Guidelines for Seismic Verification of HVAC Duct and Damper Systems

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ABSTRACT

EPRI has developed guidelines [1] that can be used to perform an experience-based seismic capability verification of HVAC duct and damper systems in nuclear power plants. The EPRI report summarizes earthquake and shake table experience data for these systems and identifies the characteristics that could lead to failure or unacceptable behavior in an earthquake. The seismic experience data show that HVAC duct and damper systems exhibit extremely good performance under strong-motion seismic loading, with the pressure boundary being retained in all but a handful of cases.

The guidelines were applied to verify the seismic adequacy of a non-seismically designed HVAC system at a nuclear power plant. The trial application [2] included an independent peer review [3]. The EPRI report incorporates lessons learned from the trial application and the recommendations of the peer reviewer.

The trial application was successful and proved the methodology to be a practical, rigorous and cost-effective means to verify the seismic adequacy of HVAC duct and damper systems. Seismic weaknesses were readily identified for further evaluation or modification. Quantitative analysis of duct runs not meeting the screening criteria showed that the screening criteria were conservative. There was a significant cost savings to the plant in not having to carry out conventional seismic analysis of all of the ductwork, and not installing unnecessary seismic bracing on the ductwork.

INTRODUCTION

The EPRI Seismic Qualification Utility Group (SQUG) provides guidelines for seismic capability verification of nuclear plant electrical and mechanical equipment; relays, tanks and heat exchangers; and electrical raceway systems using seismic experience and test data [4]. As a continuation of this effort, the performance of HVAC duct and damper systems in power and industrial facilities in strong-motion earthquakes and shake table testing has been compiled into a seismic experience database. This database has been used to establish guidelines to seismically verify as-installed HVAC duct and damper systems and screen out potential failure modes and undesirable conditions that could lead to seismic damage or failure [1].

The guidelines rely on the evaluation of seismic failure mechanisms for duct and damper systems from seismic experience data presented in Appendices A and B and seismic test data presented in Appendix D of [1]. The data show that damage to duct systems is generally limited to direct seismic damage of the duct or supports, or indirect damage due to seismic interaction with adjacent commodities. HVAC ducting is found at nearly all industrial sites. The seismic experience database therefore includes a large amount of data on the survivability of ducting installed in many different ways, and experiencing many different seismic excitation levels. The large number of duct systems that have survived earthquakes indicate the inherent ruggedness of these systems. The limited, smaller set of HVAC duct systems that have been found to have performed poorly in a seismic event point out key characteristics of HVAC installations that may contribute to seismic damage.

The HVAC database includes thirty-nine sites in fourteen different earthquakes where ducting experienced PGAs of at least 0.25g. Eighteen of the thirty-nine experienced 0.40g or greater. The earthquakes investigated range in Richter magnitude (M) from 5.5 to 8.1. The strong motion duration is as high as forty seconds. Local soil conditions range from deep alluvium to rock. The buildings housing the ductwork have a wide range in size and type of construction. As a result, the database covers a wide diversity of seismic input to duct installations, in terms of seismic motion, amplitude, duration, and frequency content.

The database sites contain a wide variety of duct sizes, shapes, configurations and support types. Round and rectangular ducts were found at seventeen and thirty-five sites, respectively, with sizes ranging from six to seventy-two inches. The above data have been compiled and summarized according to database site, duct construction type and size, support type, building type, and noted damage.

The large number of duct systems that have survived earthquakes indicates the inherent ruggedness of these systems. The light gauge sheet metal ducts were constructed with pocket locks, companion angles, and riveted connections. In many cases the ducting had no stiffener angles and still survived the strong motion. Generally, the database HVAC ducts were supported with either rod hangers or long sheet metal straps; however, there were also instances of frame-mounted ducts. Some HVAC ducts were hung with rope, cables, or wire. Rod hanger supports were typically trapezes which were attached to concrete ceilings with expansion anchors, or either clamped or threaded and tapped into overhead steel structures. Figures 1 through 4 illustrate some of the typical database duct configurations and supports that have survived past strong-motion earthquakes.

Figure 1. Sylmar Converter Station, 1971 San Fernando Earthquake. Strap-Hung and Wall-Mounted Duct with Wall Penetrations

Figure 2. El Centro Steam Plant, 1979 Imperial Valley Earthquake. Trapeze Rod-Hung Rectangular Duct with Close Up of the Trapeze Detail

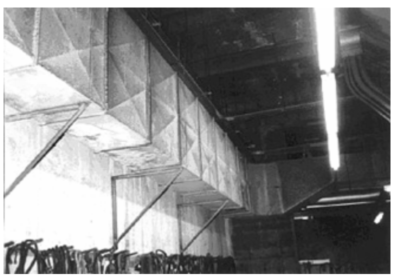

Figure 3. Glendale Power Plant, 1971 San Fernando Earthquake. Cantilever Bracket Supported Rectangular Duct

Figure 4. California Federal Bank Facility, 1987 Whittier Earthquake. Typical Strap-Hung Rectangular Duct with Vertical Cantilevers and Diffusers

It is important to note that nearly all of the HVAC duct installations in the database facilities were designed and installed without specific consideration of seismic loads. Also, some facilities were up to forty years old at the time of the earthquakes. In addition to the effects of age, the initial installation and any subsequent modifications to database ducts and their supports included all of the normal oversights and deficiencies of field-run industrial construction.

Ductwork ruggedness was demonstrated in most instances, but there were some cases in which one or more attributes led to seismic damage. A summary, organized by earthquake, of the configurations and structural characteristics which contributed to the damage is given in the report. Seismic damage to HVAC duct systems documented in the seismic experience database can be attributed to the following categories:

- *Broken and Fallen Cantilevered Sections*. Cantilevered sections of duct and duct diffusers have broken due to high inertia loading at weak joints, and due to inadequate flexibility of short duct segments to accommodate header movement.
- *Opened and Sheared Seams*. Light gage circular duct constructed with riveted lap joints have opened up and sheared in past strong-motion earthquakes. This damage has occurred at locations subject to high bending strain in very flexible duct systems.
- *Duct Fallen off Support*. The database includes one example where the end of a cantilevered duct section jumped off of its end hanger support and was damaged. The duct was not tied to the support, and was subject to high levels of seismic motion.
- *Equipment on Vibration Isolators*. HVAC duct has been damaged by excessive movement of in-line equipment components supported on vibration isolators.

The seismic experience database indicates that dampers possess characteristics that generally preclude damage in earthquakes. The experience database contains no instances of damage or significant seismic effects to dampers or their actuators.

EPRI GUIDELINES

The guidelines for seismic adequacy verification of HVAC duct and damper systems include the following steps:

- Applicability Determination
- Walkdown Screening
- Selection of Bounding Supports and Duct Runs
- Analytical Review
- Outlier Resolution

Applicability Determination

The guidelines apply to existing heating, ventilation and air-conditioning (HVAC) ducts, dampers and supports. Appurtenances such as registers, access doors, turning vanes, filters, louvers, air diffusers and similar components normally attached to HVAC ducts are also included. The guidelines apply to duct fabricated of hot-rolled and cold-rolled carbon steel, galvanized sheet steel, stainless steel and aluminum in accordance with SMACNA standards [5].

The guidelines are applicable to any HVAC duct and damper system at any elevation in a plant where the nuclear plant free-field ground motion 5% damped seismic design spectrum does not exceed the Seismic Motion Bounding Spectrum of [4] and the horizontal zero period acceleration (ZPA_h) of the in-structure response spectra at the HVAC support anchorage does not exceed 2.0g. The Bounding Spectrum is shown in Figure 5. The 2.0g ZPA_h restriction is from [6].

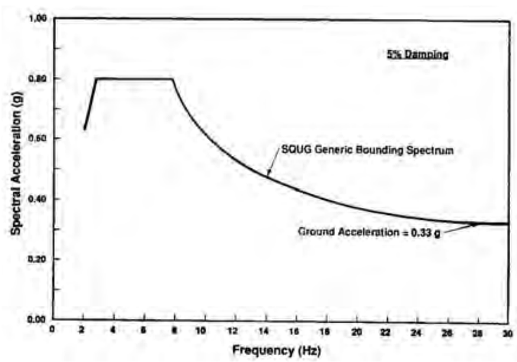

Figure 5. Seismic Motion Bounding Spectrum.

The guidelines are intended to be applied by qualified engineers who meet the training and experience requirements defined in this section. The Seismic Review Team (SRT) should consist of at least two engineers who meet the requirements for Seismic Capability Engineers (SCEs) as defined in Section 2 of the SQUG GIP [4]. These individuals are required to be degreed engineers, or equivalent, who have completed a SQUG developed training course on seismic adequacy verification of nuclear power plant equipment. They are required to have at least five years experience in earthquake engineering applicable to nuclear power plants and in structural or mechanical engineering. At least one engineer on each Seismic Review Team should be a licensed professional engineer.

The earthquake experience-based seismic evaluation approach presented herein relies heavily on the judgment and experience of the SRT. This judgment and experience is used in lieu of extensive analysis. The SQUG GIP [4] and EPRI SMA Methodology [7] also utilize an experience-based approach. The USNRC required the implementation of these methodologies include an independent peer review of the judgments and conclusions made by the SRT as well as a sampling review of the limited analytical evaluations. As part of the application of the guidelines of this report, it is therefore recommended that use of the methodology include an independent peer review by a knowledgeable individual who is not a member of the SRT.

Walkdown Screening

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.

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

- Review duct system structural features that may lead to poor performance as illustrated by the seismic experience and test data
- Review support system for undesirable conditions that may lead to poor performance
- Review potential seismic interaction hazards
- Review vertical support span lengths
- Identify bounding configurations/samples for analytical evaluations

Allowable duct spans are based on stress considerations. Chapter 4 of [1] gives a procedure for determining allowable spans between vertical supports as a function of the ratio of horizontal support span to vertical support span. The equations are based on keeping the combined seismic stress and dead load stress below the applicable factored allowable stress limit. For duct runs with large distance between horizontal supports, the allowable vertical support span is reduced so that bending stresses in the ducts are kept low. Rectangular ducts are assumed to carry stress only in the corner regions; this screening restriction guards against buckling of the duct corners.

The peer review comments on the EPRI guidelines [3] recommended using the following additional span limits to place the duct spans within the limits of earthquake experience data:

- Duct support to support spans should not exceed 15 feet.
- Supports should be provided within 5 feet from fittings such as Tees and Wyes in each branch of the fitting
- Duct cantilevered length (beyond end of last support) should not exceed 6 feet.

The in-plant screening review is documented on Screening and Evaluation Worksheet (SEWS) forms from Chapter 5 of [1]. Items not meeting the in-plant screening review are identified as outliers for further evaluation and disposition.

Selection of Bounding Supports and Duct Runs

As part of the in-plant screening review, representative, worst-case HVAC duct and duct supports are selected as bounding configurations subject to analytical review. The goal is to establish a biased, worst-case sampling, representative of and bounding the different HVAC configurations in the scope of work. Detailed evaluation of bounding, worst-case configurations assures the seismic adequacy of the entire population.

The EPRI guidelines recommend that the extent of the sample should be determined by the SRT based on the diversity, complexity, extent and functional requirements of the systems being reviewed. For duct systems requiring structural integrity or reasonable assurance for pressure boundary integrity (where potential small tears or leaks are acceptable), the sample selection only needs to include worst-case bounding duct supports. For systems where full pressure boundary integrity is required, the worst-case bounding sample should include the duct run itself as well as the supports.

Analytical Review

The representative samples of ductwork and supports are analytically reviewed in accordance with Chapter 4 of [1]. The duct evaluation criteria are based primarily on the design approach utilized in SMACNA's construction standards for rectangular and round industrial duct [8,9]. Ductwork is checked for combined dead load and seismic load against a factored allowable working stress for acceptance. The allowable stress for rectangular steel duct is taken as 8 ksi, with an increase factor of 1.7 for the Safe Shutdown Earthquake. The duct is generally represented as a continuous beam spanning between supports. For rectangular ducts, the effective area of sheet metal for calculation of the duct section modulus is limited to a 2-inch by 2-inch region at the four corners of the duct. A reduced section modulus is 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. Use of this procedure results in a conservative estimate of the true duct capacity and is compatible with data obtained from various test programs [10-13].

The duct support analytical review methodology is included in Appendix F of [1]. Simplified support evaluation requirements, similar to those presented in Section 8 of [4] for limited analytical review of electrical raceway supports, are used to analyze the duct supports selected by the SRT. These include the following checks:

- *Dead load check*. This check serves the function of an inclusion rule as the experience database supports are assumed to have been properly designed for gravity loading. The complete load path from the duct to the building structure is checked against the normal allowable stresses. Special attention is given to expansion anchor bolts.

- *Vertical capacity check*. This check ensures high capacity of anchorage and primary anchor connections for the support, using simple calculation methods. The primary support members and connections are checked for a vertical 5g load, ignoring eccentricities (this is similar to the vertical capacity check in Section 8 of [4] except that 5 times dead load is used instead of 3 times dead load). Position retention is considered the most important aspect of ensuring structural integrity.
- *Ductility check*. This requires an assessment of how the support responds to lateral and longitudinal seismic motion, and what are the weak links in the support load path. If the failure modes are ductile, then lateral and longitudinal load checks may not be required.
- *Lateral and longitudinal load check*. This checks if there is adequate lateral and longitudinal restraint, for non-ductile supports, to prevent excessive support distortion leading to brittle failure.
- *Rod hanger fatigue evaluation*. For ducts supports on short, fixed-end threaded rod trapeze supports, an evaluation of the fatigue effect of plastic cycling of the rod is required.

The analytical review is intended to demonstrate that the duct supports are at least as rugged as supports that performed well in actual strong motion earthquakes. Items not meeting the analytical review guidelines are identified as outliers for further analysis or modification.

Outlier Resolution

An outlier is defined as an HVAC duct, damper or support feature that does not meet the walkodwn screening guidelines, or an HVAC duct or support selection that fails the analytical review. HVAC duct, dampers or supports that do not pass the walkdown screening or analytical review criteria may still be shown to be seismically adequate by obtaining additional information or by performing additional evaluations. Generally, the additional evaluation will be a detailed dynamic analysis of the duct and support system using standard seismic analysis techniques. Outlier resolution is discussed further in Chapter 6 of [1].

TRIAL APPLICATION

The trial application was performed at Hatch Unit 1 [2]. The ductwork in the scope of work consisted of the normal turbine building HVAC return ductwork to the main exhaust plenum in the reactor building. Collector runs with registers at regular intervals are located in several sectors and elevations of the turbine building and condenser bay. The collector runs go to risers that run vertically up the building to the operating deck. Here the risers come together and exit the building, running through a set of filters and fans in the reactor building, ending at the stack.

The required function of the ductwork is to remove air from the condenser bay. The ductwork is required to remain intact during and after an earthquake. Duct distortions should not be large enough to restrict airflow to the exhaust plenum. Small tears of the duct skin or small openings at duct joints as a result of an earthquake were shown to be acceptable; however, the evaluation assumed that full pressure integrity in the condenser bay was required. The walkdowns were performed using these functional criteria. The review included ductwork, duct supports and associated in-line components such as registers, dampers, damper actuators, in-line fans, expansion joints, filter units and plenums.

Applicability

The original plant duct construction specification was reviewed to determine materials, wall thickness, reinforcing, joint types and construction details. The specification states that all ductwork sections, joints, support and other accessories shall be in accordance with SMACNA standards. Earthquake experience data has shown that ductwork that conforms to SMACNA standards performs well in strong motion earthquakes [1]. The walkdowns confirmed that the ductwork and supports conform to SMACNA standards and typical construction for this type of system, meeting the applicability requirements.

Walkdown Screening

Seismic verification walkdowns of the ductwork were performed in March, 2004. Results of the walkdowns were documented on the Screening Evaluation Worksheets (SEWS). The duct supports selected for analytical review were documented on the Duct Support Analytical Review Data Sheets. The duct runs selected for analytical review were documented on the HVAC Duct System Analytical Review Data Sheets. Walkdown outliers were documented on HVAC System Outlier Sheets. All documentation forms were from the EPRI guidelines [1].

Allowable span tables were determined prior to the walkdowns. These allowable span tables were used for screening existing duct spans in the plant. Allowable duct span lengths between vertical supports and lateral restraints were determined following the approach in Appendix C of the EPRI guidelines [1]. The tables provided the maximum span between vertical supports for various ratios of horizontal span length to vertical support length. Separate tables were used for each applicable elevation in the turbine, control and reactor/radwaste buildings.

Duct joint types and spacing were judged to conform to SMACNA standards, based on review of the HVAC construction specification and field observations. Transverse joints for rectangular ducts were judged to be pocket lock joints similar to SMACNA joints T-17 through T-19 for smaller ducts, and companion angle joints similar to SMACNA joint T-22 for larger ducts. Round ducts were observed to have beaded sleeve joints secured with sheet metal screws for smaller diameter ducts, and butt-welded joints for larger diameter ducts. Duct joints were judged adequate to remain intact and maintain structural integrity during and after an earthquake.

Duct supports were generally welded frame types fabricated from structural steel angles, or strap hangers fabricated from rectangular steel straps attached to the sides of the ducts with sheet metal screws. Duct support types and spacing were judged adequate to meet the span tables, span restrictions based on the EPRI guidelines. Duct support anchorages were visually inspected by the SRT and found to be acceptable. Bolted connections and concrete expansion anchors appeared adequately installed and properly sized for the anticipated support loads. Welded anchorages appeared to be of good quality and free from defects.

A total of four outliers were identified as a result of the walkdowns. Table 4-1 provides a summary of the walkdown outliers.

Table 1. Walkdown Outlier Summary

Outlier No.	Outlier Description	Comments
1	10 x 12 duct run is flexible longitudinally (N-S) which could overload bends near T8.	Duct System Analytical Review No. 3
2	Strap hanger support on 14" diameter duct was found unbolted.	Strap hanger to be repaired by plant
3	Duct run could overload bend due to longitudinal forces.	Duct System Analytical Review No. 2
4	Duct penetrates masonry wall. Failure of wall could cause duct failure.	Masonry wall to be evaluated by plant

Five duct supports were selected for analytical review as a result of the walkdown. In addition, three duct runs were selected for analytical review (two of which were walkdown screening outliers). The analytical review selections were representative, worst case bounding samples of the different types of ductwork and supports reviewed during the walkdowns. The duct runs included configurations that could experience high stresses due to seismic inertia loads.

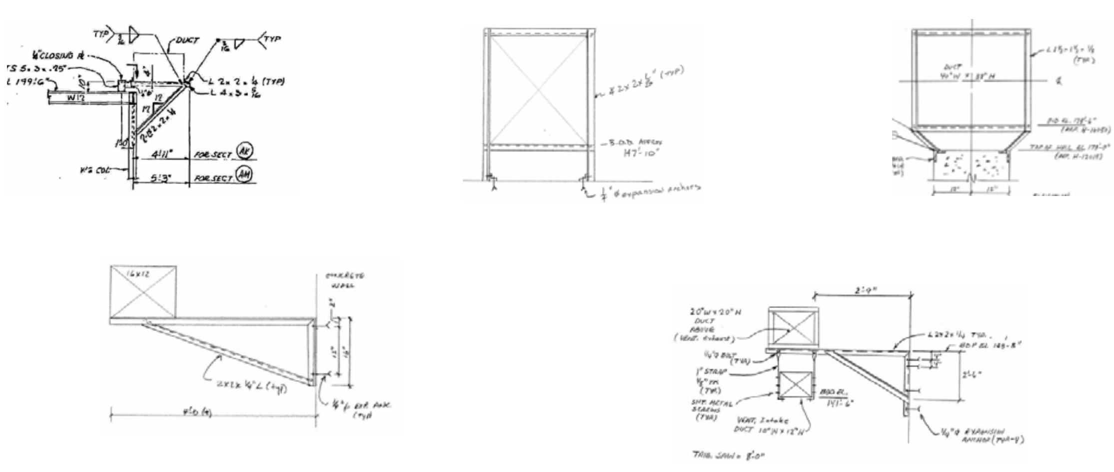

Figure 6. Bounding Case Supports for Analysis.

Analytical Review

Ductwork and duct supports were analyzed for the dead load plus seismic load cases from Section 4.1 of [1]. The original plant HVAC duct specification was reviewed to determine the material gauge, type of longitudinal and lateral joints, joint locations, stiffener size and stiffener spacing for each duct size. This information was used to calculate the equivalent duct weight including an allowance for stiffeners and joints that is used in the calculation.

Seismic input was in-structure response spectra (IRS) for the Safe Shutdown Earthquake (SSE) [Plant Hatch has different terminology for the applicable earthquake level used in the analysis; for clarity purposes, the commonly understood SSE terminology is used herein]. The SSE IRS were specified at 5% damping. The applicable damping for calculating the duct seismic stress is 7% per Section 4.2 of Reference 1. Therefore the 5% damping peak spectral acceleration values were multiplied by the square root of the damping ratios per Section 4.4.3 of the SQUG GIP [2] to obtain 7% damping values for analysis of the ductwork.

The duct supports were analyzed in accordance with Appendix F of the EPRI guidelines. The lateral and longitudinal load checks were performed using the equivalent static load method. The applicable tributary lengths of ductwork for each direction of load were determined using the judgment of the SRT and review of the ductwork drawings. Seismic input was equal to the peak of the SSE IRS for all analytical review selections except selection No. 3. The seismic input at the duct/support system dominant mode frequency was used to evaluate selection No. 3.

The duct run selections were evaluated using the computer program SAP2000. The duct and duct supports were modeled and analyzed using the response spectrum method. Accelerations were taken from the SSE IRS for the applicable building support elevations. Dead load stresses were summed absolutely with the Square Root Sum of the Squares (SRSS) of the vertical and horizontal seismic stresses.

Seismic modal responses were combined by SRSS and seismic directional responses were combined by SRSS. Modes were calculated out to 33 Hz with missing mass correction applied for participating mass above 33 Hz. The missing mass correction option was chosen within the SAP2000 computer program.

The duct stresses were compared to a normal allowable bending stress of 8 ksi for rectangular galvanized steel duct per Section 4.2.1 of the EPRI guidelines [1]. The duct joint types met the requirements to allow increasing the normal bending stress by a factor of 1.7 for SSE seismic loads as detailed in Section 4.2.1 of [1].

The duct analysis included application of frequency correction factors for the transverse duct joints based on Section 4.2 of [1]. Frequency correction factors of 0.59 and 0.87 were applied for pocket lock and companion angle joints respectively. This factor was applied for the response spectrum analysis by increasing the frequencies and shifting the input response spectra. Frequencies for each acceleration were increased by 1/0.59 = 1.695 for pocket lock type joints, and by 1.0/0.87 = 1.149 for companion angle joints.

Ductwork Analytical Review Results

All three duct run analytical review selections passed the evaluation criteria. Duct bending stress for the dead load plus SSE seismic load case was less than 8 ksi for all three ductwork sections. This is conservative since the allowable stress could be increased by a factor of 1.7. Two of the duct runs were selected for analysis because they had excessively long spans without lateral support. The fact that the analysis showed that the stresses in the duct were low indicates that the walkdown screening criteria are conservative.

Support Analytical Review Results

Duct support analytical review selections 1 and 2 passed the dead load, vertical capacity, lateral and longitudinal load checks. Both supports were considered non-ductile. Duct support analytical review selections 3, 4 and 5 passed the dead load, lateral and longitudinal load checks. These supports were also considered non-ductile. These supports did not pass the vertical capacity check and were classified as analytical review outliers. The outliers were resolved by passing the lateral and longitudinal load checks.

Outlier Resolution

The walkdown outliers are summarized above in Table 1. Outliers Nos. 1 and 3 involved ductwork configurations that the SRT judged could be overloaded at bends due to longitudinal seismic forces. These duct configurations were analyzed in the ductwork analytical review. The analysis showed that duct stresses met allowable stress limits, and the outliers were resolved on this basis.

Outlier No. 2 involves a strap hanger on a section of 14” diameter round duct that was found unbolted. This outlier was resolved by plant modification. The strap hanger was restored to its original configuration by re-installing the missing bolt.

Outlier No. 4 identified a masonry wall that could be a seismic interaction hazard to a section of ductwork that penetrates the wall. The SRT noted that failure of the wall could cause the duct to fail. To resolve this outlier, the plant will analyze the masonry wall for seismic loading using plant licensing basis criteria and, if the criteria are not satisfied, modify the wall to prevent seismic interaction with the ductwork.

CONCLUSIONS

The EPRI report [1] provides guidelines that can be used to perform an experience-based seismic capability verification of HVAC duct and damper systems in nuclear power plants. The report contains seismic experience data from actual earthquakes and shake-table tests. The data show that HVAC duct and damper systems, if free of identified seismic vulnerabilities and with good vertical load carrying capability, can withstand seismic ground excitations levels up to the SQUG Bounding Spectrum. The guidelines were subjected to an independent peer review by a noted seismic expert. The peer review comments and recommendations were incorporated into the guidelines

The guidelines were exercised in a trial application at a nuclear power plant. They were found to be a practical and cost-effective mechanism for verifying seismic capability compared to conventional seismic qualification by analysis. Outlier configurations were analyzed using standard response spectrum analysis techniques, and were found to meet commonly accepted stress criteria. This provides further evidence that the screening criteria in the guidelines are conservative.

REFERENCES

1. *Seismic Evaluation Guidelines for HVAC Duct and Damper Systems*, EPRI, Palo Alto, CA, 2006, 1012022.
2. *Hatch Nuclear Plant Unit 1, Seismic Verification of the Turbine Building Exhaust Ductwork*, ABS Consulting for Southern Nuclear Services, Revision 0, October 2004.
3. *Peer Review Comments on EPRI Seismic Evaluation Guidelines for HVAC Duct and Damper Systems*, Kennedy, R.P., for Southern Nuclear Services, February 7, 2004.
4. *Generic Implementation Procedure (GIP) for Seismic Verification of Nuclear Plant Equipment*, Seismic Qualification Utility Group (SQUG), Revision 3A, December 2001.
5. *HVAC Duct Construction Standards, Metal and Flexible*, Sheet Metal and Air Conditioning Contractors National Association, Inc., Chantilly, Virginia, Second Edition, 1995.
6. *Advanced Light Water Reactor (ALWR) First-of-a-Kind-Engineering (FOAKE) Project on Design Concepts for HVAC Ducting and Supports*, Advanced Reactor Corporation, April 1995.
7. *A Methodology for Assessment of Nuclear Power Plant Seismic Margin: Revision 1*, EPRI, Palo Alto, CA, NTS Engineering, Long Beach, CA, and RPK Consulting, Yorba Linda, CA: July 1991. Report NP-6041.
8. *Rectangular Industrial Duct Construction Standards*, Sheet Metal and Air Conditioning Contractors National Association, Inc., Chantilly, Virginia, Copyright 1980.
9. *Round Industrial Duct Construction Standards*, Sheet Metal and Air Conditioning Contractors National Association, Inc., Chantilly, Virginia, Second Edition, September 1999.
10. Neely, B. B., and Warrix, L, “A Qualification and Verification/Improvement Test Program for HVAC Ducts Used in Nuclear Power Plants,” *Century 2 Pressure Vessels and Piping Conference*, August 1980.
11. Neely, B. B., and Warrix, L., “A Procedure for Seismically-Qualifying HVAC Ducts Used in Nuclear Power Plants,” *Second ASCE Conference on Civil Engineering and Nuclear Power*, September 1980.
12. Desai, S. C., Buchert, K. P., and Marcinkevich, E. A., “Structural Testing of Seismic Category I HVAC Duct Specimens,” *Second ASCE Conference on Civil Engineering and Nuclear Power*, Volume I., Knoxville, TN, September 1980.
13. Dizon, J. O., Frevold, E. J., and Osborne, P. D., “Seismic Qualification of Safety Related HVAC Duct Systems and Supports,” *1993 ASME Pressure Vessel and Piping Division Conference*, Denver, Colorado, July 1993.