SEISMIC RESTRAINT SPACING FOR PIPE AND DUCT

S11.1 – Introduction:

The SMACNA Seismic Restraint Manual – Guidelines for Mechanical Systems 3rd Edition has been an industry standard for many years. And, even though it is not specifically identified as a reference document for 2006/2009 IBC, ASCE/SEI 7-05, it is still widely accepted in most jurisdictions. The seismic restraint spacing traditionally used for piping and ductwork were developed by SMACNA, and represent the experience accumulated across the industry.

In reality the actual seismic restraint spacing used in any particular application will depend on several variables, of which the following four are probably the most important.

1. The buckling strength of the pipe or duct between the longitudinal seismic restraints.
2. The weight of the pipe or duct being restrained.
3. The capacity of the seismic restraints being used for the project.
4. The hanger rod spacing along the run of pipe or duct.

This section will determine the maximum allowable seismic restraint spacing for pipe and duct between the longitudinal seismic restraints. It will begin by examine the seismic restraint spacing requirements for pipe and duct developed by SMACNA.

S11.2 – Seismic Hazard Level SHL:

The seismic restraint spacing recommended by SMACNA for piping and ductwork is based on the Seismic Hazard Level, SHL. The SHL is related to the design horizontal seismic force defined in the various building codes. The determination of this force for 2006/2009 IBC is discussed in Section 5.0 of this manual. Historically, the code based design horizontal seismic force has had the following form.

$$F_P = C_S W_P$$ **Equation S11-1**

Where:

F_P = the design horizontal seismic force acting on a pipe or duct acting at its center of gravity.

C_S = the seismic coefficient which represents a combination of various factors defining the expected ground level acceleration, ductility of the piping or ductwork and its attachment to the building, the importance of the piping or ductwork, and the elevation of the attachment of the piping and ductwork to the building's structure.

W_P = the operating weight of the pipe or duct that is being restrained.

SMACNA relates the SHL to the base seismic coefficient, which is defined as;

$$C_S = \left(\frac{F_P}{W_P} \right)$$ **Equation S11-2**

Comparing Equation S11-2 with the general horizontal seismic design force defining equation from ASCE 7-05 (Equation S5-1 of Section 5.0) leads to the following;

$$C_S = \frac{0.4 a_P I_P S_{DS}}{R_P} \left(1 + 2\frac{z}{h} \right)$$ **Equation S11-3**

Where:

S_{DS} = the short period design spectral acceleration.

a_P =the component amplification factor. This factor is a measure of how close to the natural period of the building the natural period of the component is expected is expected to be. Typically this will vary from 1.0 to 2.5, and is specified by component type in ASCE/SEI 7-05 and listed in Table S5-3.

I_P = the component importance factor which be either 1.0 or 1.5.

R_P = the response modification factor which usually will vary from 1.0 to 12.0. This factor is a measure of the ability of the component and its attachments to the structure to absorb energy. It is really a measure of how ductile or brittle the component and its attachments are. The values are specified by component type in ASCE 7-05 and listed in Table S5-3.

z = the structural attachment mounting height of the pipe or duct hanger in the building relative to the grade line of the building.

h = the average height of the building roof as measured from the grade line of the building.

SMACNA defines the Seismic Hazard Level, SHL, for a project as shown in Table S11-1.

Table S11-1; Seismic Hazard Level Definition

Base Seismic Coefficient C_S	Seismic Hazard Level SHL
$0.75 < C_S \leq 1.00$	A
$0.50 < C_S \leq 0.75$	B
$0.25 < C_S \leq 0.50$	C
$0 \leq C_S \leq 0.25$	D

Note that the piping and ductwork on different floors in the same building can, and probably will, require design under a different seismic hazard level, SHL. Also, it is important to note that the newer building codes such the IBC make it possible to have a base seismic coefficient that exceeds 1.0. In which case, that project, or portion of the project, will not be covered under SMACNA, and will require special design consideration by a qualified design professional.

S11.3 – SMACNA Seismic Restraint Spacing Recommendations:

S11.3.1 – Rectangular and Round Duct:

Transverse Seismic Restraint Spacing: S_T = 30 ft. Maximum

Longitudinal Seismic Restraint Spacing: S_L = 60 ft. Maximum

S11.3.2 – Single Clevis Supported Pipe and Conduit:

Pipe & Conduit Size ≤ 5″:

Transverse Seismic Restraint Spacing: S_T = 40 ft. Maximum

Longitudinal Seismic Restraint Spacing: S_L = 80 ft. Maximum

6″ ≤ Pipe & Conduit Size ≤ 8″:

Transverse Seismic Restraint Spacing: S_T = 40 ft. Maximum

Longitudinal Seismic Restraint Spacing: S_L = 40 ft. Maximum

10″ ≤ Pipe & Conduit Size ≤ 16″:

Transverse Seismic Restraint Spacing: S_T = 20 ft. Maximum

Longitudinal Seismic Restraint Spacing: S_L = 20 ft. Maximum

S11.3.3 – Trapeze and Floor Rack Supported Pipe:

The seismic restraint spacing recommendations per SMACNA are based on the total weight of the restrained components and assume the following arrangements.

Pipe Size ≤ 5″ – Four Equal Size Pipes per Trapeze Bar (109 lb/ft)

Pipe Size = 6″ – Three Equal Size Pipes per Trapeze Bar (108 lb/ft)

Pipe Size = 8″ – Two Equal Size Pipes per Trapeze Bar (112 lb/ft)

Any combination of pipe sizes can be used as long as the total combined weight of the pipes on a trapeze bar is less than or equal to the maximum dead load up to 110 lb/ft.

Pipe Size < 4″:

Transverse Seismic Restraint Spacing: S_T = 40 ft. Maximum

Longitudinal Seismic Restraint Spacing: S_L = 40 ft. Maximum

4″ ≤ Pipe Size ≤ 8″:

Transverse Seismic Restraint Spacing: S_T = 20 ft. Maximum

Longitudinal Seismic Restraint Spacing: S_L = 20 ft. Maximum

The SMACNA seismic restraint spacing recommendations do not appear to take into account the gross buckling of the pipe or duct, and have been simplified to apply to all Seismic Hazard Levels.

11.4 – Maximum Seismic Restraint Spacing Based on the Gross Buckling:

Buckling failure of long slender structures such as pipe can be catastrophic and occur at stresses much lower than the yield point of the material. Also, for thin walled structures, localized buckling may determine the compressive failure load limit which may be lower than the load limit predicted by classical buckling theory. Also, for gross buckling some pipes and ducts, because of their relatively large cross-section may fall in to the “short column” realm, and again would not be covered by classical buckling theory. Failure modes such as local buckling and short column buckling are outside of the scope of this treatise, and should be investigated on a case by case basis. The intent of this section is to determine the validity of the SMACNA seismic restraint spacing recommendations for various pipe cross-sections and materials, and standard duct cross-sections base on the gross buckling of a long “Euler” column.

At question here is not necessarily the maximum spacing between longitudinal seismic restraints, but how much pipe or duct can be handled by one set of longitudinal seismic restraints without the danger of buckling. This scenario is typified by the run of pipe or duct that has one set of longitudinal seismic restraints at one end of the run. The pipe and duct does not form a "column" with the axial load concentrated at the ends. Rather the axial load is evenly distributed along the length of the column, which is shown in Figure S11-1.

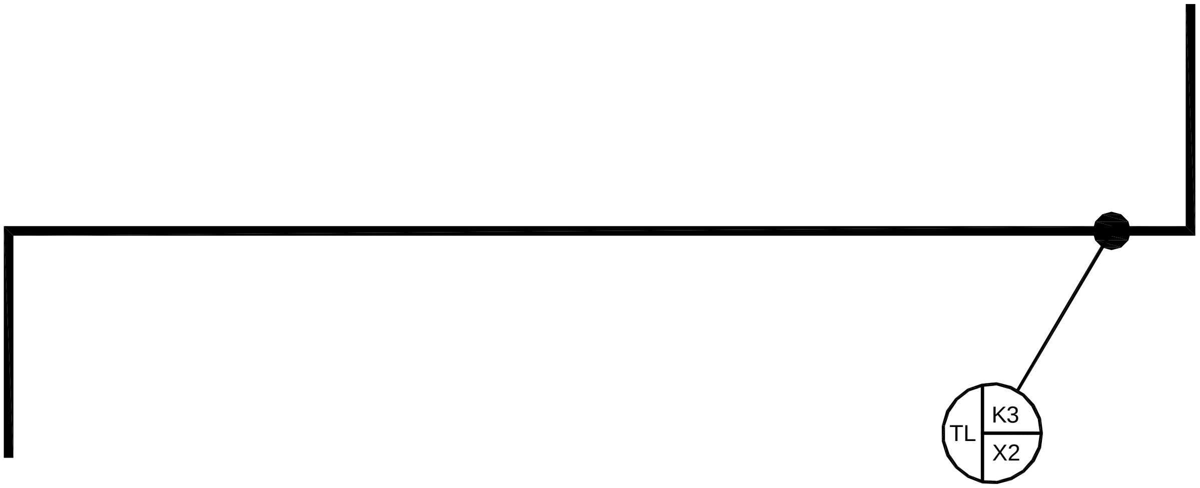

Figure S11-1; Typical Model for Determining the Maximum Length of Pipe or Duct That Can Be Supported by a Single Set of Longitudinal Seismic Restraints.

With the transverse and longitudinal seismic restraints located on the right end of the run, the run will behave as though that end were pinned. The left end of the run can be considered to be free. The analytical model of this situation is shown in Figure S11-2. The weight of the pipe will induce a bending stress in the pipe which would significantly shorten the length of the pipe or duct that can be supported by the longitudinal seismic restraints. However, that form of the analysis would be outside the bounds of an elastic stability analysis and would be too complicated for the purposes of this section. Instead, a healthy factor of safety will be imposed on the applied load to account for the effects of the weight of the pipe, and any other unknowns concerning the end conditions of the run of pipe.

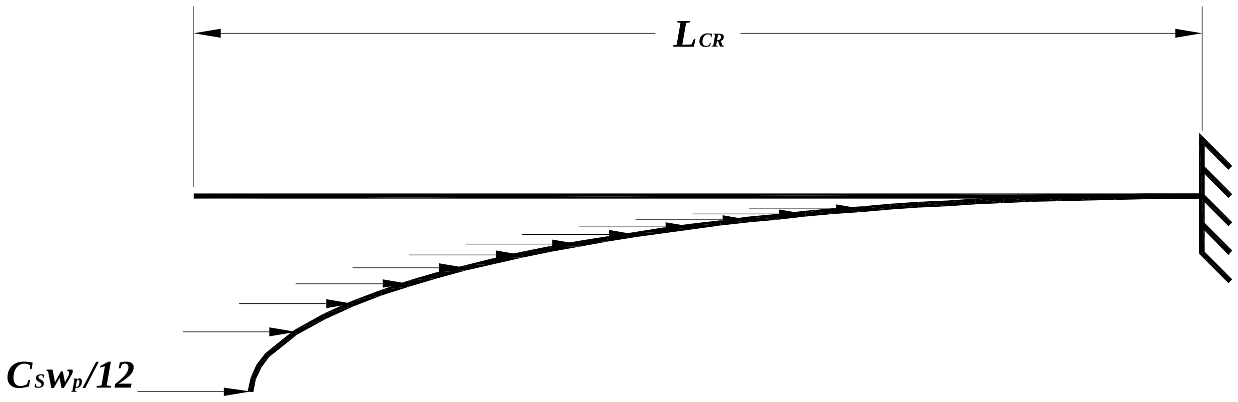

Figure S11-2; Seismic Gross Buckling Model for Pipe and Duct

Euler's buckling equation for this situation may be found in the following reference.

> Hsu, Teng S.; Stress and Strain Data Handbook – Graphs, Tables, and Worked Examples for Design Engineers, Gulf Publishing Company, Huston, Texas, 1986; Pp 342-343.

The critical buckling load for the model in Figure S11-2 according to Hsu is;

$$p_{cr}L = \frac{C\pi^2 EI}{L^2}$$ **Equation S11-4**

Where:

p_{cr} = the critical distributed compressive load acting along the length column (lb/in).

L = the length of the column (in).

C = a constant determined by the loading and the end conditions.

E = the modulus of elasticity for the column material (psi).

I = the minimum area moment of inertia of the column cross-section (in^4).

In the case of the column shown in Figure S11-2, these variables will become;

$$p_{cr} = \frac{C_S w_P}{12}$$ **Equation S11-5**

$$L = L_{cr}$$ **Equation S11-6**

Where:

w_P = the weight of the distributed pipe or duct (lb/ft).

L_{cr} = the critical length of the pipe or duct that can be supported by one set of longitudinal restraints without the fear of gross buckling (in).

Let:

N = the factor of safety with respect to the applied load.

From Table 11-1 of Teng, the value of C for the situation shown in Figure S11-2 will be $C = 0.794$. Equation S11-4 may now be rewritten as;

$$\frac{C_S w_P L_{cr}}{12} = \frac{C\pi^2 EI}{NL_{cr}^2}$$ **Equation S11-7**

Then;

$$L_{cr}^3 = \frac{12C\pi^2 EI}{NC_S w_P}$$ **Equation S11-8**

And;

$$L_{cr} = \sqrt[3]{\frac{12C\pi^2 EI}{NC_S w_P}}$$ **Equation S11-9**

In practical terms, Equation S11-9 represents the distance from the transverse and longitudinal restraints on the right hand end of the run of pipe or duct in Figure S11-1 to the next transverse seismic restraint at the left hand end of the pipe or duct that would stabilize the pipe or duct and prevent the deflection that would precipitate gross buckling. Since this analysis is intended to cover a wide range of pipe and duct sizes and materials, and due to all of the unknowns, a suitable factor of safety with respect to the applied load is $N = 2.0$. Substituting this factor of safety and the value for C into Equation S11-9, the maximum allowable transverse seismic restraint spacing will be determine by Equation S11-10 or 40 ft. which ever is less.

$$S_T = \left(\frac{1}{12}\right)\sqrt[3]{\frac{4.764\pi^2 EI}{C_S w_P}}$$

Equation S11-10

The maximum allowable longitudinal seismic restraint spacing will be twice the value determined by Equation S11-10 or 80 ft. which ever is less. The addition of a transverse restraint at the spacing indicated by Equation S11-10 would stabilize the column formed by the pipe, essentially making it a guided column. Having the longitudinal seismic restraint spacing to be twice that of the transverse seismic restraint spacing will ensure that the stability of the pipe column is not compromised. Note; these findings do not affect the application of Rules #5, #6, #7, #8, #9, #10, or #11 of Section S1.0 of this manual.

11.5 – Discussion and Summary:

The results from Equation S11-10 for various pipe and duct sizes and materials are tabulated in Appendices A6.1 through A6.6 by Seismic Coefficient and Seismic Hazard Level. These results will be discussed appendix by appendix beginning with Appendix A6.1

Appendix A6.1:

This appendix is based on single clevis hung standard steel pipe. For pipes with a nominal size that is less than or equal to 5 in. in size SMACNA recommends S_T =40 ft and S_L =80 ft. Note in Tables A6.1-1 through A6.1-4 that for nominal pipe sizes less than or equal to 2 in. that there may be instances where the SMACNA recommended spacings are too large. Kinetics Noise Control recommends that for these smaller pipe sizes, the maximum allowable transverse restraint spacing from the tables be used to prevent buckling of the pipes during a seismic event.

For nominal pipe sizes that are greater than or equal to 6 in. and less than or equal to 8 in., SMACNA recommends that $S_T = S_L$ =40 ft. This is consistent with the recommendations found in Tables A6.1-1 through A6.1-4, and indicates that the longitudinal seismic restraint spacing in SMACNA for these pipe sizes is limited by the capacity of the seismic restraints and attachment hardware specified by SMACNA.

For nominal pipe sizes that are greater than or equal to 10 in. and less than or equal to 16 in., SMACNA recommends that $S_T = S_L$ =20 ft. This recommendation also appears to be based on the capacity of the restraints and attachment hardware specified by SMACNA.

Appendix A6.2:

This appendix is based on single clevis hung fire protection piping. The comments made concerning the standard steel pipe in the discussion for Appendix A6.1 will also apply here. The transverse seismic restraint spacing recommendations made in NFPA 13 for fire protection piping should be followed unless the spacings indicated in Tables A6.2-1 through A6.2-6 are less and therefore, more stringent. Pay careful attention to fire protection piping systems utilizing copper pipes o the CPVC sprinkler piping such as BlazeMaster®. Due to the difference in material properties, these types of pipes have much lower critical buckling loads than steel pipes of an equivalent size, and therefore, must have seismic restraints placed closer together to prevent buckling under longitudinal seismic loads.

Appendix A6.3:

This appendix is for single clevis hung cast iron soil and drain pipe. The actual spacing of the restraints for this type of pipe will depend on the actual lengths of the sections of pipe, see Section S10.0 of this manual for the restraint of waste (soil), drain, and vent lines. The transverse seismic restraint spacing for the cast iron soil pipes must not exceed that shown in Appendix A6.3 Tables A6.3-1 through A6.3-9.

Appendix A6.4:

This appendix is based on single clevis hung PVC and CPVC pipe. The mechanical properties of PVC and CPVC that control bending and buckling are two orders of magnitude less than those for steel. The decrease in weight does not offset the loss in strength, and for many cases, the maximum allowable transverse seismic restraint spacing for a given pipe size is much less than that recommended by SMACNA for steel pipe. So, SMACNA recommendations for seismic restraint spacing on PVC and CPVC piping systems should not be followed blindly. Caution must be used when sizing, selecting, and locating seismic restraints for PVC and CPVC piping systems. Tables A6.4-1 through A6.4-20 covers several different conditions and applications for PVC and CPVC pipe.

Appendix A6.5:

This appendix applies to single clevis hung copper water piping. The mechanical properties of copper that control the bending and buckling of the pipe are approximately half of those for steel pipe. So, the normal SMACNA recommendations for seismic restraint spacing may not apply to all of the trade sizes for copper water piping. Tables A6.5-1 through A6.5-3 may be used for determining the maximum allowable transverse seismic restraint spacing for an application.

General Notes for Piping Applications:

1. Where SMACNA recommendations represent the most conservative approach, it is always appropriate to follow the SMACNA recommendations.
2. Minimum seismic restraint spacings specified for special applications in other sections of the manual will apply unless they exceed the maximum allowable transverse seismic restraint spacings tabulated in Appendices A6.1 through A6.5.
3. For trapeze supported piping, the maximum allowable seismic restraint spacing will be determined by the smallest pipe size being supported on the trapeze bar.

Appendix A6.6:

This appendix applies to duct constructed from 22 gage steel sheet metal that has been reinforced to bring its supported weight up to that specified in the SMACNA Seismic Restraint Manual – Guidelines for Mechanical Systems. The maximum allowable transverse seismic restraint spacing in Table A6.6-1 for rectangular duct and in Table A6.6-2 for round duct exceeds the recommended value by SMACNA of S_T =30 ft. The SMACNA recommendation is more conservative and is probably based on local buckling and bending failures in the duct sheet metal. Therefore, it is prudent to use S_T =30 ft. and S_L =60 ft.