CONSEQUENTIAL DAMAGE – SWINGING THINGS

S14.1 – Introduction:

This is a single paragraph in ASCE 7-05 that may have far reaching consequences for contractors. This is especially true for those contractors who are on the job site first, and whose systems and/or components may have a code based exemption from the need for seismic restraint. The paragraph is Section 13.2.3 of ASCE 7-05, and reads as follows.

> The function and physical interrelationship of components, their supports, and their effect on each other shall be considered so that the failure of an essential or nonessential architectural, mechanical, or electrical component shall not cause the failure of an essential architectural, mechanical, or electrical component.

In this section, or rule, the nonessential components would have a Component Importance Factor I_P=1.0, and the essential components would have a Component Importance Factor I_P=1.5.

The application of this rule in ASCE 7-05 may require a contractor to go back and install restraints after other systems have been installed. This is a very difficult and expensive process. This section of the Pipe & Duct Seismic Application Manual will discuss the conditions where this rule will apply, and help define the limiting factors for the application of the rule.

S14.2 – Conditions of Application:

There are two basic conditions for which this rule will apply above, and side-by-side.

1. **Above:** In this case the component(s) with a code based exemption from the need for Seismic restraints and Component Importance Factor of either I_P=1.0, or I_P=1.5 are installed above a component or component(s) the have a Component Importance Factor of I_P=1.5. The component(s) which are installed above will need to be restrained to prevent the failure

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of the component(s) with a Component Importance Factor of I_P=1.5 that have been installed below. Examples are given below.

a. Assume a building assigned to Occupancy Category IV, and Seismic Design Category C. A duct whose Component Importance Factor is I_P=1.0 has been installed directly above a cross main for the fire suppression sprinkler system, which has a Component Importance Factor of I_P=1.5. Even though the duct carries a code based exemption from the need for seismic restraint, it would need to be restrained to prevent the possibility of the failure of the fire suppression sprinkler system if the duct should fall.

b. Assume a hospital assigned to Occupancy Category IV, and Seismic Design Category D. A single clevis supported 3″ IPS schedule 40 steel water line with a Component Importance Factor of I_P=1.0 has been installed above a trapeze bar that carries the main feed for the medical gas and vacuum whose Component Importance Factors are I_P=1.5. The single clevis supported 3″ IPS schedule 40 steel water line would need to be restrained to prevent the possible failure of the medical gas and vacuum systems if the 3″ pipe should fall.

2. **Side-by-Side:** Keep in mind that the earthquake will move the building, and the building will drag the components attached to it along with it. Those components that have been adequately restrained per the code will move exactly with the building. That is, there will be no lag between the times the building moves, and when the components begin to move. Those components that have not been restrained will not move with the building, they will be out of phase with the building motion. Impacts can occur in one of two ways. First the building and restrained components can run into the unrestrained components because they can't get out of the way in time. Second, the unrestrained components can be in resonance with the earthquake motion, and their displacements can build up enough so that they swing into the building and/or the restrained components. The big question is how much space to leave between restrained and unrestrained components, and between unrestrained components and the building. The answer is not entirely simple. It will depend on the Site Specific seismic parameters for the project. Estimating these spacings will be the subject of the next section. Some examples are presented below.

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a. Assume a building assigned to Seismic Design Category C. A 2″ IPS natural gas line is installed as being single clevis supported, and is hung so the OD of the pipe is 1 inch away from the structural wall. This pipe would have a Component Importance Factor of I_P=1.5 because it carries a hazardous material, but would have a code based exemption from the need for seismic restraint due to its size. In this case, either the building could "run into" the pipe, or the pipe could swing into the building causing the pipe and/or its hangers to fail. It would require seismic restraint.

b. Assume a building assigned to Seismic Design Category D. There are two pipes which are single clevis supported, and are located side-by-side such that their ODs are 2″ apart. The first pipe is a natural gas line with a Component Importance Factor of I_P=1.5 that is 1-1/2″ IPS. It has been seismically restrained per the code. The second pipe is a 3″ IPS schedule 40 steel water line with a Component Importance Factor of I_P=1.0. It has a code base exemption from the need for seismic restraint. However, the possibility exists that the gas line could "run into" the water line and be damaged, or the water line could swing into the gas line and damage it as the water line displacement builds up during the earthquake. The 3″ IPS water line would need to be restrained as well to prevent damage to the gas line.

S14.3 – Estimating the Allowable Spacing between Objects:

The analysis developed in this section will permit the allowable spacing between an unrestrained component and a building or restrained object, and the allowable spacing between two unrestrained objects to be estimated. The analysis will depend on certain basic assumptions.

1. The run of pipe or duct, when viewed along their long axis, will behave like a simple pendulum of length L.
2. The run of pipe or duct is supported by threaded hanger rods.
3. The hanger rods will behave like flexible members, and have a damping coefficient that is equal to 3% of critical.

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4. The length of the pendulum, L , will be the average length of all of the hanger rods supporting the run of pipe or duct.
5. The simple pendulum formed by the run of pipe or duct will be assumed to be in resonance with the earthquake ground motion.
6. The building itself is relatively small when compared to the portion of the earth's surface that will be excited by the earthquake. Therefore, at this scale, the building will behave like a particle.
7. The simple pendulum formed by the run of pipe or duct and it's hanger rods may be viewed as a single degree of freedom system whose motion is being forced through the attachment point to the building structure by the earthquake motion.
8. The earthquake ground motion will be assumed to be a square wave with constant acceleration in one direction for half the period and then constant acceleration in the opposite direction for half the period.

The motion of the run of pipe or duct may now be described by the following equation which is derived from classical vibration analysis.[1 & 2]

$$X = Y\sqrt{\frac{1+\left(2\xi\frac{T_N}{T}\right)^2}{\left(1-\left(\frac{T_N}{T}\right)^2\right)^2+\left(2\xi\frac{T_N}{T}\right)^2}}$$

Equation S14-1

Where:

X = The displacement of the run of pipe or duct relative to the building.

Y = The displacement of the building attachment point for the hanger rods.

T_N = The natural period of oscillation for the run of pipe or duct.

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[1] Beer, Ferdinand P. and Johnston, E. Russel; Vector Mechanics for Engineers: Dynamics 2nd Edition, McGraw-Hill Book Company, Inc., 1972, Pp 832-866.

[2] Thompson, William T.; Theory of Vibration with Application, Prentice-Hall Inc., 1972, Pp 56-62.

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T = the period of the earthquake ground motion.

ξ = the damping coefficient for the Pipe and duct hangers and their attachments. This is assumed to be 3% of the critical damping, or $\xi = 0.03$.

Per the basic assumption number 5; $T = T_N$ or $T_N / T = 1.0$. The radical in Equation S14-1 will now become;

$$\sqrt{\frac{1+\left(2\xi\frac{T_N}{T}\right)^2}{\left(1-\left(\frac{T_N}{T}\right)^2\right)^2+\left(2\xi\frac{T_N}{T}\right)^2}} = \sqrt{\frac{1+(2(0.03)(1.0))^2}{\left(1-(1.0)^2\right)^2+(2(0.03)(1.0))^2}} = 16.6966$$ **Equation S14-2**

Equation S14-1 will now become simply;

$$X = 16.6966Y$$ **Equation S14-3**

Because the building is assumed to behave like a particle with respect to the earth, the displacement of the building at grade level may be expressed as;

$$y = \frac{at^2}{2}$$ **Equation S14-4**

Where:

y = the displacement of the base of the building at grade.

a = the acceleration imparted to the base of the building due to the earthquake ground motion.

t = the time period over which the acceleration acts.

The code based acceleration value that will be used in Equation S14-4 is to be derived from the design horizontal force equation which is the same for all three versions of the IBC.

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$$F_P = \frac{0.4 a_P S_{DS} W_P}{\left(\frac{R_P}{I_P}\right)}\left(1 + 2\frac{h}{z}\right)$$ **Equation S14-5**

And;

$$0.3 S_{DS} I_P W_P \leq F_P \leq 1.6 S_{DS} I_P W_P$$ **Equation S14-6**

Where:

F_P = the seismic design horizontal force.

S_{DS} = the spectral acceleration, short (0.2 sec) period. This includes the modification for the Site Class, or the type of soil on which the project has been constructed.

a_P = the component amplification factor. This factor is a measure of how close the natural period of the component is expected to be to the natural period of the building. This factor will vary from 1.0 to 2.5 with 2.5 being the case where the two natural periods are very close.

R_P = the component response modification factor. This factor accounts for the ability of the component and its attachments to absorb energy. The larger this factor, the more able the component and its attachments are to absorb the earthquake energy.

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

W_P = the operating weight of the component.

z = the height of the structural attachment point for the hanger rods of the components within the building.

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

$\left(1 + 2\frac{z}{h}\right)$ = a term that recognizes that the building structure is flexible, and that the motion at any elevation above grade in the building will exceed the motion at grade level.

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If W_P is dropped from equation S14-5, then what is left is a design acceleration factor that depends on the attachment location in the building. This design acceleration factor has been known in the past as the seismic coefficient, and that seems applicable here as well.

$$C_S = \frac{0.4 a_P S_{DS}}{\left(\frac{R_P}{I_P}\right)}\left(1 + 2\frac{h}{z}\right)$$ **Equation S14-7**

And;

$$0.3 S_{DS} I_P \le C_S \le 1.6 S_{DS} I_P$$ **Equation S14-8**

Where:

C_S = the seismic coefficient.

Note that at grade line, $z = 0$, therefore;

$$a = \frac{0.4 a_P S_{DS}}{\left(\frac{R_P}{I_P}\right)}$$ **Equation S14-9**

So, the displacement of the hanger rod attachment points for the pipe or duct will be as follows.

$$Y = \frac{at^2}{2}\left(1 + 2\frac{z}{h}\right) = \frac{C_S t^2}{2}$$ **Equation S14-10**

Now then, the maximum time period over which the acceleration can act will be one half of the earthquake period, which has also been assumed to be the natural period of the pendulum

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composed of the pipe or duct and it's supporting hanger rods. For a simple pendulum, the natural period may be estimated by;

$$T_N = T \cong 2\pi\sqrt{\frac{L}{g}}$$ **Equation S14-11**

Where:

g = the acceleration due to gravity, 386.4 in/sec^2.

Then;

$$t = \frac{T_N}{2} = \pi\sqrt{\frac{L}{g}}$$ **Equation S14-12**

Substitute Equation S14-12 into Equation S14-10 to obtain;

$$Y = \frac{\pi^2 C_S L}{2g}$$ **Equation S14-13**

Substituting this result into Equation S14-3 will yield the following.

$$X = \frac{16.6966\pi^2 C_S L}{2g}$$ **Equation S14-14**

This can be reduced even further to;

$$S_{R-U} = X = 0.2132 C_S L$$ **Equation S14-15**

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Where:

S_{R-U} = the minimum safe allowable horizontal spacing between an unrestrained component and a restrained component or the building structure.

For two unrestrained components positioned side-by-side, the minimum safe allowable horizontal spacing between the two objects will be;

$$S_{U-U} = 2X = 0.4265 C_S L$$ **Equation S14-16**

Where;

S_{U-U} = the minimum safe allowable horizontal spacing between two adjacent unrestrained components.

There are times when knowing the angle through which the run of pipe or duct can swing may also be a valuable piece of information. Referenced to the vertical, this angle may be estimated using the following formula.

$$\theta_P = \pm Tan^{-1}\left[\frac{X}{L}\right] = \pm Tan^{-1}\left[0.2132 C_S\right]$$ **Equation S14-17**

Where:

θ_P = the angle through which the unrestrained ruin of pipe or duct will swing from the vertical.

S14.4 – Summary:

1. Consequential damage must be addressed for each project and each piece of equipment, run of pipe, duct, or any other distribution system.
2. Consequential damage from components above and from components and structure located side-by side are defined in Section S14.2 above.

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3. A method of estimating the minimum allowable spacing between adjacent objects is presented in Section S14.3. This method is not easily employed by the either the installing contractor or the inspector. The calculation should be performed by the design professional of record for the system or the system designer.

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