

### 3A Criteria for Distribution System Analysis and Support

This appendix provides the design criteria for the U.S. EPR distribution system analysis and supports. As noted in Section 3.7.3, this appendix describes criteria for design of supports for:

- Piping.
- Heating, ventilation, and air conditioning (HVAC) ducts.
- Cable trays.

#### 3A.1 Piping and Supports

Information on piping, instrumentation, and supports is provided in AREVA NP Topical Report ANP-10264NP-A (Reference 1).

#### 3A.2 Heating, Ventilation, and Air Conditioning Ducts and Supports

HVAC ductwork and its associated support structures are designed to withstand the loadings and load combinations presented in Section 3A.2.2 and Section 3A.2.3, based on the Codes and Standards provided in Section 3A.2.1. A typical HVAC duct system includes structural components (e.g., sheet metal ducts, duct stiffeners, duct supports) and inline components (e.g., heaters and dampers).

Safety-related, Seismic Category I HVAC ductwork, supports, and restraints meet the stress allowables provided in paragraph AA-4321 of ASME AG-1 (Reference 2). Seismic Category II HVAC ductwork, supports, and restraints are analyzed to make sure that a failure would not impair the safety function of safety-related equipment or components. Seismic Category II requirements are satisfied by meeting the criteria as established in Section 3.7.2.3.3.

Non-Seismic HVAC ductwork meets Sheet Metal and Air Conditioning Contractors National Association (SMACNA) standards (Reference 5). Non-Seismic HVAC ductwork support and restraint systems meet the analysis requirements of the American Institute of Steel Construction (AISC) Manual (Reference 3).

##### 3A.2.1 Codes and Standards

HVAC ductwork, ductwork supports, and ductwork restraints conform to the following codes and standards:

- ASME AG-1-2003, Code on Nuclear Air and Gas Treatment, with 2004 Addenda (Reference 2).
- AISC Manual of Steel Construction, Ninth Edition (Reference 3).

- American Iron and Steel Institute (AISI), North American Specification for the Design of Cold-Formed Steel Structural Members, 2001 Edition with 2003 Errata (Reference 4).
- SMACNA, HVAC Duct Construction Standards, Metal and Flexible, Third Edition, 2005 (Reference 5).
- American Welding Society (AWS) D1.1/D1.1M: 2004, Structural Welding Code-Steel, with errata through June 2005 (Reference 6).
- AWS D1.3-98, Structural Welding Code – Sheet Steel (Reference 7).
- ANSI/AISC-N690-1994, AISC “Specification for the Design, Fabrication, and Erection of Steel Safety-Related Structures for Nuclear Facilities,” with Supplement 2 (10/06/2004) (Reference 8).

### 3A.2.2 HVAC Ductwork

#### 3A.2.2.1 HVAC Ductwork Loads

The structural loads for the HVAC ductwork are listed below:

- Additional Dynamic Loads (ADL)—loads resulting from system excitations due to structural motion caused by safety relief valve actuation and other hydrodynamic loads due to the design basis accident (DBA), small pipe break accident (SBA), and intermediate pipe break accident (IBA); also, liquid slosh in tanks and vessels and mechanical shock loads.
- Constraint of Free End Displacement Loads (T)—loads caused by constraint of free end displacement that results from thermal or other movements.
- Dead Weight (DW)—weight of the equipment or ductwork including supports, stiffeners, insulation, any contained fluids, and internally and externally mounted components.
- Design Pressure Differential (DPD)—dynamic pressure loads resulting from a DBA, IBA, or SBA. Generally, HVAC is routed outside the local pipe break affected area. If HVAC is subjected to these loads, the design specification shall address the specific design requirements considering a Level D load combination.
- Design Wind Loads (W)—loads due to design hurricane, design tornado, or other abnormal meteorological conditions. See Section 3.3 for a discussion of design wind loads.
- External Loads (EL)—applied loads caused by attached piping, accessories, or other equipment.
- Fluid Momentum Loads (FML)—momentum and pressure forces because of fluid flow, as clarified in SA-4211 of ASME AG-1.

- Live Loads (L)—loads occurring during construction and maintenance and may also include loads due to snow, ice and ponded water. Live loads will not be less than a 250 lb construction or maintenance midspan man load over a 10 square inch area.
- Normal Operating Pressure Differential (NOPD)—maximum positive or negative differential pressure that may occur during normal plant operation including start-up and test conditions; this includes pressures resulting from normal airflow, and valve or damper closure.

For ease of design, a duct system may be designed using one pressure value that envelops NOPD and SOPT. NOPD and SOPT may be positive or negative pressures. The worst case shall be considered in the design.

- Seismic Loads (SL)—Loads that are the result of the safe shutdown earthquake (SSE). Both orthogonal components of the horizontal seismic excitation are applied simultaneously with the vertical seismic loading. These seismic forces are applied in the directions that produce worst case stresses and deflections.
- System Operational Pressure Transient Loads (SOPT) – overpressure transient loads due to events such as rapid damper, plenum or housing door, and valve closure, or other normal loads that result in a short duration pressure differential.

For ease of design, a duct system may be designed using one pressure value that envelops NOPD and SOPT. NOPD and SOPT may be positive or negative pressures. The worst case shall be considered in the design.

- Normal Loads (N) – loads consisting of normal operating pressure differential, system operating pressure transients, dead weight, external loads, and fluid momentum loads.

$$N = \text{NOPD} + \text{SOPT} + \text{DW} + \text{EL} + \text{FML}$$

As noted above for SOPT, if an enveloped pressure valve for NOPD and SOPT is utilized in the design, utilize the following load combination for Normal Loads:

$$N = \text{Envelop of (NOPD, SOPT)} + \text{DW} + \text{EL} + \text{FML}$$

### 3A.2.2.2 HVAC Ductwork Load Combinations

Table 3A-1 lists the HVAC ductwork loading combinations for the design of HVAC ductwork.

### 3A.2.3 HVAC Duct Supports and Restraints

#### 3A.2.3.1 HVAC Support and Restraint Loads

Loads ADL, DPD, DW, EL, FML, L, NOPD, SOPT, SL, T, and W (see Section 3A.2.2.1) apply to HVAC ductwork supports and restraints.

For HVAC ductwork supports and restraints, Normal Loads (N) = NOPD + SOPT + DW + EL + FM, or if an enveloped pressure value for NOPD and SOPT is utilized in the design,  $N = \text{Envelop of (NOPD, SOPT)} + DW + EL + FML$ .

### **3A.2.3.2 HVAC Support and Restraint Load Combinations**

Table 3A-2 lists the HVAC support and restraint loading combinations for the design of HVAC supports and restraints.

## **3A.2.4 Design and Analysis**

### **3A.2.4.1 Allowable Stress Criteria**

Ductwork stresses are based on Reference 4. Ductwork support stresses are based on AISC "Specification for the Structural Steel Buildings - Allowable Stress Design and Plastic Design," contained in Reference 3.

The basic general membrane design stress for Service Level A condition does not exceed  $0.6 S$  and is reduced as appropriate to account for lateral-torsional buckling of bending members and effective lengths of compression members. The combined membrane and bending stress for Service Level A does not exceed  $1.5 \times 0.6 S$ . The basic general membrane design stress allowable, and the combined membrane and bending stress allowable for Level B are the same as those for Level A. The basic general membrane stress for Service Level C condition does not exceed  $1.2 \times 0.6 S$  and is reduced as necessary to account for lateral-torsional buckling of bending members and effective lengths of compression members. The combined membrane and bending stress for Service Level C does not exceed  $1.8 \times 0.6 S$ . The basic general membrane design stress for Service Level D condition does not exceed the lesser of  $1.5 \times 0.6S$  or  $0.4S_u$ , where  $S_u$  is the ultimate stress. The combined membrane and bending stress for Service Level D does not exceed the lesser of  $2.25 \times 0.6S$  or  $0.6S_u$ .

### **3A.2.4.2 Deflection Limits**

The allowable deflections for the load combinations described above are provided in Table 3A-3. Deflection criteria conform to Section SA-4230 of Reference 2.

### **3A.2.4.3 Damping**

The damping values for the design of HVAC duct systems are discussed in Section 3.7.1.2 and are contained in Table 3.7.1-1.

### **3A.2.4.4 Seismic Analysis**

This section describes the seismic analysis criteria for HVAC duct systems and their supports.

### **3A.2.4.4.1 Seismic Analysis Methods**

Seismic analysis of HVAC duct system and associated supports is performed using dynamic analysis or the equivalent static load method. The dynamic analysis procedures include the response spectrum method and time history method as discussed in Section 3.7.3.1.1 and Section 3.7.3.1.2 respectively. The equivalent static load method, as described in Section 3.7.3.1.4, may be used for simple systems such as straight run ducts with uniformly spaced supports or subsystems that can be represented as simple frames.

### **3A.2.4.4.2 Determination of Number of Earthquake Cycles**

Section 3.7.3.2 discusses the required number of earthquake cycles to be considered for seismic-induced fatigue. Rolled structural steel members for HVAC supports may be qualified for fatigue by evaluation in accordance with the provisions of ANSI/AISC N690 (Reference 8). Cold-formed members for HVAC supports may be qualified for fatigue by evaluation in accordance with the provisions of American Iron and Steel Institute (AISI), North American Specification for the Design of Cold-Formed Steel Structural Members (Reference 4). Connections for structural steel members are qualified by cyclic testing for the number of earthquake cycles specified in Section 3.7.3.2. Similarly, hardware components used to connect cold-formed members are also qualified by cyclic testing for the number of earthquake cycles specified in Section 3.7.3.2.

### **3A.2.4.4.3 Analytical Modeling Procedures**

The modeling guidelines for accurate representation of duct systems and supports are presented in Section 3.7.3.3. The design of HVAC duct system is generally controlled by two failure modes: duct sheet failure by corner crippling and stiffener failure by buckling.

The response of the ductwork in the global bending mode is determined by modeling the duct section as an equivalent beam. The section modulus for rectangular HVAC ducts is reduced by determining an effective duct corner length; however, the entire section is considered effective for round HVAC ducts. The ductwork panels, including the stiffeners, may be modeled using shell elements to simulate the local yielding behavior, which occurs as sheet crippling or stiffener buckling. The local inelastic behavior is usually eliminated by proper selection of duct aspect ratio and stiffener spacing facilitating linear analysis of the subsystem.

### **3A.2.4.4.4 Basis for Selection of Frequencies**

Refer to Section 3.7.3.4.

**3A.2.4.4.5 Analysis Procedure for Damping**

Refer to Section 3.7.3.5 for analysis procedure for damping. The damping criterion is further described in Section 3A.2.4.3.

**3A.2.4.4.6 Three Components of Earthquake Motion**

Refer to Section 3.7.3.6.

**3A.2.4.4.7 Combination of Modal Responses**

Refer to Section 3.7.3.7.

**3A.2.4.4.8 Interaction of Other Systems with Seismic Category I Systems**

Refer to Section 3.7.3.8.

**3A.2.4.4.9 Multiply-Supported Equipment and Components with Distinct Inputs**

Refer to Section 3.7.3.9.

**3A.2.4.4.10 Use of Equivalent Vertical Static Factors**

Refer to Section 3.7.3.10.

**3A.2.4.4.11 Torsional Effects of Eccentric Masses**

Refer to Section 3.7.3.11.

**3A.2.5 Other Criteria****3A.2.5.1 Vibration Isolation**

The vibration isolation equipment restraints resist the loads generated by any service condition.

**3A.2.5.2 Relative Movement**

Clearances are provided that allow for relative movement between equipment, ductwork, and supports.

**3A.2.5.3 Tolerances**

Fabrication tolerances comply with Subarticle SA-6400, of Reference 2.

**3A.2.5.4 Attachments**

Attachments withstand the load combinations listed in Section 3A.2.2.2. The allowable types of welded joints are designed in accordance with the applicable

requirements of AWS Structural Welding Code-Steel and Sheet Steel, D1.1 and D1.3 (References 6 and 7). Local stresses induced in the ductwork by integral attachments, as defined in Paragraph AA-4243 of Reference 2, are analyzed. The material selected for items used as part of an assembly for supporting or guiding the ductwork is compatible for welding. Consideration is given to the mechanical connection and local stresses induced in the ductwork by nonintegral attachments, as defined in Paragraph AA-4243 of Reference 2. The design of bolts for structural supports meets the requirements of Subarticle AA-4360 of Reference 2.

### **3A.3 Cable Tray, Conduit, and Supports**

The following criteria apply to Seismic Category I and II cable trays, conduits, and the associated supports and restraints.

#### **3A.3.1 Codes and Standards**

Cable tray, conduit, and cable tray supports and restraints conform to the following codes and standards:

- ANSI/AISC-N690-1994, AISC “Specification for the Design, Fabrication, and Erection of Steel Safety-Related Structures for Nuclear Facilities,” with Supplement 2 (10/06/2004), (Reference 8).
- American Iron and Steel Institute (AISI), North American Specification for the Design of Cold-Formed Steel Structural Members, 2001 Edition with 2003 Errata (Reference 4).
- AISC Manual of Steel Construction, Ninth Edition, (Reference 3).

#### **3A.3.2 Loads**

The following loads are considered for the design of cable trays, conduits, and their supporting structures:

- Dead Load (D)—weight of cable trays or conduits, supports, cable inside of the raceways, tray covers, and other permanently attached components and fittings.
- Live Loads (L)—loads occurring during construction and maintenance. Live loads will not be less than a 250 lb load applied to a tray span in a manner providing worst case stresses in the tray and/or maximizing support loads. This load is not combined with seismic loads and is not applicable for conduits.
- Seismic (S)—See Section 3A.2.2.1.
- Thermal (T)—Loads resulting from thermal expansion or contraction. These loads are avoided by placing expansion/contraction joints along raceway runs.

### 3A.3.3 Load Combinations

Table 3A-4 lists the raceway and support loading combinations for the design of cable trays, conduits and supports.

### 3A.3.4 Allowable Stress Criteria

The basic stress allowables for carbon steel cold formed sections are in accordance with the AISI cold-formed structural design specification (Reference 4). The basic stress allowables for support structural steel, welds, and bolts are in accordance with Reference 8.

### 3A.3.5 Damping

The damping values for the design of cable tray and conduit systems and their associated supports are addressed in Section 3.7.1.2, and are provided in Table 3.7.1-1.

Cable tray systems may use higher damping values based on testing, which includes the proposed installed configuration, loading, and support system. Historic tests have demonstrated that a substantial amount of energy is dissipated by friction between cables and through movement and bouncing of cables within the tray. The increase in damping is more pronounced for loaded trays with higher input excitation but the maximum critical damping is limited to 15 percent for cable trays with a minimum loading of 50 percent of the trays full rated loading (for input ground motion ZPA exceeding 0.25 g). Other cable tray systems are limited to a maximum critical damping of 10 percent for cable tray systems with more than 50 percent loading and 7 percent with less than 50 percent loading in accordance with RG 1.61 and as shown in Figure 3.7.1-16. The damping value is to be reduced to the values indicated in Table 3.7.1-1 for conduit, cable trays loaded to less than 50 percent of the cable tray rated capacity, cable trays loaded primarily with conduit, or when rigid fire proofing materials are used causing the cables to become effectively bundled together.

### 3A.3.6 Seismic Analysis

This section describes the seismic analysis criteria for cable trays, conduits and their supports.

#### 3A.3.6.1 Seismic Analysis Methods

Refer to Section 3.7.3.1.

#### 3A.3.6.2 Determination of Number of Earthquake Cycles

Section 3.7.3.2 discusses the required number of earthquake cycles to be considered for seismic-induced fatigue. Rolled structural steel members for cable tray and conduit supports may be qualified for fatigue by evaluation in accordance with the provisions

of ANSI/AISC N690 (Reference 8). Cold-formed members for cable tray and conduit supports may be qualified for fatigue by evaluation in accordance with the provisions of American Iron and Steel Institute (AISI), North American Specification for the Design of Cold-Formed Steel Structural Members (Reference 4). Connections for structural steel members are qualified by cyclic testing for the number of earthquake cycles specified in Section 3.7.3.2. Similarly, hardware components used to connect cold-formed members are also qualified by cyclic testing for the number of earthquake cycles specified in Section 3.7.3.2.

**3A.3.6.3 Analytical Modeling Procedures**

Refer to Section 3.7.3.3.

**3A.3.6.4 Basis for Selection of Frequencies**

Refer to Section 3.7.3.4.

**3A.3.6.5 Analysis Procedure for Damping**

Refer to Section 3.7.3.5 for analysis procedures for damping. The damping criteria is further described in Section 3A.3.5.

**3A.3.6.6 Three Components of Earthquake Motion**

Refer to Section 3.7.3.6.

**3A.3.6.7 Combination of Modal Responses**

Refer to Section 3.7.3.7.

**3A.3.6.8 Interaction of Other Systems with Seismic Category I Systems**

Refer to Section 3.7.3.8.

**3A.3.6.9 Multiply-Supported Equipment and Components with Distinct Inputs**

Refer to Section 3.7.3.9.

**3A.3.6.10 Use of Constant Vertical Static Factors**

Refer to Section 3.7.3.10.

**3A.3.6.11 Torsional Effects of Eccentric Masses**

Refer to Section 3.7.3.11.

**3A.4****References**

1. ANP-10264NP-A, Revision 0, "U.S. EPR Piping Analysis and Support Design Topical Report," AREVA NP Inc., November 2008.
2. ASME AG-1-2003, "Code on Nuclear Air and Gas Treatment," The American Society of Mechanical Engineers, 2003 with 2004 Addenda.
3. AISC "Manual of Steel Construction," Ninth Edition, American Institute of Steel Construction, April 2002.
4. AISI, "North American Specification for the Design of Cold-Formed Steel Structural Members," American Iron and Steel Institute, 2001 Edition with 2003 Errata.
5. SMACNA, "HVAC Duct Construction Standards, Metal and Flexible," Sheet Metal and Conditioning Contractors National Association, Third Edition, 2005.
6. AWS D1.1/D1.1M: 2004, "Structural Welding Code-Steel," American Welding Society with errata through June 2005.
7. AWS D1.3-98, "Structural Welding Code – Sheet Steel," American Welding Society, 1998.
8. ANSI/AISC-N690-1994, AISC "Specification for the Design, Fabrication, and Erection of Steel Safety-Related Structures for Nuclear Facilities," American National Standards Institute/American Institute of Steel Construction, with Supplement 2, October 2004.
9. NUREG-0484, "Methodology for Combining Dynamic Responses," U.S. Nuclear Regulatory Commission, May 1980.
10. Report 1053-21.1-4, "Cable Tray and Conduit Raceway Seismic Test Program, Release 4," Bechtel-ANCO Engineers, Inc., December 15, 1978.
11. Koss, P., "Seismic Testing of Electric Cable Tray Systems," 48th Annual Convention of the Structural Engineers Association of California, October 4-6, 1979.
12. ASCE/SEI 43-05, "Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities," American Society of Civil Engineers, 2005.

**Table 3A-1—HVAC Ductwork Load Combinations<sup>5</sup>**

<b>Service Level</b>	<b>Load Combination (see Section 3A.2.2.1)</b>	<b>Stress Criteria</b>
A	N + T N + L	See 3A.2.4.1
B	N + W + T N + T + ADL	See 3A.2.4.1
C	N + W + T N + SL + ADL	See 3A.2.4.1
D	N + DPD + SL + ADL	See 3A.2.4.1

**Table 3A-2—HVAC Support and Restraint Load Combinations<sup>5</sup>**

<b>Service Level</b>	<b>Load Combination (see Section 3A.2.2.1 and 3A.2.3.1)</b>	<b>Stress Criteria</b>
A	N + T N + L	See 3A.2.4.1
B	N + W + T N + T + ADL	See 3A.2.4.1
C	N + W + T N + SL + ADL	See 3A.2.4.1
D	N + DPD + SL + ADL	See 3A.2.4.1

**Table 3A-3—Deflection Limits<sup>1,2</sup>**

Service Level	Deflection Limit
A <sup>3</sup>	$d_{all} \leq 0.6 d_{max}$
B <sup>3</sup>	$d_{all} \leq 0.6 d_{max}$
C <sup>4</sup>	$d_{all} \leq 0.9 d_{max}$
D <sup>4</sup>	$d_{all} \leq 0.9 d_{max}$

**Notes:**

1. If particular equipment design criteria require more restrictive limits on deflections, those requirements will be stated in the applicable equipment section of Reference 2.
2. Deflections are limited to prevent transmission of excessive load to other components such as filter frames, coils, bearings, and access doors.
3. Deflections are limited to values that prevent buckling in primary load carrying elements.
4. Deflections are limited to values as described in AA-4323 of Reference 2.
5. Loads due to dynamic events are combined considering the time phasing of the events (i.e., whether the loads are consistent in time). When the time phasing relationship can be established, dynamic loads may be combined by the square-root-sum-of-the-squares (SRSS) method, provided it is demonstrated that the non-exceedance criteria given in NUREG-0484 (Reference 9) are met. When the time phasing relationship cannot be established or when the non-exceedance criteria in Reference 9 are not met, dynamic loads are combined by absolute sum. Safe shutdown earthquake (SSE) and high-energy line break loads—loss-of-coolant accident (LOCA) and secondary side rupture—are always combined using the SRSS method.

**Table 3A-4—Load Combinations for Cable Trays, Conduits and Supports**

<b>Service Level</b>	<b>Category</b>	<b>Load Combination</b>	<b>Stress Limit<sup>1</sup></b>
A	Normal Condition	D+L	$1.0 \times S_a$
C	Emergency Condition	D+S	$1.6 \times S_a (<0.9 F_y)$

**Notes:**

1.  $S_a$ = The basic allowable stress.