. Thus, exploratory dynamic testing was performed on typical wedge and shell anchors. It was found that, when the installation torque is properly applied, residual preload does not significantly affect anchor load displacement characteristics until the preload drops to less than 50% of the full installation preload. It was concluded that this must be considered in design situations where support stiffness is an important factor. Table 8 presents the dynamic test results for typical wedge anchor bolts. It can be seen from the ultimate dynamic load capacity and the number of cycles to failure, that there is a large design margin (a minimum of 2.4 for test number DW-SR). The number of cycles exceeds the number of seismic cycles recommended in the Standard Review Plan (10 SSE and 50 OBE) by approximately a factor of three. It should be noted that 3 out of 20 tests did experience 1/4 inch bolt pullout at a load less than the static design load (which is based on a safety factor of four). The 1/4 inch pullout occurred at approximately 80 percent of the static design load.

Thus, the staff finds that the dynamic testing performed by Bechtel and Hanford Engineering Development Laboratory provide similar results. Both testing results appear to indicate that a safety factor of four for dynamic vibratory loads is adequate for the number of peak cycles associated with seismic events, and that the ultimate anchorage capacity is not completely lost although some degree of bolt slippage might occur. Thus, the staff concludes that based on the dynamic testing discussed above, the wedge-type expansion anchor bolt when designed with a safety factor of four to the static anchor capacity and when properly installed is capable of withstanding the dynamic loads associated with a design basis seismic event.

The staff discussed the effect of the prying action of the support baseplates on the anchor bolts. The applicant does not account for prying effects in its anchor bolt design for non-piping supports. The AISC, ACI-318, and ACI-349 criteria do not address the prying action of baseplates on bolt loads. However, ACI and AISC do address the steel-to-steel prying action. Bechtel concluded that because the concrete is relatively soft compared to steel, the effects of the baseplate prying action will be small. In addition, Bechtel believes that the slippage of the bolt does not degrade the ultimate anchorage capacity. The staff review of responses to IE Bulletin 79-02 found similar conclusions. A test report summary by Sargent & Lundy(10) found that for a flexible baseplate with four expansion anchors, the prying action is of the order of 15-20 percent of the applied load. The S&L report also concluded that the small increase was much lower than the expected increase in an assembly with embedded steel bolts where the prying action was calculated to be 110 percent because of the effective lower stiffness of expansion anchors in concrete. Thus, based on the consistency in the results of the prying action of baseplates on concrete anchor bolts as discussed above, the staff concludes that the prying action will not cause a significant increase in the expansion bolt loads.

With regards to the use of lesser grade materials, the staff believes that it is unlikely that material substitution is a significant concern for expansion anchor bolts because of their unique application and configuration. Use of low strength bolts or bolts made of poor quality materials would likely become evident during bolt installation when the bolt preload torque is applied. A low-strength or poor quality bolt would likely yield or break before the required preload torque could be achieved. If an expansion anchor bolt were made with a substitute material of a lesser quality (e.g., A307 material) and remained undetected following application of the preload, high shear strengths given in the manufacturer's catalogs could be unconservative. However, the staff believes that the safety factor of four when applied to the manufacturer's ultimate shear loads provides an adequate margin of safety to account for substitute materials. The ultimate anchor pullout load is not likely to be affected because the ultimate anchor pullout load is in all cases less than the tensile requirements for A307 bolts.

A comparison of the bolt preload values with ASTM A307 tensile strength requirements is shown in Table 9. The staff has found that use of lesser grade materials could be a potential concern with the ITT Phillips Wedge Anchors (7/8 inch diameter only). ITT Phillips supplies both a nuclear grade and a non-nuclear (commercial) grade expansion anchor bolt. For Midland, the procurement specification specifies an NWS-7880 (nuclear grade) wedge anchor. The difference in the nuclear grade and the non-nuclear grade bolts is in material and traceability. The nuclear grade bolt material is AISI 1144 grade with an average tensile strength of 100-120 ksi and a yield strength of 90-110 ksi. The nuclear grade is stamped "NWS" and has a "gold" chromate finish. The commercial grade bolt is 1213 to 1215 carbon steel (no traceability) with a tensile strength of 80-95 ksi and a yield strength of 70-80 ksi. The commercial grade is stamped "WS" and has a silver finish. In accordance with the manufacturer's recommendations, the nuclear grade bolt for 7/8 inch diameter has a pullout ultimate load capacity of 14 ksi (vs 11.85 ksi for commercial) and a shear capacity of 22.5 ksi through the threads and 30.0 ksi through the shank (vs. 24.9 ksi for commercial). Thus, the use of a commercial grade bolt instead of a nuclear grade bolt could reduce the design capacity by 15-20 percent. Based on a review of the dynamic test data, the staff concludes that a reduction of 15-20 percent of the anchor capacity, or in equivalent terms, a reduction of the safety factor from 4.0 to 3.2 appears to be acceptable.

V. Conclusions

A significant effort has been expended by the staff on the subject of expansion anchor bolts largely because of the many uncertainties involved in the actual strength of the installed anchor bolt. The conclusions of the tests, performed on the expansion bolts were based on properly installed bolts and under controlled loadings. Some uncertainties which could affect the overall findings of the staff include 1) improperly installed expansion anchor bolts, 2) the dynamic effects of a seismic event on the anchorage capacity of floors and walls in which the expansion anchor bolts are installed, 3) the long-term aging effects on the anchor strength, and 4) the uncertainties in the dynamic loadings itself. The staff has found that the most limiting component in the HVAC structural design is the expansion anchor bolt assembly. Although the factor of safety used in the design of the anchor bolt capacity appears to be adequate to account for the static and dynamic loads associated with normal and design basis accidents, there is some degree of uncertainty involved with as-installed expansion anchor bolts and the actual loading conditions which could occur that remain as potential concerns of the staff. These concerns extend beyond the scope of this evaluation and into the areas identified above where further generic development should be performed. Thus, our findings on the design margins do not take into account the above uncertainties, except in a qualitative manner.

Based on a detailed review of the typical design margins available in the structural design of the HVAC ductwork and supports, the staff has concluded that there is an adequate margin between the stress or load level that would result under normal and design basis accident conditions and the stress or load level that would result in structural failure of the HVAC ductwork and support systems. The staff further concludes that the available design margin provides adequate compensation for potential degradations in the structural integrity that could result from substitution of lesser quality or lesser grade materials. Therefore, the staff finds that the overall structural design of the Midland HVAC systems is adequate and provides a sufficient margin of safety to failure under normal and design basis accident conditions.

VI. References

1) "Technical Specification for Seismic Class I Heating, Ventilating and Air Conditioning Equipment and Ductwork Installation," for the Midland Plant Units 1 & 2, 7220-M-151A(Q), Rev. 15.

2) "Design Guide for HVAC Supports," (DRAFT) Calc. No. 3471(Q).

3) "Design Guide for Nuclear Power Plant Seismic Category I Rectangular HVAC Ducts (DRAFT)," dated April 15, 1978.

4) "Report on Testing of Class I Seismic HVAC Duct Specimens for the Limerick Generating Station, Units 1 & 2," April 1976.

5) Calculation No. 34-323(Q), Revision 0, dated 10-11-83.

6) Teledyne Engineering Service, Summary Report, "Generic Response to USNRC I&E Bulletin Number 79-02, Base Plate/Concrete Expansion Anchor Bolts," August 1979.

7) NUREG/CR-2137, "Realistic Seismic Design Margins of Pumps, Valves, and Piping," June 1981.

8) FFTF Report, "Drilled-in Expansion Bolts Under Static and Alternating Load," January 1975 (BR-5853-C-4).

9) "Final Report USNRC Anchor Bolt Study Data Survey And Dynamic Testing," NUREG/CR-2999, dated December 1982.

10) Sargent & Lundy report, "Summary Report on Static and Dynamic Relaxation Testing on Expansion Anchors in Response to I&E Bulletin 79-02," dated July 20, 1981.

Table 1

HVAC Support Material

ASTM Material Specification	ASTM Minimum Yield Strength (ksi)	ASTM Minimum Tensile Strength (ksi)	M-151 Minimum Yield Strength (ksi)	Notes
A 36	36	58-80	same as ASTM	
A 572 Gr. 50	50	65	same as ASTM	
A 284 Gr. A	25	50	same as ASTM	plate
A 500 Gr. B	46	58	same as ASTM	tube steel
A 575 (M1020)	not required	not required	36	angle

Table 2

HVAC Support Material Properties (A575)

ASTM-A575	Minimum Yield Strength (ksi)
Grade M1008	34.0
Grade M1010	35.7
Grade M1015	36.1
Grade M1020	37.2

Table 3

HVAC SUPPORTS

Tabulation of Calculated vs. Allowable Stress

Location	Reference Calc. No.	Description[1]	Calculated Stress / Allowable Stress	Design Margin
Control Room	21 G (4.4143)	W 6 x 12	0.23	4.3
		L 3 x 3 x ¼	0.19	5.3
		L 2 x 2 x ¼	0.13	7.7
		L 2 x 2 x ¼	0.13	7.7
		L 3½ x 3½ x ¼	0.05	20.0
		weld	0.76	1.3
		weld	0.10	10.0
		weld	0.61	1.6
		weld	0.51	2.0
Control Room	21 G (4.146)	all structural members	0.48	2.1
		weld	0.03	33.3
		anchor bolt	0.50	2.0
Control Room	29 D 276	L 3 x 3 x ¼ (all)	0.33	3.0
		W 6 x 12	0.04	25.0
		TS 2 x 2 x ¼	0.04	25.0
		weld	0.42	2.4
		weld	0.73	1.4
		weld	0.57	1.8
Service Water Bldg	648-S126	TS 3 x 3 x ¼	0.15	6.7
		TS 2 x 2 x ¼	0.09	11.1
		L 2 x 2 x ¼	0.13	7.7
		weld	0.03	33.3
		weld	0.12	8.3
		weld	0.68	1.5
		weld	0.06	16.7
		weld	0.35	2.9
		anchor bolt	0.40	2.5
		anchor bolt	0.88	1.1
		anchor bolt	0.64	1.6
		anchor bolt	0.80	1.3
Auxiliary Bldg	21 F (3.136)	L 2 x 2 x ¼	0.13	7.7
		TS 2 x 2 x ¼	0.14	7.1
		weld	0.04	25.0
		weld	0.20	5.0
		weld	0.15	6.7
		weld	0.04	25.0
		anchor bolt	0.58	1.7
		anchor bolt	0.34	2.9

Table 3 (continued)

Location	Reference Calc. No.	Description [1]	Calculated Stress / Allowable Stress	Design Margin
Auxiliary Bldg	21 I (6.95)	TS 4 x 4 x ¼	0.32	3.1
		TS 2 x 2 x ¼	0.48	2.1
		L 2 x 2 x ¼	0.36	2.8
		PL ½ x 18	0.13	7.7
		weld	0.40	2.5
		weld	0.35	2.9
		weld	0.15	6.7
		weld	0.24	4.2
		weld	0.29	3.4
		weld	0.25	4.0
		weld	0.10	10.0
		weld	0.23	4.3
		weld	0.32	3.1
		L 4 x 4 x ½	0.44 (shear controlling)	2.3

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[1] W = wide flange
L = angle
TS = tube steel
PL = plate

Table 4

HVAC Ductwork Material

ASTM Material Specification	ASTM Minimum Yield Strength (ksi)	ASTM Minimum Tensile Strength (ksi)	M-151 Minimum Yield Strength (ksi)
A526	not required	not required	30
A526	not required	not required	30
A366	not required	not required	30
A607 Gr. 50	50	65	same as ASTM
A240 Type 304	30	75	same as ASTM

Table 5

Summary of HVAC Duct Analysis Results(3)

Duct Size (inches)(1)	Sheet Metal Gauge	Stiffener(4)	Allowable Pressure (psi)		Governing Allowable Pressure (psi)	Calculated Worst Loading (psi)(2)	Design Margin
			Sheet Metal	Stiffener			
Control Room (Aux Bldg)							
60x26	18	L2x2x3/16	0.86	0.69	0.69	0.294	2.35
36x26	16	L1½x1½x1/8	1.40	1.40	1.40	0.301	4.65
Diesel Generator Bldg							
60x60	16	L2x2x3/16	1.086	0.691	0.69	0.253	2.73
30x40	16	L1½x1½x1/8	1.322	1.40	1.32	0.253	5.22
Service Water Pump Structure							
72x44	16	L3x3x3/16	1.064	1.102	1.102	0.230	4.79
72x24	18	L3x3x3/16	0.865	1.102	0.865	0.223	3.88
52x44	16	L2x2x1/16	1.237	0.98	0.98	0.230	4.26
42x26	18	L1½x1½x1/8	1.111	0.94	0.94	0.223	4.22
28x26	18	L1½x1½x1/8	1.408	1.04	1.04	0.223	4.66
Auxiliary Building							
108x16	14	C 3x5.0	1.14	0.47	0.47	0.335	1.40
108x16	14	C 5x6.7	1.14	1.25	1.14	0.628	1.75
60x32	18	L2x2x3/16	1.15	0.69	0.69	0.326	2.12
38x38	16	L1½x1½x3/16	1.44	1.22	1.22	0.330	3.70
76x40	16	L3x3x3/16	1.04	0.97	0.97	0.254	3.82
50x40	16	L2x2x3/16	1.25	1.08	1.08	0.259	4.17
54x36	18	L2x2x3/16	0.98	0.89	0.89	0.320	2.78
28x14	18	L1x1x1/8	1.41	1.05	1.05	0.234	4.49
24x24	18	L1x1x1/8	1.56	1.59	1.56	0.223	7.00
12x6	18	L1x1x1/8	2.59	11.10	2.59	0.234	11.07
60x36	16	L3x3x3/16	1.15	1.70	1.15	0.593	1.94

(1) Largest duct size for the same gauge sheet metal and stiffener.

(2) Worse case loading is Dead Load + P + W, where P = operating pressure, W = wind load. The worst case loading bounds seismic load combinations.

(3) Summary of results from Bechtel Calc. No. SQ-180(q) dated 5/16/83. Stresses due to dead load, seismic load, wind and internal pressures are converted to equivalent internal pressure loads for comparison.

(4) L = angle
C = channel

Table 6

Table of HVAC Duct Flange Bolt Loads

			Forces in Bolt @ Safe Shutdown Earthquake			
Duct Size (in)	Sheet Thickness (gauge)	Operating Pressure in W.G. (in)	Max. Tension In Bolt of Companion Flange (lb)	Allowable Tension (lb)	$\frac{\text{Max. Calculated Load}}{\text{Allowable Load}}$	Design Margin
60 x 26	16	13	1200	2340	0.51	1.96
60 x 60	14	13	1900	2340	0.81	1.23
30 x 30	18	13	586	2340	0.25	4.00
60 x 60	16	4	840	2340	0.36	2.78

Table 7

Concrete Expansion Anchor Bolt Material Properties

Type	Size (inches)	Material Properties	Requirements Met
Stud (bolt)	1/4-1/2	AISI 11L41	ASTM A108
	5/8-1¼	AISI 1144	ASTM A108
Expansion Wedges		ANSI 1050 spring steel	
Nuts		commercial manufacture	ASTM A307
Washers		SAE material	ASA B27.2-1949

Table 8
Dynamic Test Results (From Reference 9)

					Test Results			
Test No.	Anchor Type	Load Type	Ultimate Static Strength (Kips)	Preload**	No. of Cycles	Ult. Load Kips	Note	Load at 1/4" Displ. Kips
DW-1	Wedge	Tension	(25.3)	Full	845	25.3	1, 2	15.2
DW-1R				Full	141	20.2	1, 2	15.2
DW-2				Full	255	25.3	1, 2	10.1
DW-3				Half	239	25.3	1, 2	15.2
DW-4				Half	181	25.3	1, 2	10.2
DW-5				Zero	133	20.2	2, 3	5.0
DW-5R				Zero	105	15.2	2, 3	5.0
DW-6				Zero	179	25.3	2, 3	10.2
DW-7		Shear	(24.0)	Full	208	28.8	2, 4	24.0
DW-8				Full	179	24.0	2, 4	14.4
DW-9				Half	176	24.0	2, 4	14.4
DW-10				Half	165	24.0	2, 4	14.4
DW-11				Zero	163	24.0	2, 4	14.4
DW-12				Zero	167	24.0	2, 4	14.4
DW-13		Combined*		Full	161	25.3	2, 5	10.1
DW-14				Full	135	20.2	2, 5	15.2
DW-15				Half	139	20.2	2, 4	5.0
DW-16				Half	161	25.3	2, 4	10.1
DW-17				Zero	161	25.3	2, 4	15.2
DW-18				Zero	140	20.2	2, 4	15.2

* $\frac{\text{Tension}}{\text{Shear}} = 1.732$

** Full preload: 125-175 foot-pounds
Half preload: 62-88 foot-pounds
Zero preload: Finger tight

NOTES
1. Anchor pullout, no concrete failure
2. Test stopped at 1" displacement
3. Anchor pullout and local concrete failure
4. Anchor shear failure
5. Anchor shear and local concrete failure

Table 9

Comparison of Anchor Bolt Load Requirements

Bolt Diameter (in)	Minimum Preload Torque (ft-lbs)[a]	Minimum Anchor Bolt Preload (lbs)[b]	Ultimate Anchor Pullout Load Capacity (lbs)[c]	A307 Bolt Requirement for Tensile Strength (lbs)[d]
1/2	35	2,800	5,510	8,500
5/8	130	8,320	9,100	13,550
3/4	240	12,800	13,400	20,050
7/8	275	12,571	14,000	27,700
1	425	17,000	18,900	36,350

(a) per Specification 7220-C-305(Q) Rev. 17

(b). Calculated using the equation:

$$T = KDL$$

where: T = preload torque applied
K = assume 0.3 for unlubricated threads
D = nominal bolt diameter
L = bolt preload force

(c) per Hilti Fastening Systems and ITT Phillips Drill Company Catalogs Based on 3500-4000 psi strength concrete

(d) per ASTM Specification, "Standard Specification for Carbon Steel Externally and Internally Threaded Standard Fasteners," A307-76b.

ENCLOSURE 2

EVALUATION OF FUNCTIONAL DESIGN ADEQUACY OF MIDLAND HVAC SYSTEMS

The Midland heating, ventilation and air conditioning (HVAC) systems consist of various individual systems, each of which is designed to maintain the specific building or area within certain limits required for habitability and/or equipment operability. A description of the function of each of these systems and areas that each system serves is provided in Section 9.4 of the Midland SER (NUREG-0793, May 1982).

In support of the review of the structural design adequacy of the HVAC systems at the Midland Plant, the staff also reviewed the functional design adequacy of the ventilation systems. The objective of this review was to verify that the conclusions reached by the staff in Section 9.4 of the Midland SER continue to be valid for the actual ventilation system design at Midland.

In performing its review, the staff reviewed the latest revisions to drawings of the Midland ventilation systems and compared them with earlier drawing revisions upon which the staff's FSAR review had been based. The staff concluded that there were no design changes that would alter the conclusions reached in the SER based on the later drawings.

A particular focus of the drawing review was on any changes to transition points and isolation capabilities between safety related and non-safety related portions of the systems from those described in the FSAR and the SER. This portion of the review was in support of the structural design adequacy evaluation (i.e., if the safety-related boundaries had changed from those reviewed in the FSAR, then the structural design adequacy review would need to determine whether or not those changes had been taken into account in the design of the structural supports.) The staff concluded that the transition points and isolation capabilities between safety related and non-safety related portions of the ventilation systems remained as described in the FSAR and SER.

Based on its review of the functional aspects of the present ventilation systems design at Midland, the staff determined that the evaluations and the conclusions reached in Section 9.4 of the Midland SER remain valid. Verification of the HVAC systems fuctional capability to meet the design requirements will be performed during the intial testing program as described in FSAR Section 14A.

ENCLOSURE 3

EVALUATION OF MIDLAND HVAC MATERIALS

The specifications and records for materials of the Midland HVAC systems were audited October 6-7, 1983. The purpose of the review and audit was to verify that the materials incorporated into the construction met the requirements called out in the design and procurement documents.

The identification of materials for use in the Midland HVAC systems is contained in Bechtel Technical Specification 7220-M-151A(Q), "Seismic Class 1 Heating Ventilation and Air Conditioning Equipment and Ductwork Installation for the Consumers Power Company, Midland Plant Units 1 and 2, Midland, Michigan."

It is the applicant's practice to revise this Specification during construction by incorporating into the Specification those deviations that were considered to be acceptable. These deviations were originally accepted by QC documents such as Supplier Deviation Deficiency Requests (SDDRs), Specification Change Notices (SCNs), and Field Change Requests (FCRs). Although the practice of incorporating these deviations in the Specification reduces the amount of repetitive paper work required, the practice tends to degrade the original Specification. It also means that an audit of QA records will show that all accepted material met the Specification.

An extensive sample of the procurement packages for HVAC materials was reviewed during the audit. No discrepancies were found in the system. Some of the dates of certification were observed to be retroactive, but no indication was found that nonconforming material had been installed.

As noted in Franklin Research Center's Report F-C5896-001, samples of material taken from the actual duct work installed at the site or from storage were tested. The intent was to determine if the material samples met the specifications for chemical analysis and relevant material properties. Although the chemical analyses and mechanical property tests performed did not reflect the specification requirements in all cases, the only discrepancy found of potential significance was that some of the bolts were harder than permitted by the Specification. The potential problem associated with bolts of higher than specified hardness is that if torqued to high stress levels, they can be susceptible to stress corrosion cracking. Upon further review, however, we find that the threshhold hardness for susceptability to stress corrosion failure is significantly greater than the hardnesses exhibited by the Midland bolt samples. Thus, failure of the Midland HVAC bolts due to stress corrosion cracking is unlikely.

In summary, this investigation did not disclose any materials discrepancies that would be expected to cause operating problems with the HVAC system as installed at Midland, although some of the installed material was apparently not in compliance with the appropriate specification.