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Revision Record	D7.0A

D7.0- Piping Systems

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SEISMIC FORCES ACTING ON PIPING SYSTEMS

When subjected to an earthquake, piping systems must resist lateral and axial buckling forces, and the restraint components for these systems must resist pullout and localized structural failures.

Most piping systems are suspended from the deck above on either fixed or isolated hanger rod systems. They may be supported singly or there may be several pipes attached to a common trapeze. On some occasions the pipes may run vertically or may be mounted to the floor.

D7.1.1 Suspended Systems

Most codes do not require that piping supported on non-moment generating (swiveling) hanger rods 12 in or less in length be restrained. The 12 in length was determined based on the natural frequency of systems supported on the short hanger rods. In practice, it has been found that the vibrations generated by earthquakes do not excite these types of systems and, although the pipes move back and forth somewhat as a result of an earthquake, they do not tend to oscillate severely and tear themselves apart.

There are also exclusions in most codes for small pipes, no matter what the hanger rod length. Again, the basis for this exclusion is based on the post-earthquake review of many installations. It has been found that smaller pipes are light and flexible enough that they cannot generate enough energy to do significant damage to themselves.

For cases where restraints are required, however, the forces involved can be significant. This is due to the difference between the spacing of piping system supports and piping system restraints. Supports for piping systems are typically sized to carry approximately a 10 ft length of piping (in the case of trapezes, multiple pipes each approximately 10 ft long). Seismic restraints, on the other hand, are normally spaced considerably further apart with the spacing varying by restraint type, restraint capacity, pipe sizes, and the seismic design load. It is very important to be aware of the impact of the difference in spacing as the wider this spacing, the larger the seismic load when compared to the support load. Guidance in determining restraint spacing requirements is available in Chapter D4 of this manual.

To illustrate this difference, consider a simple example of a single pipe weighing 50 lb/ft being restrained against a 0.2g seismic force with restraints located on 80 ft centers and supports located on 10 ft centers. The load that is applied to the hanger rods by the weight of the pipe is 50 lb/ft x 10 ft or 500 lb each (assuming single rod supports). The horizontal load that occurs at the restraint locations is the total restrained weight (50 lb/ft x 80 ft = 4000 lb) multiplied by the seismic force (0.2g) or 800 lb. Thus the seismic load is larger than the vertical dead load.

Restraints for suspended systems are normally in the form of cables or struts that run from the pipe up to the deck at an angle. Because of the angle, horizontal seismic loads also generate

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vertical forces that must be resisted. Therefore, restraint devices must be attached at support locations so that there is a vertical force-resisting member available.

As the angle becomes steeper (the restraint member becomes more vertical), the vertical forces increase. At 45 degrees the vertical force equals the horizontal force and at 60 degrees the vertical force is 1.73 times the horizontal force.

The net result is that for cable systems or for struts loaded in tension, the uplift force at the bottom end of the restraint can be considerably higher than the downward weight load of the pipe. Returning to our example, assume that we have a restraint member installed at a 60 degree angle from horizontal and that the lateral force will load it in tension. In this case, the 800 lb seismic force generates an uplift force of 1.73×800 lb or 1384 lb. This is 884 lb more than the support load and, depending upon the support rod length and stiffness, can cause the support rod to buckle. Rod stiffeners are used to protect against this condition and sizing information is available in Chapter D4 of this manual.

Unlike cables, if struts are used for restraint they can also be loaded in compression. In the example above, if the strut were loaded in compression, the 1384 lb load would be added to the support load (trying to pry the hanger rod out of the deck). The total support capacity required would be 1384 lb + 500 lb or 1884 lb. As a consequence, when using struts, the hanger rod must be designed to support 1884 lb instead of the 500 lb maximum generated with cables. Hanger rod sizing information is also available in Chapter D4 of this manual.

D7.1.2 Riser Systems

Where piping systems are running vertically in structures, except for the loads directly applied by vertical seismic load components identified in the code, there will be little variation in vertical forces from the static condition. Lateral loads are normally addressed by pipe guides and the spacing between pipe guides is not to exceed the maximum tabulated lateral restraint spacing indicated in the design tables in Chapter D4.

D7.1.3 Floor-Mounted Systems

The primary difference between floor- and ceiling-mounted piping systems is that the support loads in the pipe support structure are in compression instead of tension (as in the hanger rods). Although a support column and diagonal cables can be used, a fixed stand made of angle or strut is generally preferred. Rules relating to restraint spacing and the sizing information for diagonal struts are the same as for hanging applications.

However, the support legs need to be designed to support the combined weight and vertical seismic load (for a two-legged stand and the example above, 500 lb / 2 + 1384 lb or 1634 lb) in compression (Note: 500 lb / 2 is the load per leg for two legs). The anchorage for the legs needs to be able to withstand the difference between the dead weight and the vertical seismic load (in the example above 1384 lb - 500 lb / 2 or 1134 lb).

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VIBRATION ISOLATION & SEISMIC CONTROL
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BASIC PRIMER FOR SUSPENDED PIPING

Failures in piping systems resulting from earthquakes have historically resulted in large quantities of water or other materials being dumped into occupied spaces of the building structure. The resulting dollar damage to the building and its contents is often considerably more than the costs of damage to the building structure itself. In addition, failure of the building's mechanical systems can render the structure unfit for occupation until the damage is corrected, and result in major problems for the tenants and/or owners.

Because of the impact that failures of these systems have had in the past, design requirements for piping systems have become much more stringent.

Within a building structure, there are multitudes of different kinds of piping systems, each with its own function and requirements. These include potable water, sanitary, HVAC, fire piping, fuel, gas, medical gases, and process systems to name a few. Requirements for the systems vary based on the criticality or hazardous nature of the transported fluid. Code mandated requirements for the restraint of piping systems are addressed in Chapter D2 of this manual (Seismic Building Code Review).

Prior to applying this section of the manual, it is assumed that the reader has reviewed Chapter D2 and has determined that there is indeed a requirement for the restraint of piping. This chapter of the manual is a "how to" guide and will deal only with the proper installation and orientation of restraints and not whether or not they are required by code or by specification.

This chapter also does not address the sizing of restraint hardware. Chapter D4 includes sections on sizing componentry based on the design seismic force and the weight of the system being restrained.

Process piping is not directly associated with building operating systems and often has its own set of requirements. If there are no applicable special requirements, these systems should be restrained in a similar fashion to the building mechanical systems. This manual will not address any special requirements for process piping systems.

Building mechanical systems (potable water, HVAC, sanitary) can normally be grouped together and have similar design requirements. In many cases, requirements for fuel, gas, and medical gasses are more stringent. Refer to the code review chapter (D2) of the manual for applicable design requirements.

Fire piping restraint is normally addressed in the applicable fire code. There is always some requirement for restraint, as triggering a nozzle generates thrust in the piping and must be countered. This thrust may be unidirectional, unlike the loads generated by an earthquake, and can sometimes be countered by unsymmetrical restraint arrangements.

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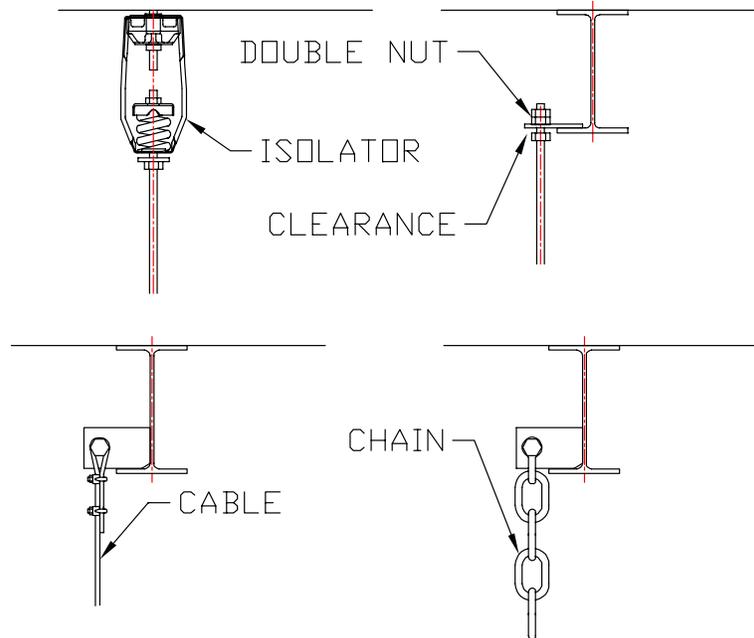
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These types of non-seismic restraints are not addressed in this chapter. To determine the design requirements for seismic applications, refer again back to the code review Chapter D2.

In many cases, piping can be excluded from restraint if it is small enough in size or mounted in close proximity to the ceiling structure. When applying this exemption, current codes require the installation of a “non-moment generating connection” at the top anchorage point. This term is often confusing and deserves further clarification. A “non-moment generating connection” is one that will allow the supported pipe to swing freely in any direction if acted on by an outside force. Some examples of “non-moment generating connections” are illustrated below.

Figure D7.2-1; Non-moment generating connections



PROS AND CONS OF STRUTS VERSUS CABLES

Both cables and struts have their place in the restraint of piping. In order to minimize costs and speed up installation, the differences between the two should be understood.

In general, piping restrained by struts will require only 1 brace per restraint location while piping restrained with cables requires that 2 cables be fitted forming an “X” or a “V”. As a trade-off, the number of restraint points needed on a given run of piping will typically be considerably higher for a strut-restrained system than for the cable-restrained system and, generally, strut-restrained systems will be more costly to install.

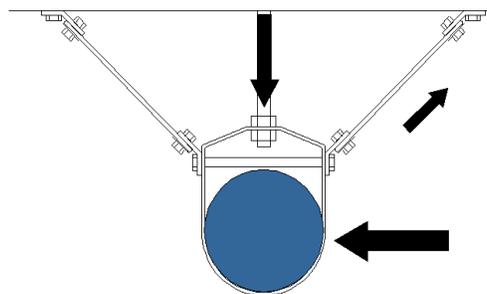
An added factor to consider when selecting a restraint system is that once a decision is reached on the type to use for a particular run, code requirements state that the same type of system must be used for the entire run (all cable or all strut). Later sections in this chapter will define runs, but for our purposes at present, it can be considered to be a more or less straight section of piping.

The obvious advantage to struts is that, when space is at a premium, cables angling up to the ceiling on each side of a run may take more space than is available. Struts can be fitted to one side only, allowing a more narrow packaging arrangement.

The advantages of cables, where they can be used, are numerous. First, they can usually be spaced less frequently along a pipe than can struts. Second, they cannot increase the tensile forces in the hanger rod that results from the weight load, so rod and rod anchorage capacities are not impacted. Third, they are easily set to the proper length. And fourth, they are well suited to isolated piping applications.

To better explain the differences between the systems, it is necessary to look at how seismic forces are resisted with cables and struts. Shown below are sketches of both cable-restrained and strut-restrained piping.

Figure D7.3-1; Cable Restrained



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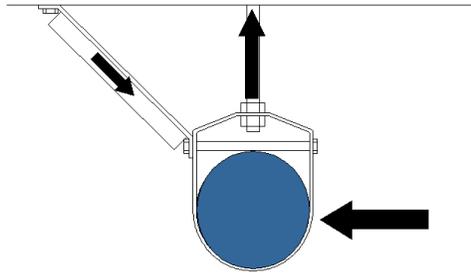
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Figure D7.3-2; Strut Restrained



The key factor to note is that cables can only be loaded in tension. This means that seismic forces can only generate compressive loads in the pipe hanger rod. Seismic forces can, however, load the strut in compression resulting in a tensile load on the hanger rod.

This tensile load is in addition to any deadweight load that may already be supported by the hanger and is often significantly higher than the original load. This has the potential to rip the hanger rod out of the support structure and must be considered when sizing components.

Because of this added tensile component and the resulting impact on the necessary hanger rod size, most strut manufacturers limit the maximum allowable strut angle (to the horizontal) to 45 degrees. This is lower than typical allowable angles for cables that often reach 60 degrees from the horizontal. Although the data provided in Section D4.4 of this manual allow the use of higher angles for strut systems, users will find that the penalties in hanger rod size and anchorage will likely make these higher angles unusable in practice. To put this into context, examples will be provided at both 45 degrees and 60 degrees from the vertical to indicate the impact on capacity that results from the angle.

For a 45 degree restraint angle, if we assume a trapeze installation with the weight (W) equally split between 2 supports, the initial tension in each support is $0.5*W$. Using a 0.25g lateral design force (low seismic area), the total tensile load in a hanger increases to $0.75*W$ for bracing on every support and $1.0W$ for bracing on every other support, if a strut is used.

For reference, if struts are used in a 60 degree angle configuration (from the horizontal), the tensile force in the hanger rod for all cases increases by a factor of 1.73 ($\tan 60$) over that listed in the previous paragraph. This means that the tensile force becomes $.94*W$ for bracing on every support and $1.36*W$ for bracing on every other support.

On the other hand, where 0.25g is applicable, buckling concerns in the pipe are such that the spacing between lateral restraints can be as high as 40 ft and for axial restraints, 80 ft. If we were to try to use struts placed at a 40 ft spacing in conjunction with supports spaced at 10 ft, the tensile force developed by a seismic event in the rod increases to $1.5*W$ for 45 degree configurations and to $2.23*W$ for 60 degree configurations.

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As mentioned earlier, there is no increase in the rod forces for cable restrained systems.

Using real numbers based on a 40 ft restraint spacing and a 60 degree angle configuration, if the peak tensile load in the hanger rod is 500 lb for a cable restrained system, it becomes 2230 lb for an otherwise identical strut restrained system.

A summary of the above data, based on a 500 lb weight per hanger rod (1000 lb per trapeze bar) and including concrete anchorage sizes and minimum embedment is shown below.

Table D7.3-1; Hanger Rod Tensile Loads

Summary of Hanger Rod Tensile Loads based on 500 lb per Rod Weight				
	Tens Force (lb)	Min Rod (in)	Min Anc (in)	Embed (in)
Every Hanger Braced (10')				
Cable Angle = 45	500	0.38	0.38	3.00
Strut Angle = 45	750	0.38	0.38	3.00
Cable Angle = 60	500	0.38	0.38	3.00
Strut Angle = 60	933	0.50	0.50	4.00
Every other Hanger Braced (20')				
Cable Angle = 45	500	0.38	0.38	3.00
Strut Angle = 45	1000	0.50	0.50	4.00
Cable Angle = 60	500	0.38	0.38	3.00
Strut Angle = 60	1365	0.50	0.63	5.00
Every fourth Hanger Braced (40')				
Cable Angle = 45	500	0.38	0.38	3.00
Strut Angle = 45	1500	0.63	0.63	5.00
Cable Angle = 60	500	0.38	0.38	3.00
Strut Angle = 60	2230	0.63	0.75	6.00
Max Spacing between Braces (80')				
Cable Angle = 45	500	0.38	0.38	3.00
Strut Angle = 45	2500	0.75	0.75	6.00
Cable Angle = 60	500	0.38	0.38	3.00
Strut Angle = 60	3960	0.88	1.00	8.00

Note: The above anchorage rating is based on typical anchor allowables only. Often the underside of a concrete floor slab is in tension and if this is the case, the anchorage capacity may need to be further de-rated (forcing the need for an even larger hanger rod than is indicated here).

The net result is that the ability to use struts is highly dependent on the hanger rods that are in place. If these were sized simply on deadweight, the added seismic load, even in relatively low seismic areas, can quickly overload them. The only recourse is to either replace the hanger rods with larger ones or decrease the restraint spacing to the point at which virtually every support rod is braced.

PROS AND CONS OF STRUTS VERSUS CABLES

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It should also be noted that the hanger rods in tension become seismic elements. This occurs with struts, but does not with cables. As a result, the system must comply with all of the anchor requirements specified by ICC. This includes the use of seismically rated anchors and embedment depths that are in conformance with ICC requirement for those types of anchors. With larger anchor sizes, floor slab thickness may cause this to become a significant problem.

With both cables and struts, the hanger rods can be loaded in compression. As the seismic force increases, it eventually overcomes the force of gravity and produces a buckling load in the hanger rod. It is mandatory in all cases that the rod be able to resist this force.

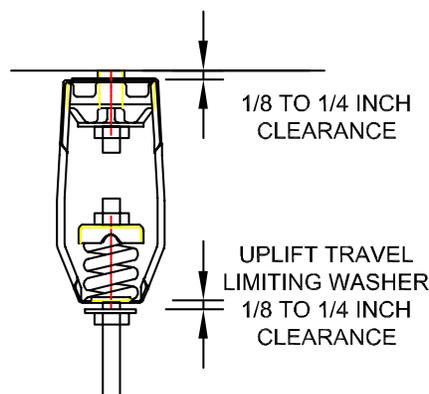
There is a wide range of variables involved in determining the need for rod stiffeners to resist this buckling load. Factors that impact this include 1) the magnitude of the compressive force, 2) the weight load carried by the hanger rod, 3) the length of the hanger rod, 4) the diameter of the hanger rod, and 5) the angle between the restraint strut or cable and the horizontal axis.

Charts are included in Section D4.4 of this manual that allow the user to determine if there is a need for a stiffener and to allow the proper selection if required.

Because uplift occurs, some attention must be given to isolated systems. First, when using isolators, the location of the isolation element needs to be at the top end of the hanger rod (close to, but not tight against the ceiling). If placed at the middle of the hanger rod, the rod/isolator combination will have virtually no resistance to bending and will quickly buckle under an uplift load.

Second, a limit stop must be fit to the hanger rod, just beneath the hanger such that when the rod is pushed upward a rigid connection is made between the hanger housing and the hanger rod that prevents upward motion. This is accomplished by adding a washer and nut to the hanger rod just below the isolator (see the sketch below).

Figure D7.3-3; Installation for an Isolation Hanger in a Seismic Application



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SECTION – D7.3

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PIPE RESTRAINTS-DEFINITIONS AND LOCATING REQUIREMENTS

There are a number of design guides that have been developed over the years but the one with the longest history and most widely accepted is SMACNA. They have developed a handbook that offers conservative guidance that an end user can reference in selecting and installing restraints for distribution systems. While the information provided in that handbook is good, it suffers from a couple of inherent drawbacks. The first is that because it is linked to generically available hardware, the ratings that are assumed for the various hardware components are the lowest of any of the many possibilities available in the marketplace. The net result is that the suggested hardware is larger in general than that which could be used if higher quality componentry it specified. The second is that their presentation of the results is extremely cumbersome and difficult to use.

While the criteria presented in this document is based on the guidance offered by SMACNA, it has been possible to increase the component ratings as the actual capacity, type and manufacture of these components is clearly known. In addition, based on a critical review of the data presentation in the SMACNA handbook, it has been possible to greatly simplify the method of selection making the end result much simpler to use.

With respect to the conceptual restraint arrangement illustrations, the SMACNA concepts are appropriate and are referenced here.

In general, pipes are restrained in lengths called “runs.” Therefore before getting into a detailed review of the restraint systems it is imperative that a definition of “run” as well as other key terms be addressed.

D7.4.1-1; Definitions

Axial In the direction of the axis of the pipe.

Lateral Side to side when looking along the axis of the pipe.

Pipe Clamp A heavy duty split ring clamp tightened against the pipe to the point that it can be used to control the axial motion of the pipe.

Restraint Any device that limits the motion of a pipe in either the lateral or axial direction.

Run A more or less straight length of pipe where offsets are limited to not more than S/16 where S is the maximum permitted lateral restraint spacing (a function of pipe size and seismic forces) and the total length is greater than S/2. (Note: S dimensions for various conditions are listed in Chapter D4.)

PIPE RESTRAINTS-DEFINITIONS AND LOCATING REQUIREMENTS

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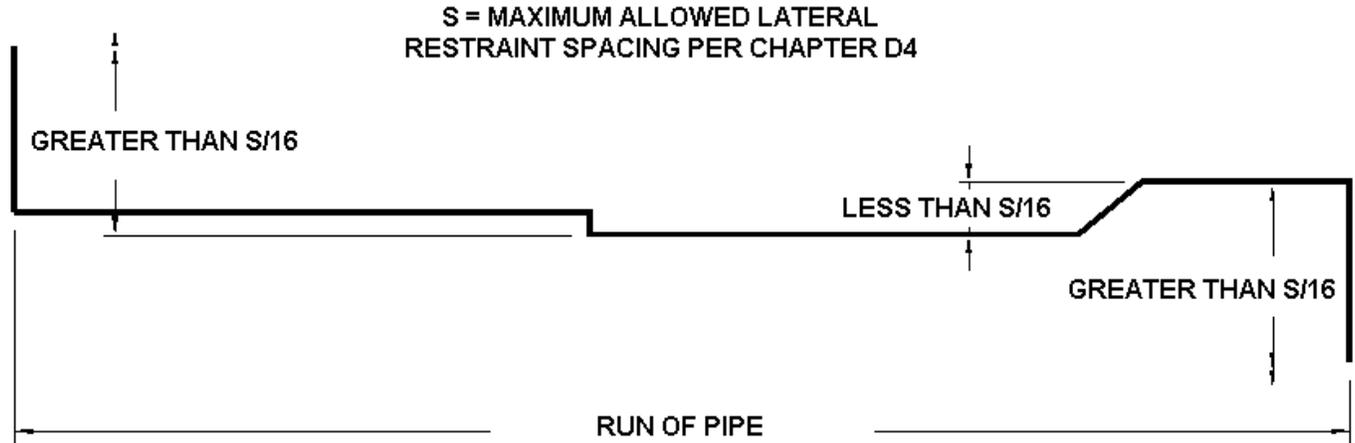
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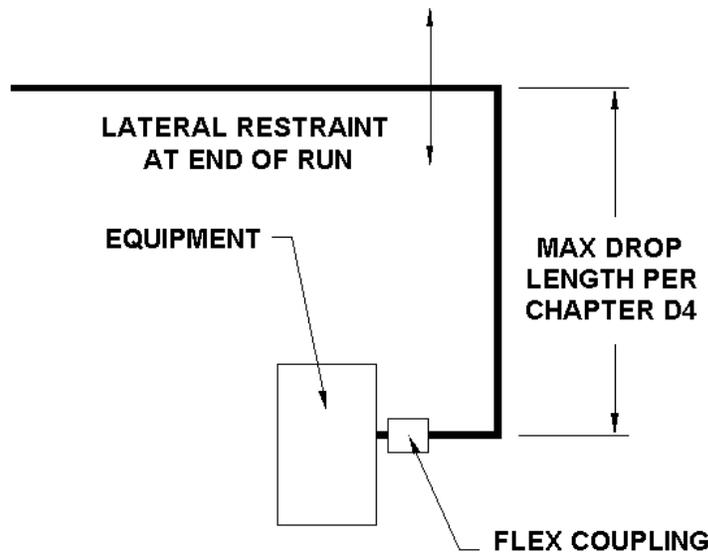
Figure D7.4.1-1; Definition of a “Run” of Pipe



Short Run A run as defined above where the total length is less than $S/2$ and where it is connected on both ends to other runs or short runs.

Drop A length of pipe that normally extends down from an overhead run of pipe and connects to a piece of equipment, usually through some type of flex connector. The drop can also extend horizontally. In order to qualify as a drop, the length of this pipe must be less than $S/2$. If over $S/2$, the length of pipe would be classified as a run.

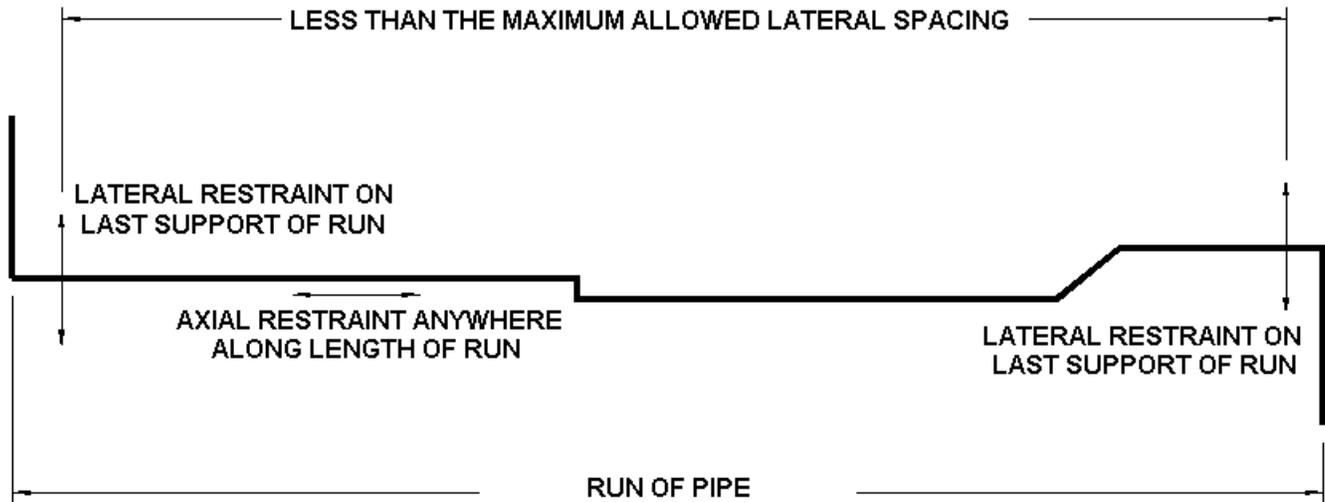
Figure D7.4.1-2; Definition of a “Drop”



D7.4.1-2; Restraint Requirements

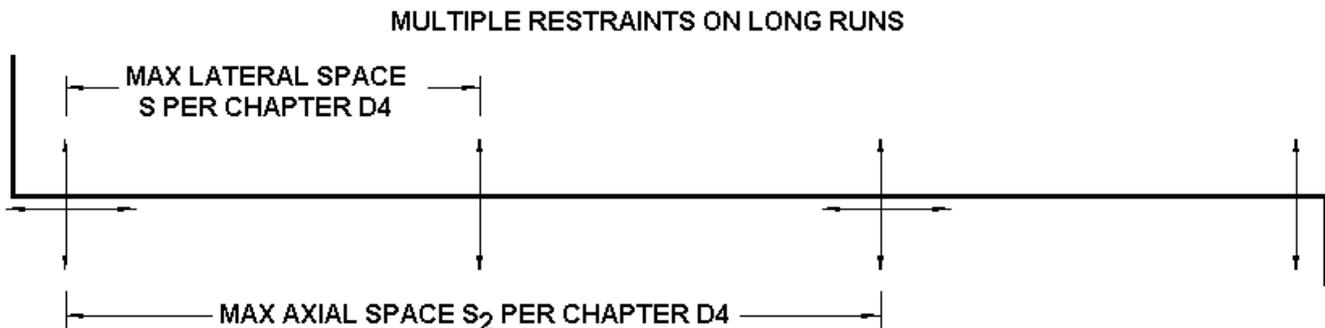
1) Full runs (Greater in length than $S/2$) must be restrained in both the axial and lateral direction. If the run is not a short run or a drop, it must, as a minimum, be laterally restrained at the last support location on each end.

Figure D7.4.1-2; Basic Restraint Requirements for a Typical “Run” of Pipe



2) If a run is longer than “S”, intermediate restraints are required to limit the spacing to that permitted by the building code (see table in Chapter D4).

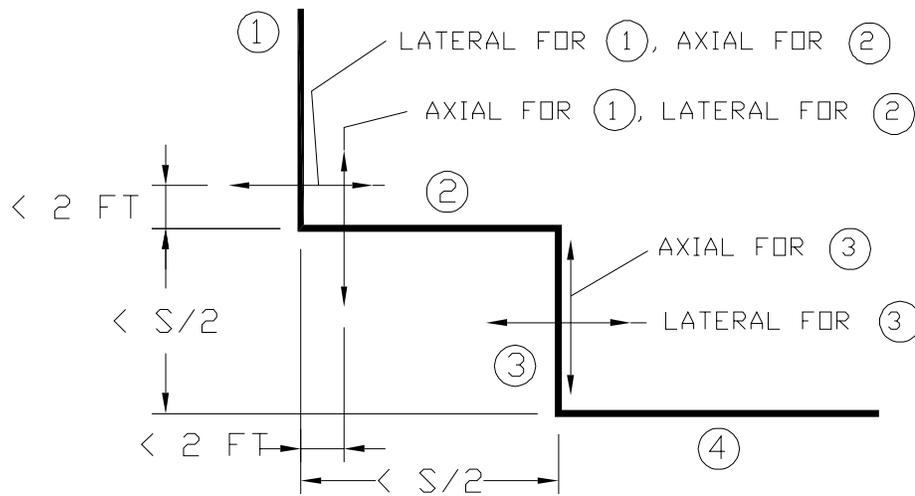
Figure D7.4.1-3; Basic Restraint Requirements for a Long “Run” of Pipe



3) Axial restraints attached to the run of piping along its length must be connected using a pipe clamp (as previously defined).

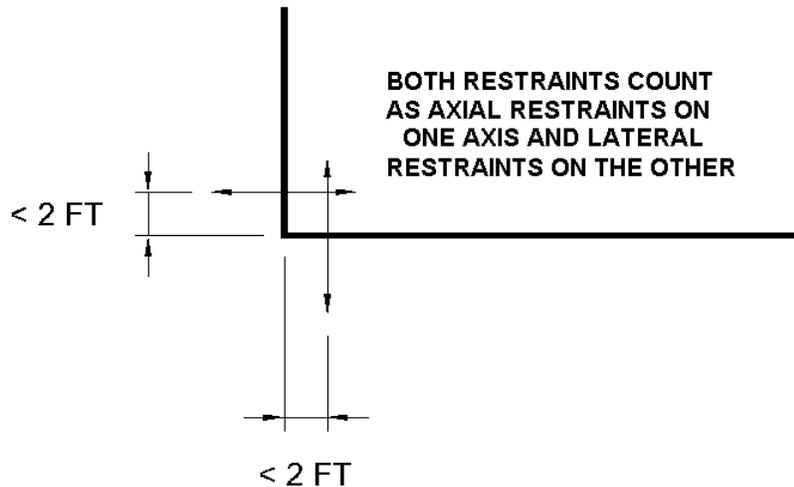
4) Short runs or drops need only have one lateral and one axial restraint.

Figure D7.4.1-4; Basic Restraint Requirements for Multiple Short “Runs” of Pipe



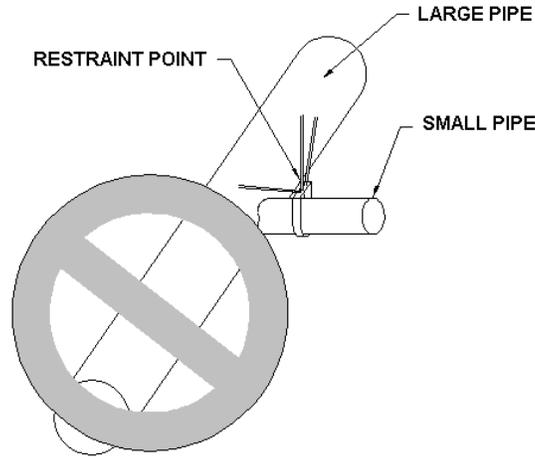
5) If a lateral restraint is located within 2 feet of a corner (based on a measurement to the pipe centerline), it can be used as an axial restraint on the intersecting run.

Figure D7.4.1-5; “Double Duty” for Corner Restraints



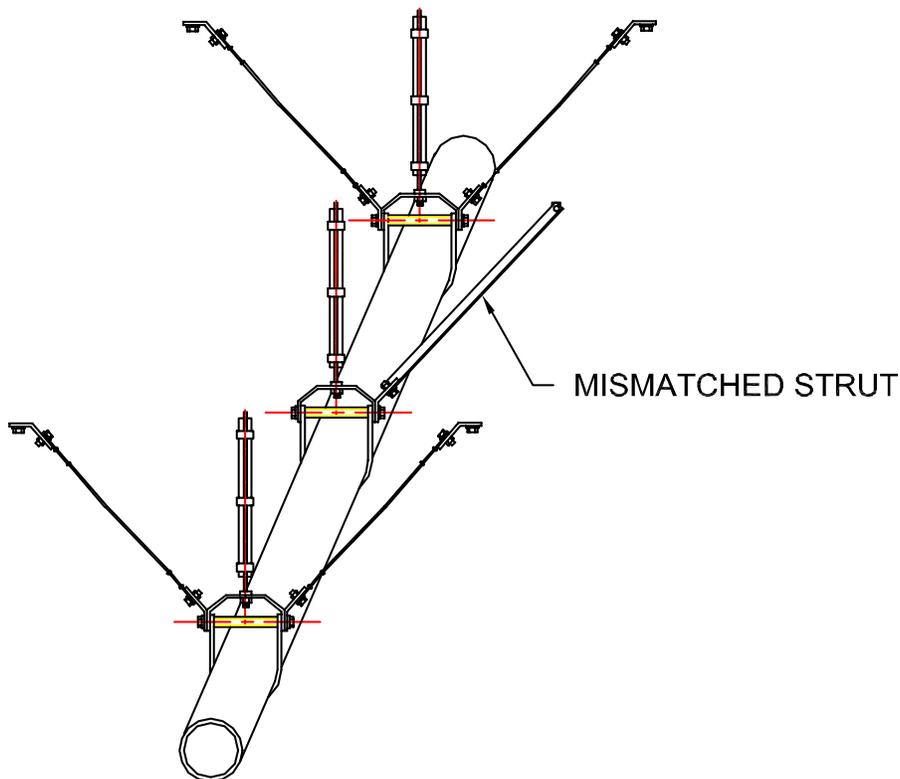
6) Larger pipes cannot be restrained with restraints located on smaller branch lines.

Figure D7.4.1-6; Do not Restrain Larger Pipes with Restraints on Smaller Ones



7) Within a run, the type of restraint used must be consistent. For example, mixing a strut with cable restraints is not permitted.

Figure D7.4.1-7; Mismatched Struts and Cable Restraints



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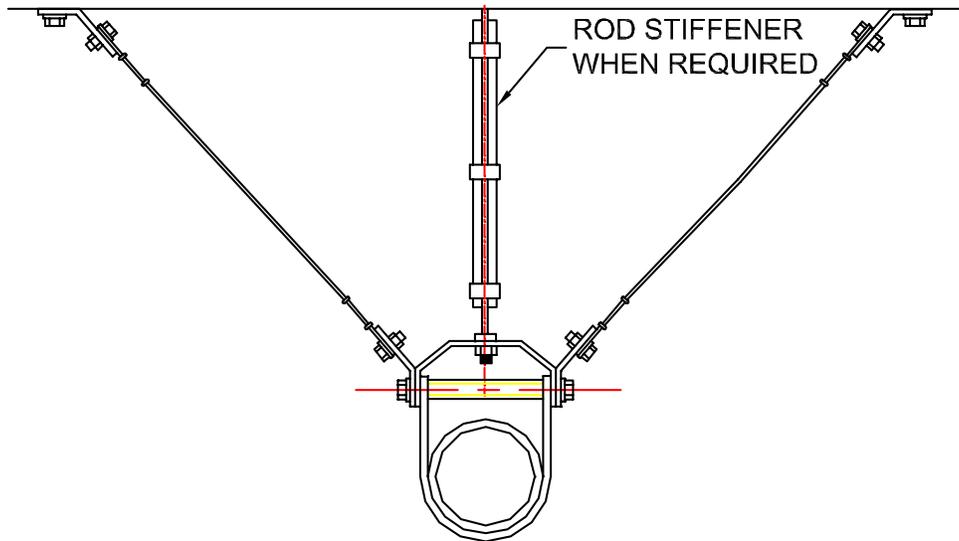


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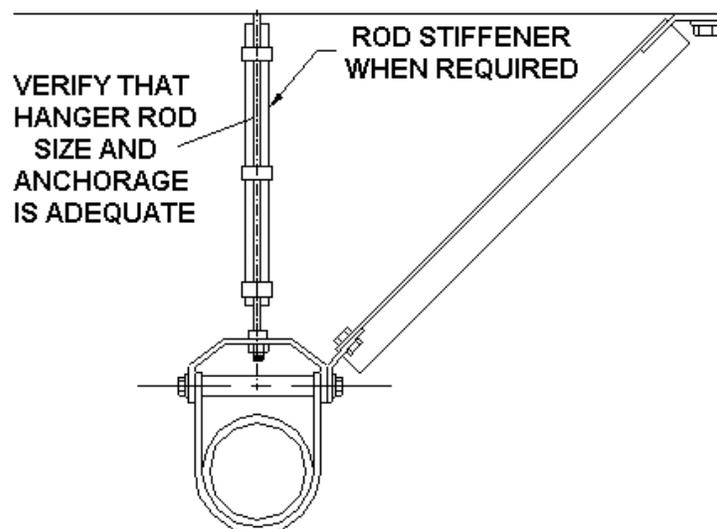
8) With longer hanger rods, rod stiffeners are likely to be required. Refer to the appropriate Document in Chapter D4 to determine: (1) if needed, (2) what size stiffener material is appropriate, and (3) how frequently it needs to be clamped to the hanger rod.

Figure D7.4.1-8; Rod Stiffener



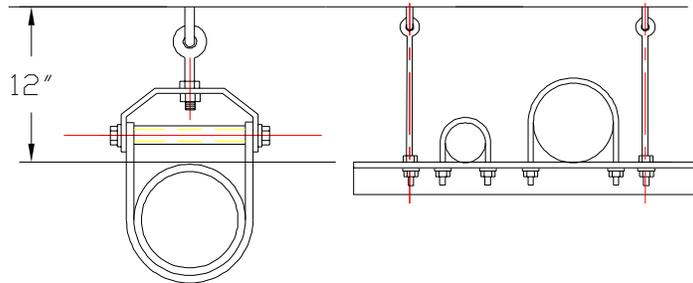
9) In addition to possibly requiring rod stiffeners, when struts are used to restrain piping, the size of the hanger rod and its anchorage also become critical. Again refer to the appropriate Document in Chapter D4 to determine the minimum allowable size for the hanger rod and anchor.

Figure D7.4.1-9; Hanger Rod Sizing (For Strut Applications)



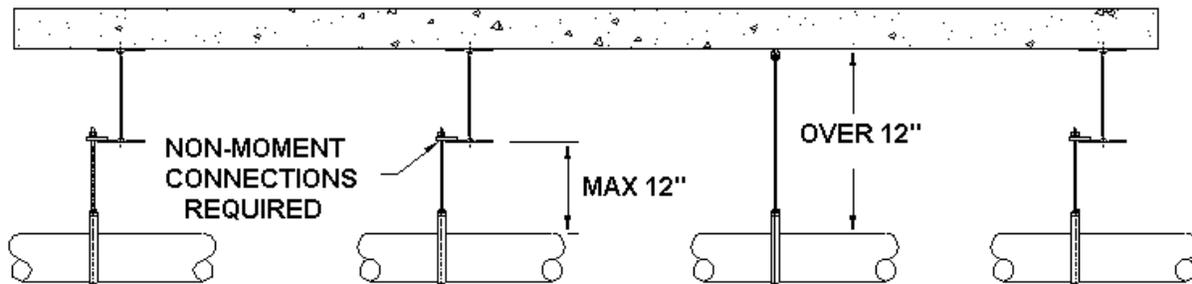
10) In some cases, it may be possible to locate the piping system close enough to the support structure (12") to eliminate the need for restraint. (Refer to the building code review chapter (D2) to determine if this exemption is applicable.) If it is applicable, the 12" dimension is measured as shown below. (Note also the required non-moment generating connection at the top of the hanger rod.)

Figure D7.4.1-10; 12" Hanger Rod Exemption



11) When using the above rule it is critical that all support locations in a run conform. If even one location exceeds 12", the run cannot be exempted from restraint.

Figure D7.4.1-11; Run Fails the Consistency Requirement for 12" Exemption



CEILING-SUPPORTED PIPE RESTRAINT ARRANGEMENTS

Although the basic principle of diagonal bracing is almost always used to design restraint systems, the actual arrangement of these systems can vary significantly. Despite what looks like substantially different designs, the design forces in the members remain the same, and the same rules apply when sizing components. Illustrated here are many different restraint arrangements, all of which can be used in conjunction with the design “rules” provided in this manual.

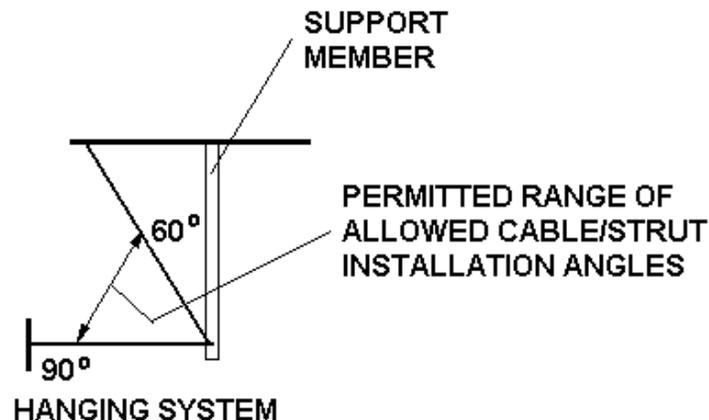
Details of the end connections and anchorage hardware are shown in subsequent sections of the manual. It is assumed in this manual that the restraint component is attached to a structural element capable of resisting the design seismic load.

Due to variations in the installation conditions such as structural clearance, locations of structural attachment points and interference with other pieces of equipment or systems, there will likely be significant benefits to using varying arrangements in different locations on the same job.

The only significant caution here is that it is not permissible to mix struts and cables on the same run.

This manual addresses diagonal bracing slopes of between horizontal and 60 degrees from the horizontal. Angles in excess of 60 degrees to the horizontal are not permitted.

Figure D7.4.2-1; Permissible Restraint Angles



When installing restraints, Transverse restraints should be installed perpendicular (± 10 degrees) to the pipe from above. Longitudinal restraints should be in line with the pipe, (± 10 degrees) again as viewed from above. All restraint cables should be aligned with each other. See the sketch below.

CEILING-SUPPORTED PIPE RESTRAINT ARRANGEMENTS

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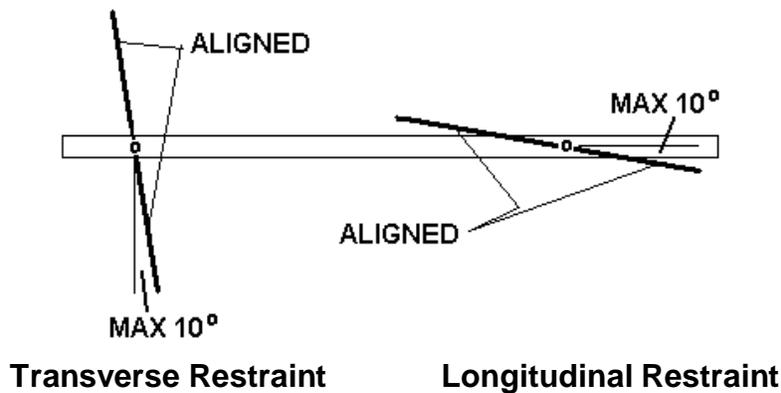
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Figure D7.4.2-2; Restraint Alignment



In general, when restraining piping the component actually being restrained is the support device for the pipe. This may be a pipe clevis, a heavy-duty pipe clamp, or a trapeze bar. Because the goal is to restrain the actual pipe, it is necessary that the restrained element be connected to the pipe in such a way as to transfer the appropriate forces between the two. For example, if an axial restraint is installed on a trapeze bar which in turn supports a pipe that is carried by a roller, it is obvious that the Longitudinal forces generated by the pipe cannot be restrained by the connection to the trapeze bar, and some other arrangement is needed.

When firmly connecting restraints to piping there are a few general rules that should be followed:

- 1) A basic pipe clevis is not capable of restraining a pipe in the axial direction.
- 2) If the pipe is wrapped with insulation and an axial restraint is needed, a riser clamp should be tightly clamped to the pipe prior to wrapping it with insulation and the restraint device should penetrate the insulation material.
- 3) If the pipe is wrapped with insulation and Transverse restraint is needed, a hardened insulation material should be fitted at the restraint location.
- 4) Piping which expands and contracts significantly should include expansion joints or loops between each axial restraint component.
- 5) Trapeze-mounted piping should be tightly clamped to the trapeze bar.

In addition, when sizing restraint components for multiple pipes, the total weight of all of the restrained piping must be considered.

Hanging Systems Restrained with Cables

CEILING-SUPPORTED PIPE RESTRAINT ARRANGEMENTS

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Hanging systems may include supports for single pipes or multiple pipes. Single pipes can be supported using clevis hangers but multiple pipes are normally supported on trapeze bars.

Transverse Restraint Examples

For a cable-restrained pipe supported by a hanger clevis, there are two common options for non-isolated installations and two similar options for isolated installations. These options are shown below. Note that the isolator is mounted with minimal clearance to the structure and that a travel limiting washer is fitted to the hanger rod just below the isolator in the isolated arrangements. While commonly used, the option of attaching restrains to the hanger rod introduces additional stress into the hanger rod because of the Force acting at the center of the pipe will rock the clevis back and forth on the hanger rod itself. While this is typically not a problem for smaller piping or for piping installed in areas where the seismic accelerations are low in magnitude, it is not the preferred arrangement when working with large piping or areas of the world where seismic forces are significant. In these cases the option of attaching the restrains directly to the cable clevis is preferred. Not shown below is a third option whereby a separate heavy duty riser clamp is fitted to the pipe adjacent to a clevis hanger and it is used as the attachment point for the restraint cable.

Figure D7.4.2-3; Transverse Cable Restraints clamped to Hanger Rod and attached to Clevis Tie Bolt (Non-isolated)

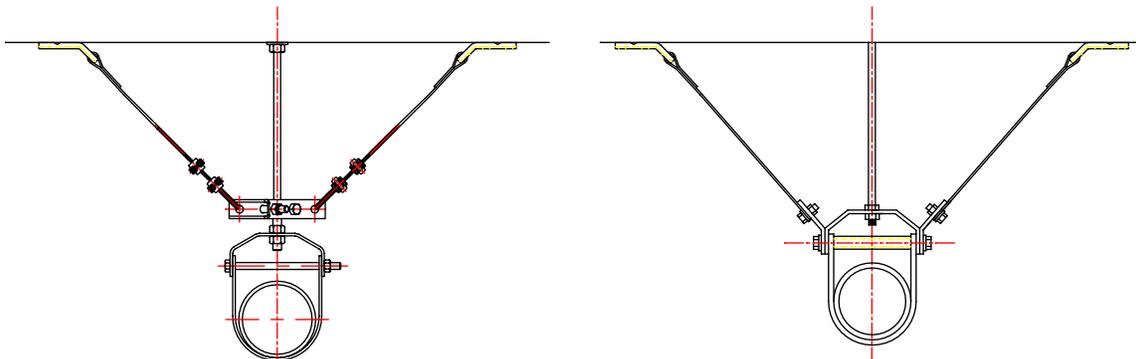


Figure D7.4.2-4; Transverse Cable Restraints clamped to Hanger Rod and attached to Clevis Tie Bolt (Isolated)

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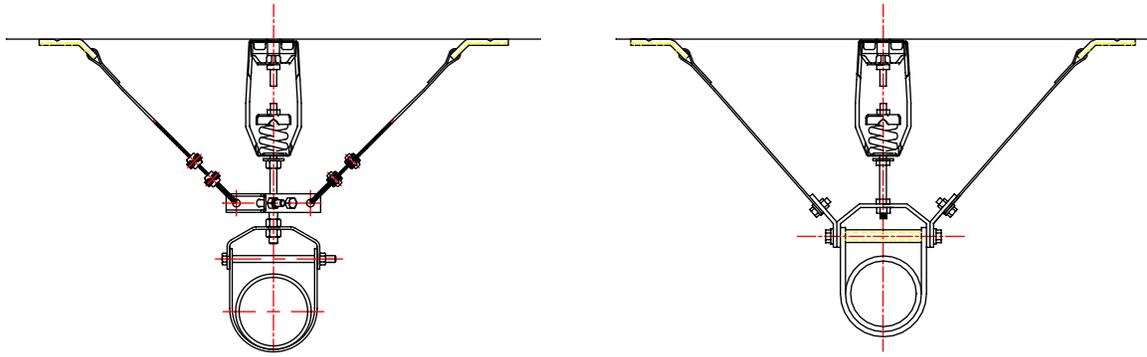
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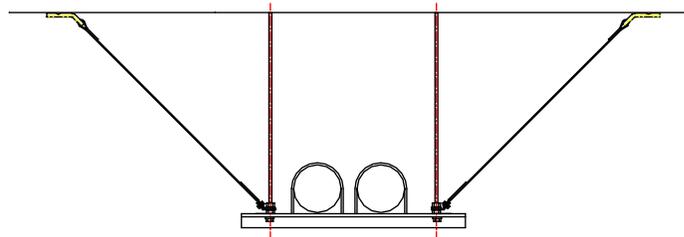
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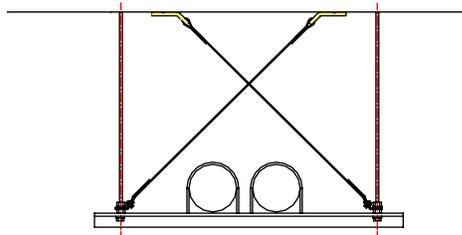
When working with trapezed piping, there are many options that exist for the arrangement of transverse restraints. Shown below are three options each for both non-isolated and isolated cable-restrained systems.

Figure D7.4.2-5; Transverse Cable Restraints Mounted to a Trapeze (Non-isolated)

TRAPEZE _/ (TOP)



TRAPEZE X (TOP)



TRAPEZE V (TOP)

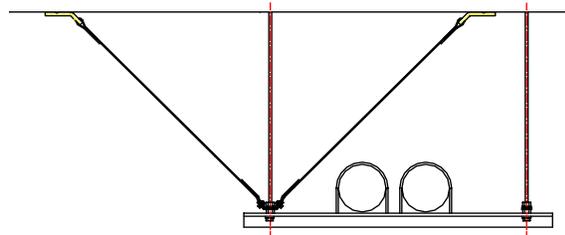


Figure D7.4.2-6; Transverse Cable Restraints Mounted to a Trapeze (Isolated)

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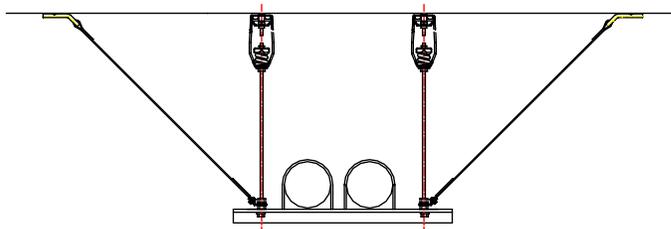
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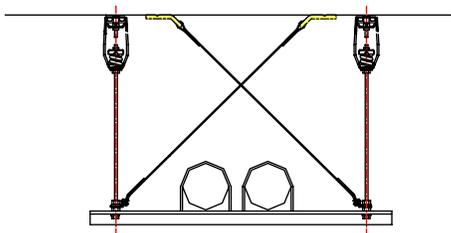
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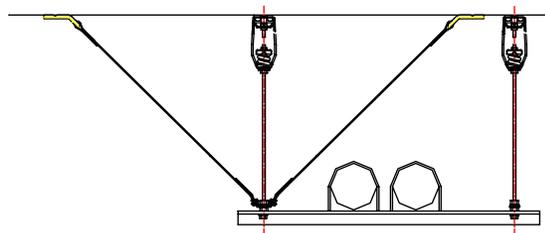
TRAPEZE _/ (TOP)



TRAPEZE X (TOP)



TRAPEZE V (TOP)



Longitudinal Restraint Examples

Longitudinal restraints cannot be connected to a standard pipe clevis. This is because the only longitudinal resistance present between the clevis and the piping is the friction that results from the weight of the pipe and this is simply not enough to transfer the forces in the pipe to the restraint. When longitudinally restraining piping, a U-Bolt to a trapeze or riser clamp tightly attached to the pipe are the most common interfacing devices used. On occasion, weld-on tabs or connections to a flange are also possibilities in some cases. Details on these connections will be addressed in later sections.

If the details of the connection are ignored at this point, general longitudinal restraint arrangements recognized in this manual are illustrated below.

Note: Longitudinal restraints should be installed in such a manner that they act along the centerline of the pipe in the case of an individual pipe or on the center of mass of a trapeze bar if there are multiple pipes attached to that trapeze bar. This is because offsetting the restraint from the center of mass will generate additional bending forces in the restrained pipe which can add to complications and failures.

Figure D7.4.2-7; Longitudinal Cable Restraints (Non-isolated)

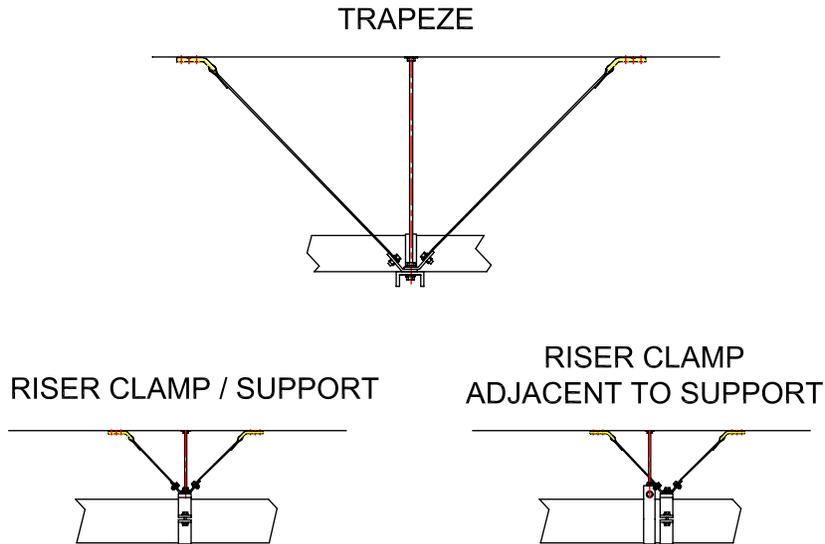
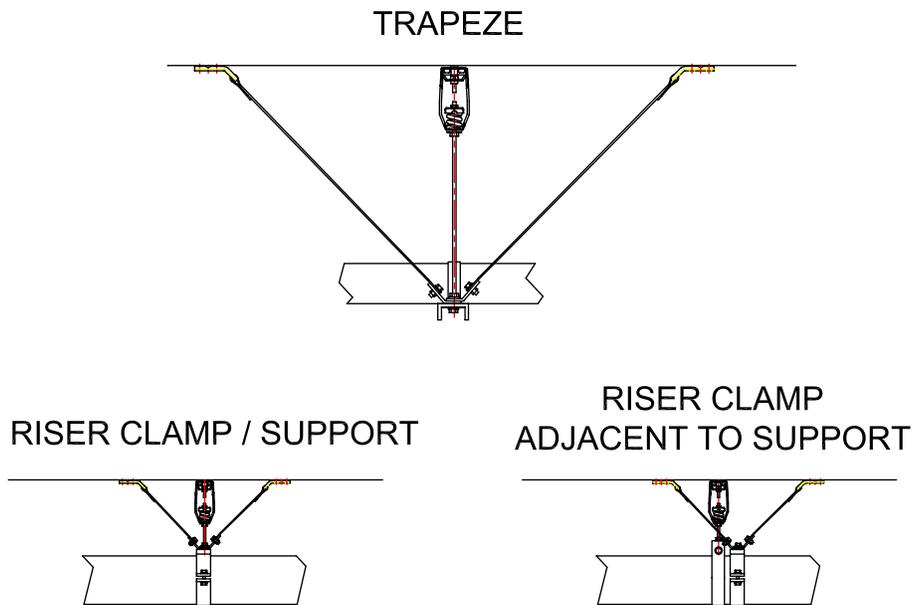


Figure D7.4.2-8; Longitudinal Cable Restraints (Isolated)



CEILING-SUPPORTED PIPE RESTRAINT ARRANGEMENTS

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Hanging Systems Restrained with Struts

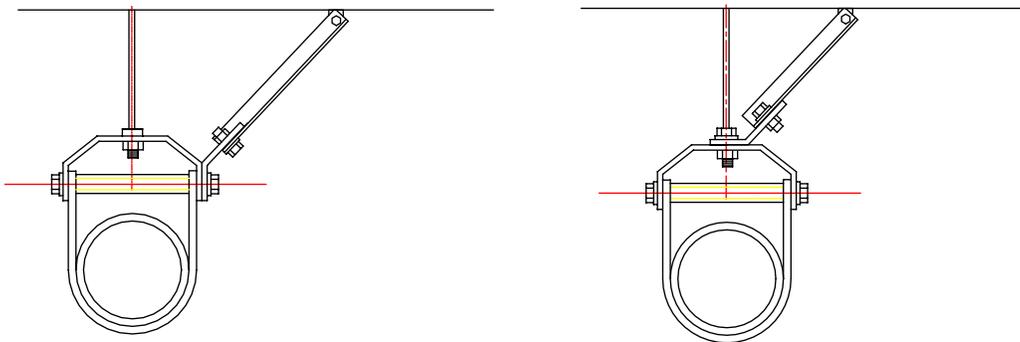
It is recommended that struts not be used to restrain isolated piping systems. Struts will generate hard connections between the piping and structure and will greatly reduce the efficiency of the isolation system. Having said that, in some special situations it may be possible to design restraint struts with integral isolation elements, but this is tedious and should be avoided unless drastic measures are required.

As with cable restraints, hanging systems may include supports for single pipes or multiple pipes. Single pipes can be supported using clevis hangers, but multiple pipes are normally supported on trapeze bars.

Transverse Restraint Examples

For a strut-restrained pipe supported by a hanger clevis there are two common options. One is to connect the restraint to the clevis bolt and the other is to connect the restraint to the hanger rod. These are shown below. A third option of fitting a heavy duty riser clamp adjacent to the clevis bracket and attaching the strut to it is viable as well.

Figure D7.4.2-9; Typical Transverse Restraint Strut Arrangements for Clevis-Supported Pipe



Shown below are 3 options for trapeze-supported piping. All are equivalent.

Figure D7.4.2-10; 3 Arrangements for Transversely Restrained Trapezes with Struts

CEILING-SUPPORTED PIPE RESTRAINT ARRANGEMENTS

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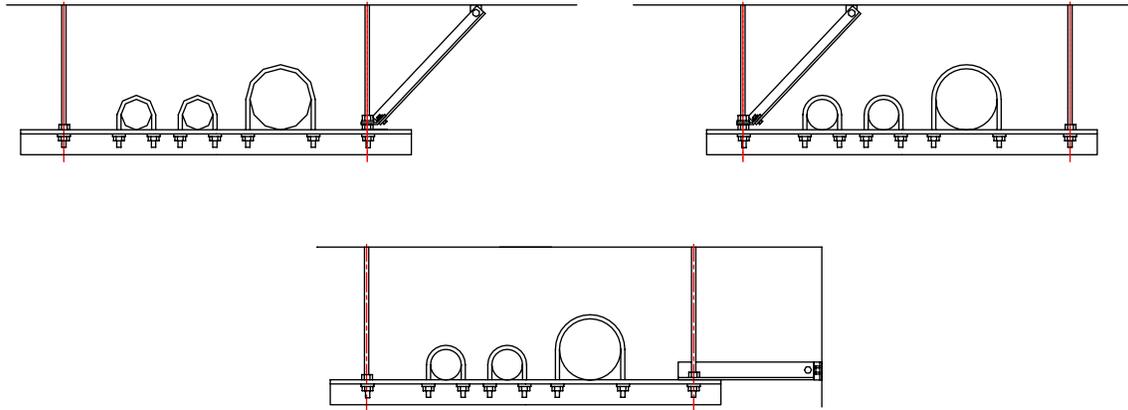
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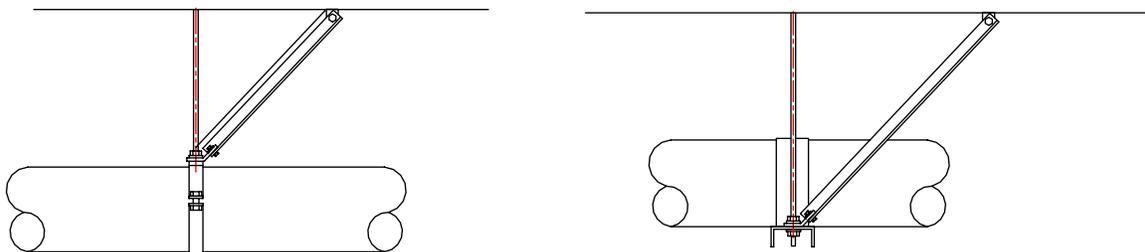
Longitudinal Restraint Examples

As with cables, longitudinal restraints using struts cannot be connected to a standard pipe clevis. When longitudinally restraining piping, a trapeze U-bolted or a riser clamp tightly attached to the pipe is the most common connecting device between the component actually restrained by the strut and the pipe itself. A weld-on tab or connection to a flange can also be used. Details on these connections will be addressed in later sections.

As with the cable section earlier, if we ignore the details of the connection at this point, common longitudinal restraint arrangements recognized in this manual are illustrated below.

As with the cable restraints, Longitudinal restraints should be installed in such a manner that they act along the centerline of the pipe in the case of an individual pipe or on the center of mass of a trapeze bar if there are multiple pipes attached to that trapeze bar. This reduces the forces that generate bending in the restrained piping that result from an offset between the restraint and the center of mass. Depending on the situation, these forces can be large and can generate failures in the piping itself.

Figure D7.4.2-11; Piping Longitudinally Restrained with Struts



CEILING-SUPPORTED PIPE RESTRAINT ARRANGEMENTS

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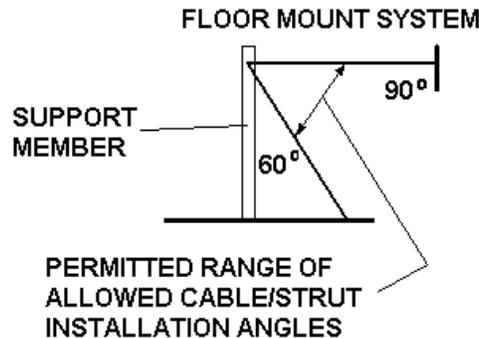
FLOOR OR ROOF SUPPORTED PIPE RESTRAINT ARRANGEMENTS

Although the basic principle of diagonal bracing is almost always used to design restraint systems, the actual arrangements of these systems can vary significantly. Despite what looks like substantially different designs, the design forces in the members remain the same, and the same rules apply when sizing components. Illustrated here are many different floor- and roof-mounted restraint arrangements, all of which can be used in conjunction with the design “rules” provided in this manual.

Details of the end connections and anchorage hardware are shown in subsequent sections of this manual. It is assumed in this manual that the restraint component is attached to a structural element capable of resisting the design seismic load.

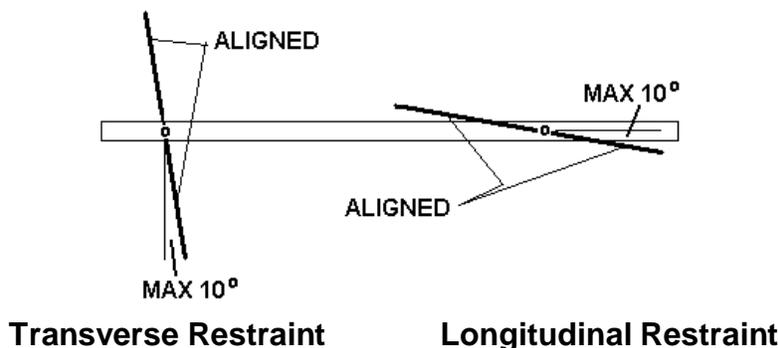
This manual addresses diagonal bracing oriented between horizontal and 60 degrees from the horizontal. Angles in excess of 60 degrees to the horizontal are not permitted.

Figure D7.4.3-1; Permissible Restraint Angles



When installing restraints, Transverse restraints should be installed perpendicular (± 10 degrees) to the pipe from above. Longitudinal restraints should be in line with the pipe, (± 10 degrees) again as viewed from above. All restraint cables should be aligned with each other. See the sketch below.

Figure D7.4.3-2; Restraint Alignment



FLOOR OR ROOF SUPPORTED PIPE RESTRAINT ARRANGEMENTS

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In general, when restraining piping the component actually being restrained is the support device for the pipe. This may be a pipe clevis, a heavy-duty pipe clamp, or a trapeze bar. Because the goal is to restrain the actual pipe, it is necessary that the restrained element be connected to the pipe in such a way as to transfer the appropriate forces between the two. For example, if an axial restraint is installed on a trapeze bar which in turn supports a pipe that is carried by a roller, it is obvious that the Longitudinal forces generated by the pipe cannot be restrained by the connection to the trapeze bar, and some other arrangement is needed.

When firmly connecting restraints to piping there are a few general rules that should be followed:

- 1) A basic pipe clevis is not capable of restraining a pipe in the axial direction.
- 2) If the pipe is wrapped with insulation and an axial restraint is needed, a riser clamp should be tightly clamped to the pipe prior to wrapping it with insulation and the restraint device should penetrate the insulation material.
- 3) If the pipe is wrapped with insulation and Transverse restraint is needed, a hardened insulation material should be fitted at the restraint location.
- 4) Piping which expands and contracts significantly should include expansion joints or loops between each axial restraint component.
- 5) Trapeze-mounted piping should be tightly clamped to the trapeze bar.

In addition, when sizing restraint components for multiple pipes the total weight of all of the restrained piping must be considered.

D7.4.3.1 Floor or Roof mounted Systems Restrained with Cables

Floor- or roof-mounted systems may include supports for single pipes or multiple pipes. Typically, simple box frames are fabricated to support piping, whether it is a single pipe or multiple pipes.

Transverse Restraint Examples

For a cable-restrained pipe support bracket there are four options normally encountered for non-isolated systems and four similar arrangements for isolated systems. These options are shown below. The vertical legs of the support bracket must be sized to carry both the weight load of the supported pipes as well as the vertical component of the seismic forces. Refer to Chapter D4 for more detailed information as to how to size these members.

Figure D7.4.3-3; Transverse Cable Restraints for Floor/Roof (Non-isolated)

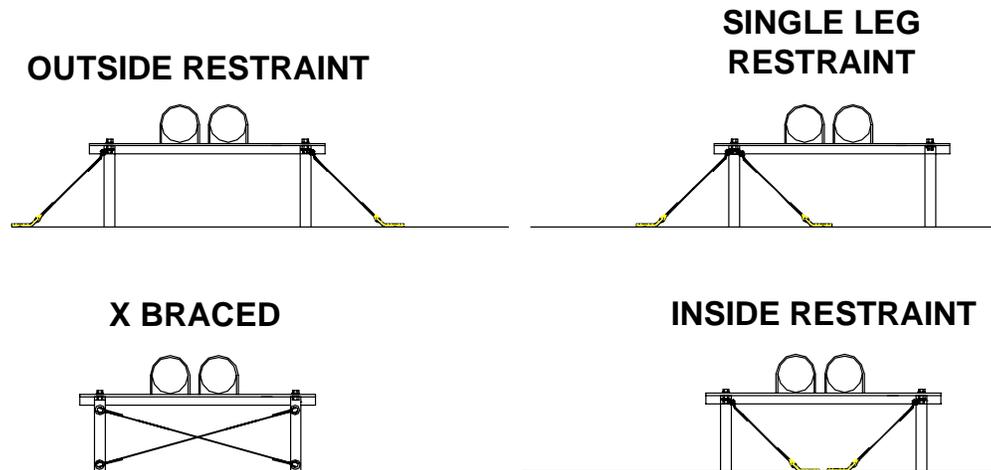
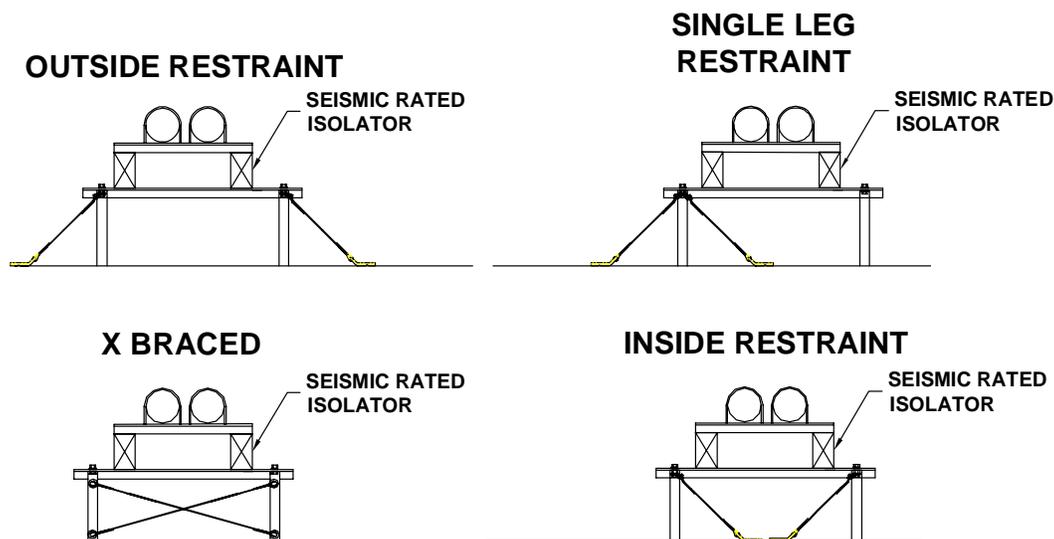


Figure D7.4.3-4; Transverse Cable Restraints for Floor/Roof (Isolated)



Longitudinal Restraint Examples

When longitudinally restraining piping, a U-Bolt to a trapeze or riser clamp tightly attached to the pipe are the most common interfacing devices used. On occasion, weld-on tabs or connections to a flange are also possibilities in some cases. Details on these connections will be addressed in later sections.

If the details of the connection are ignored at this point, general longitudinal restraint arrangements recognized in this manual are illustrated below.

FLOOR OR ROOF SUPPORTED PIPE RESTRAINT ARRANGEMENTS

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Note: Longitudinal restraints should be installed in such a manner that they act along the centerline of the pipe in the case of an individual pipe or on the center of mass of a trapeze bar if there are multiple pipes attached to that trapeze bar. This is because offsetting the restraint from the center of mass will generate additional bending forces in the restrained pipe which can add to complications and failures.

Figure D7.4.3-5; Longitudinal Cable Restraints (Non-isolated)

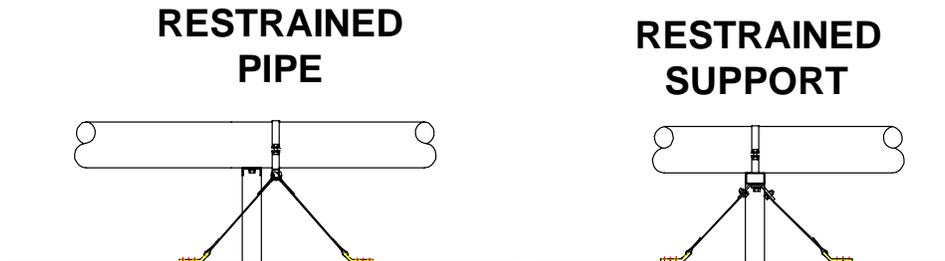
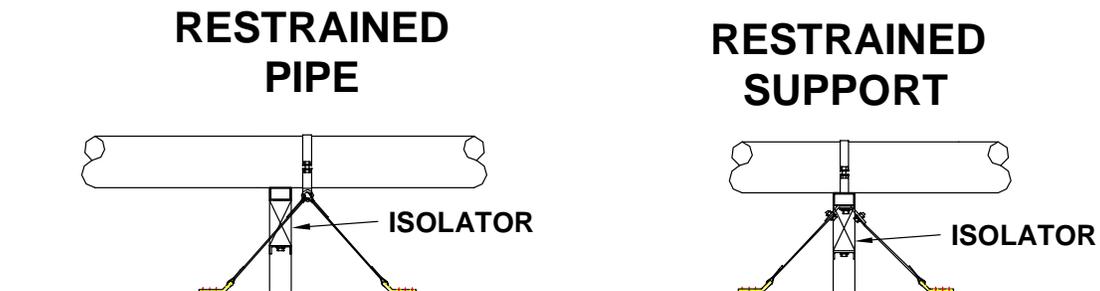


Figure D7.4.3-6; Longitudinal Cable Restraints (Isolated)



D7.4.3.2 Floor or Roof Mounted Systems Restrained with Struts

As with cable restraints, floor- or roof-mounted pipe support systems will normally involve a box frame that supports the piping (single or multiple) with some kind of a trapeze bar.

Transverse Restraint Examples

For a strut-restrained pipe supported by a box frame there are three common transverse restraint options. Two involve diagonal bracing to the deck and one is to connect the restraint to a vertical wall or structure. Examples are shown below.

Figure D7.4.3-7; Typical Transverse Restraint Strut Arrangements for Pipe (Non isolated)

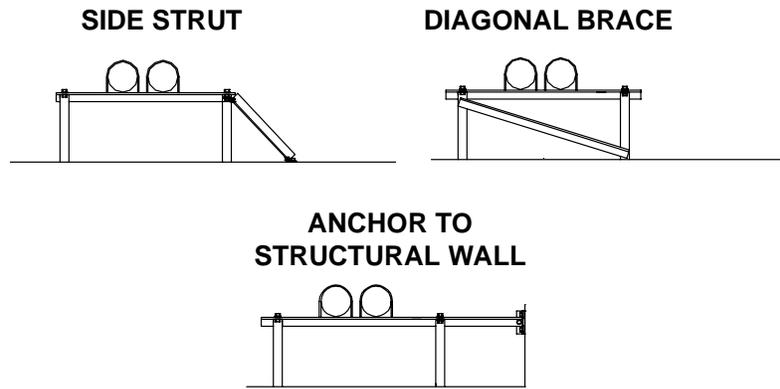
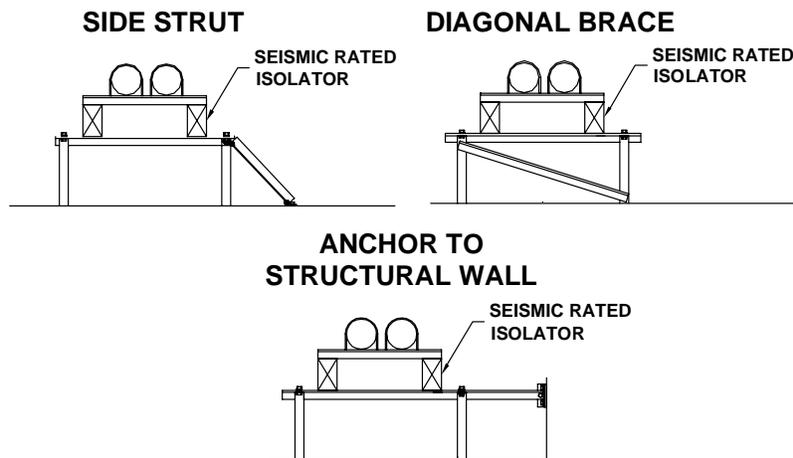


Figure D7.4.3-8; Typical Transverse Restraint Strut Arrangements for Pipe (Isolated)



Longitudinal Restraint Examples

When longitudinally restraining piping, a trapeze U-bolted or a riser clamp tightly attached to the pipe is the most common connecting device between the component actually restrained by the strut and the pipe itself. A weld-on tab or connection to a flange can also be used. Details on these connections will be addressed in later sections.

Ignoring the details of the connection at this point, common longitudinal restraint arrangements recognized in this manual are illustrated below.

As with the cable restraints, longitudinal restraints should be installed in such a manner that they act along the centerline of the pipe in the case of an individual pipe or on the center of mass of a trapeze bar if there are multiple pipes attached to that trapeze bar. This reduces the forces that generate bending in the restrained piping that result from an offset between the restraint and the center of mass. Depending on the situation, these forces can be large and can generate failures in the piping itself.

Figure D7.4.3-9; Piping Longitudinally Restrained with Struts (Non-isolated)

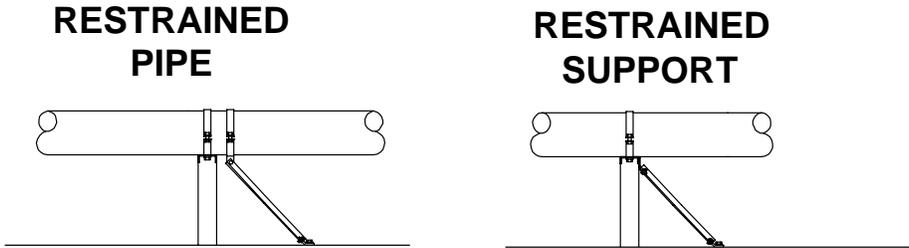
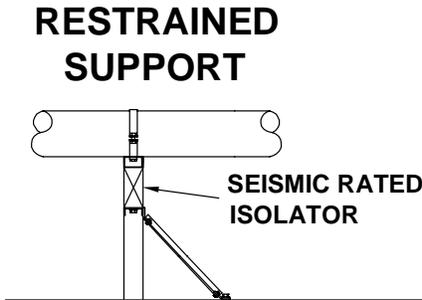


Figure D7.4.3-10; Piping Longitudinally Restrained with Struts (Isolated)



VERTICAL PIPE RUN RESTRAINT ARRANGEMENTS

Vertical runs of piping need to be restrained in the same manner as horizontal runs. The anchorage provided for the riser system will normally, but not always, have enough capacity to resist the maximum longitudinal (vertical) seismic load. If anchors were selected based on simple deadweight loads and included little or no overload capacity, the possibility exists that they might have to be upsized to meet the seismic requirements. Because the seismic requirements would be low as compared to the support loads, upsizing the anchor by one step is normally more than adequate to meet these requirements. The required capacity of transverse (horizontal) restraints (guides) would, however, be closely linked to the seismic forces.

Cables or struts are not normally used restrain riser systems. Instead the risers resistance to seismic accelerations is controlled by special guide and anchor components. In non-seismic applications, these parts are put in place to limit the buckling factors that are generated in the piping by gravity factors. These are very similar to the forces generated in horizontally oriented piping by earthquakes.

Spacing for restraints on risers must meet the same maximum span condition that applies to horizontal runs, but in most instances the spacing used to place these items for resistance to typical buckling loads will meet this requirement.

Having indicated that the spacing will likely not be a concern based on conventional riser design practices the capacity of the guides can be impacted. These must be adequate to withstand the higher seismic forces. Applicable seismic forces for risers are the same as for horizontal runs and more detail on how to determine these can be found in chapter D4.

Typical Axial Restraint Arrangements

Below are illustrations for longitudinal (vertical only) pipe restraints. A simple riser clamp can often act as a Longitudinal restraint. It need not be attached to the structure to perform the axial restraint function as the vertical weight loads will always be larger than the seismically generated uplift loads. The same basic arrangement will work for either non-isolated or pad-isolated systems and for attachment to concrete or steel. It should be noted however that these components will not offer any transverse (horizontal) restraint.

VERTICAL PIPE RUN PIPE RESTRAINT ARRANGEMENTS

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Figure D7.4.4-1; Concrete Supported Longitudinal Restraint for Vertical Pipe Run

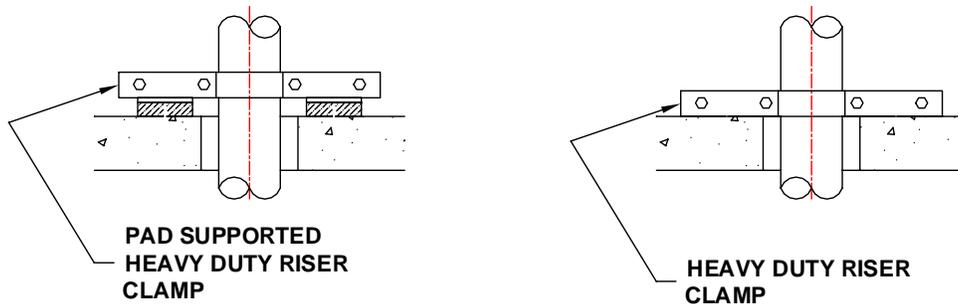
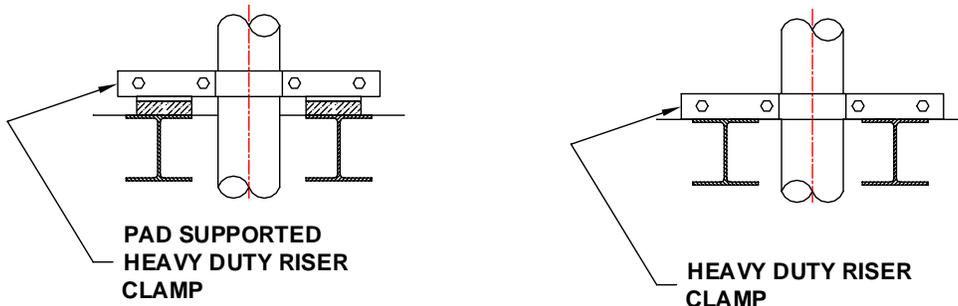


Figure D7.4.4-2; Steel Supported Longitudinal Restraint for Vertical Pipe Run

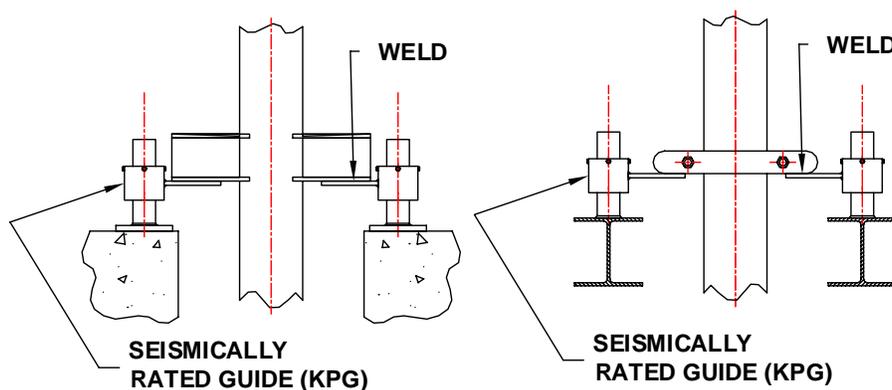


Typical Transverse Restraint Arrangements

Pipe guides act as Transverse restraints only and have a rated force capacity that is based on loads in the horizontal axis. These components do not offer any Longitudinal restraint capabilities.

There are two typical guide types. The first includes a component hard mounted to the structure, a mating portion hard mounted to the pipe, and a slip fit connection between the two. This is shown below.

Figure D7.4.4-3; Supported Transverse Restraint (Guide) for Vertical Pipe Run



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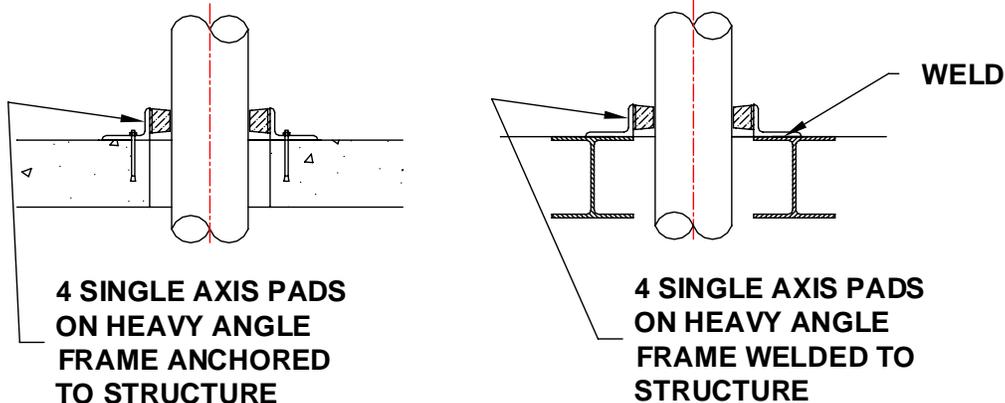
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The second type is comprised of a frame with cushioned pads located on the perimeter that bear directly against the pipe itself. This eliminates the need for a direct connection to the pipe. However, if the pipe is insulated, it does require that the insulation be adequately hardened or that a hard shield be provided to prevent damage to the insulation under seismic loads. Typical concrete slab and steel structural examples are shown below.

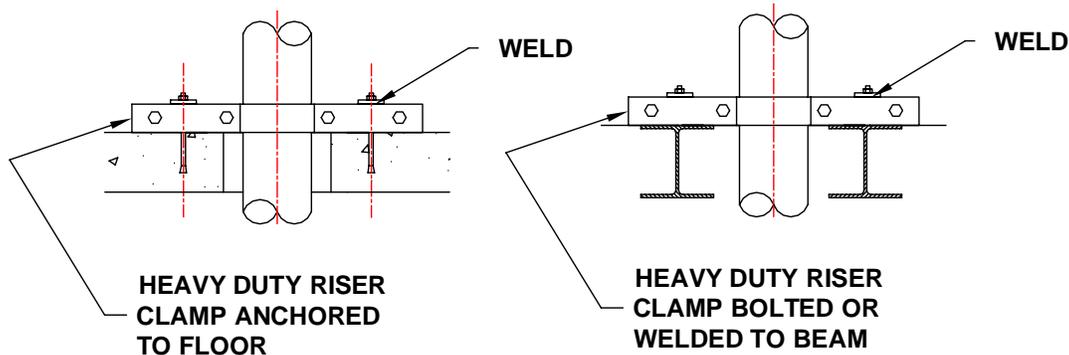
Figure D7.4.4-4; Perimeter Type Transverse Restraint (Guide) for Vertical Pipe Run



Combined Lateral and Axial Restraints

In addition to the above details showing independent axial and lateral restraint devices, there are several devices used in vertical runs of pipe that offer both of these together. Anchors for riser systems are the first of these and several types are illustrated below:

Figure D7.4.4-5; Simple Hard-mounted Riser Clamp



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Figure D7.4.4-6; Simple Hard-mounted Riser Clamp

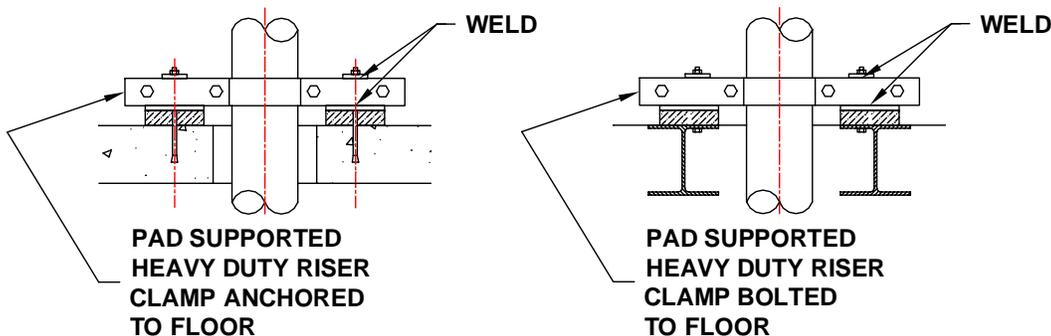
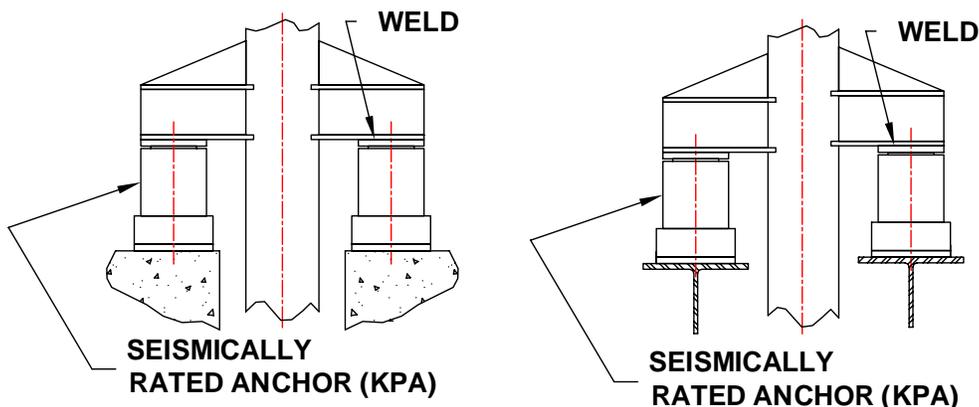
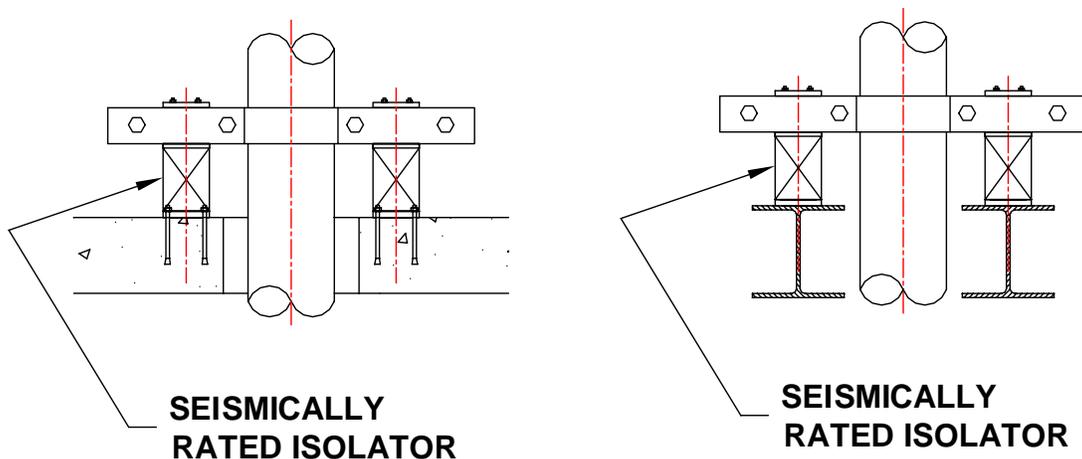


Figure D7.4.4-7; Riser Mounted on Cushioned Rated Anchor



The final combination axial and lateral restraint is a seismically rated, floor-supported isolator.

Figure D7.4.4-8; Riser Piping Mounted on Floor-Mounted Seismically-Rated Isolator



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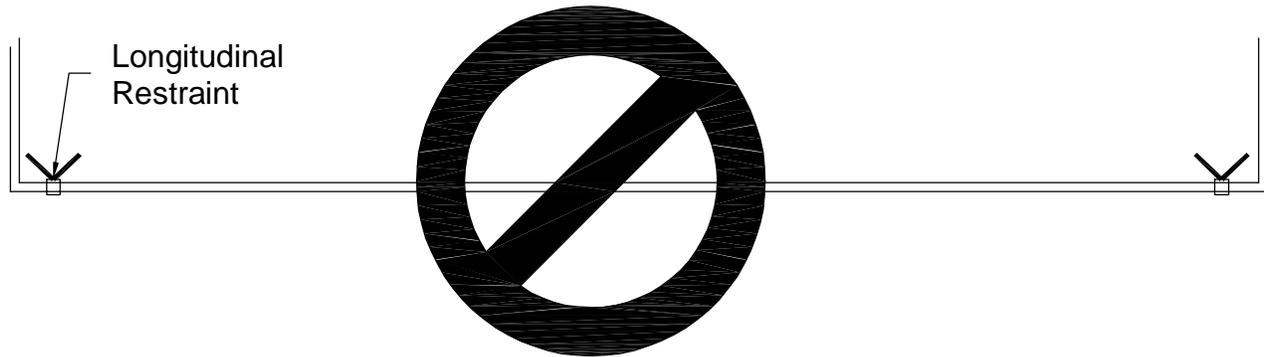


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LONGITUDINAL RESTRAINT OF STEAM OR HOT WATER PIPING

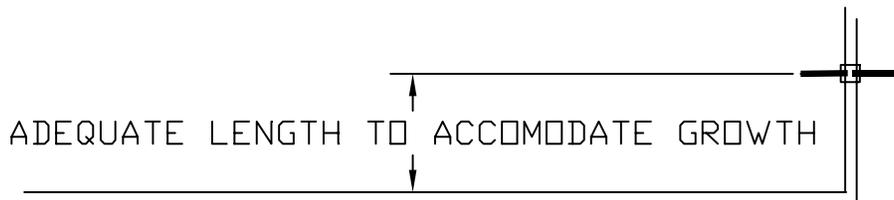
The Axial Restraint of Steam Piping raises important design configuration issues. As the pipe length grows with the temperature, the use of more than one restraint on any individual run will resist this growth and will either cause the pipe to buckle or will result in the failure of the restraint. This is unacceptable.

Figure D7.4.5-1; Limit Longitudinal Restraints to 1 per Run



For short runs, a single Longitudinal restraint should be used and caution should be exercised to ensure that if restraints are fitted at the junction points of different runs, they do not fall at both ends of the same run. Caution should also be exercised to be sure that there is adequate length between corners and the first Transverse restraint on a run to allow for the growth that can occur on the adjacent run.

Figure D7.4.5-2; Ensure Adequate Corner Spacing when Fitting Transverse restraints to Allow Growth in Adjacent Run



For long runs that require more than 1 Longitudinal Restraint, a device must be fitted into the run to absorb expansions and contractions between the restraint locations. This can take the form of an expansion loop or an expansion compensator as illustrated below.

If an expansion loop is fitted, the middle leg of the loop requires Longitudinal restraint as well. Because this restricts its movement, some caution must be used to ensure that the legs on each side of the loop are adequate to absorb the expansion for their respective runs. If the

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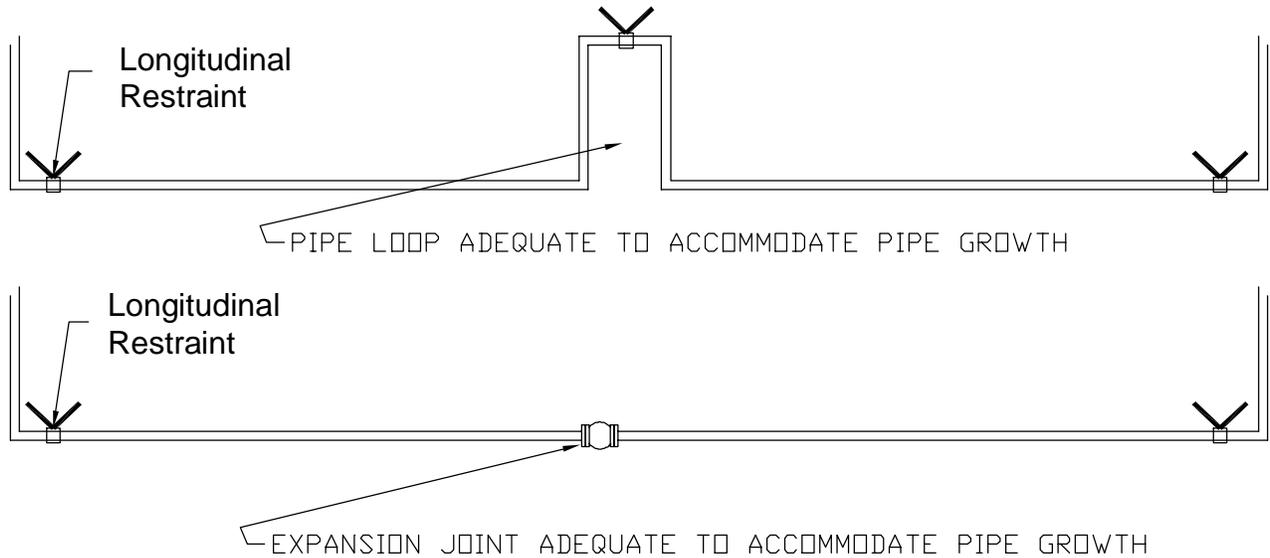
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distance between the loop and the restraints on adjacent runs is approximately the same the system will be balanced and both legs will bend about the same. If the dimensions to the axial restraints vary significantly, the distortion of the two different legs will vary from one another in direct proportion and this should be addressed in design. Kinetics is not responsible for the design of these loops.

Figure D7.4.5-2; Longitudinal Restraints on Expansion Loops



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TRANSFERRING FORCES (PIPING RESTRAINTS)

In order for a restraint system to do its job, all elements of the connections need to be sized and installed properly. Because of the large variety and quantity of interfacing conditions in any given installation, piping, duct, and electrical distribution systems are particularly prone to problems in this area.

The next several sections of this manual will deal with specific components used to clamp cable ends together, or anchor cables or struts to steel members, wood members, and concrete or masonry. There are several types of connections used for each of these conditions, and each type of connection requires some degree of care and understanding to achieve full capacity.

There are a few general rules that apply when adding restraints to systems. These are listed below along with a few comments meant to provide a basic understanding or rationale.

- 1) Friction generally cannot be counted on when dealing with dynamic, seismic load conditions. Connections, with the following exceptions, should be positive in nature and not require friction to ensure their continued long-term operation.

Exceptions:

A) Cable end connections (swaged ends, U-bolts, QuakeLocs can be used with appropriate installation procedures).

B) Toothed strut nuts used in conjunction with a purpose-designed strut material (Unistrut, for example). *(Rationale: Permitted friction connections have been well researched and deal with a narrow range of applications. In addition, once properly tightened, the components are such that the likelihood of their coming loose as a result of seismic load conditions is very low.)*

- 2) Anchors used for the support of overhead equipment cannot also be used for the anchorage of seismic restraints. *(Rationale: The loads used to size hanger rods and anchors are based on the weight loads generated by the piping system. Seismic forces can increase the tensile loads significantly, and the combination of loads can cause the anchorage to fail.)*
- 3) Anchors to concrete must comply with minimum edge distance, spacing and slab thickness requirements. To achieve full capacity ratings they must further not be installed into a surface containing significant tensile forces. *(Rationale: All anchorage must be in compliance with ICC allowables for seismic applications. Unless otherwise noted, it is assumed that connections are not made to the underside of structural concrete beams.)*
- 4) Screws attached to wood must comply with minimum edge distance, spacing and embedment requirements, and must further not be embedded into the end grain of the

TRANSFERRING FORCES (PIPING RESTRAINTS)

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wooden member. *(Rationale: All wood anchorage must be in compliance with NDS allowables for seismic applications. Full capacity can only be achieved with adequate embedment, end, and edge distances into the side grain of structural wood members.)*

- 5) Connections that have the potential to expose open bar joist chords to significant lateral loads perpendicular to their primary axis are not permitted. *(Rationale: Open joists are notoriously weak at 90 degrees to their long axis. They are not designed to take loads in this direction, particularly on the lower cord. Even light lateral loads can generate buckling and quickly cause catastrophic failure.)*
- 6) Connections that have the potential to generate significant lateral loads on the weak axis of I-beams or channels used as joists or columns are not permitted unless approved by the structural engineer of record. *(Rationale: Floor or roof support beams are significantly weaker in their minor axis than in their major axis. While they can, under some conditions, withstand some lateral loads, the engineer of record should be consulted to ensure that capacity exists on particular members to withstand the anticipated loads. If these loads are exceeded, catastrophic failures can quickly result.)*
- 7) Holes should not be added to key structural members without prior authorization from the engineer of record. *(Rationale: The addition of holes, particularly in flanges, can greatly reduce the structural capacity.)*
- 8) The pipe-to-pipe connection can become a critical factor in evaluating the performance of the system. Unless otherwise informed, Kinetics Noise Control assumes connections to be of “medium” deformability as defined by the design code. This is generally appropriate for steel or welded fittings, brazed connections. The use of groove-type coupling, cast iron couplings, glass lined pipe, Plastic or other non-standard materials will impact this and must be addressed during the design stage. *(Rationale: While generic data is available for some of these materials, it is not for groove-type or other specialty couplings and the specifying agency, prior selecting this type of hardware, must obtain the approval of the coupling manufacturer for its use in a seismic application.)*

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NON-MOMENT GENERATING CONNECTIONS

The IBC codes allow the omission of seismic restraints for piping, conduit and ductwork runs under many conditions without regard to size but that are located within 12" of the structure. Refer also to section D2 of this manual for specific exemptions by code version. This figure is 6" for fire sprinkler piping. In order to qualify for this, the following parameters must be met:

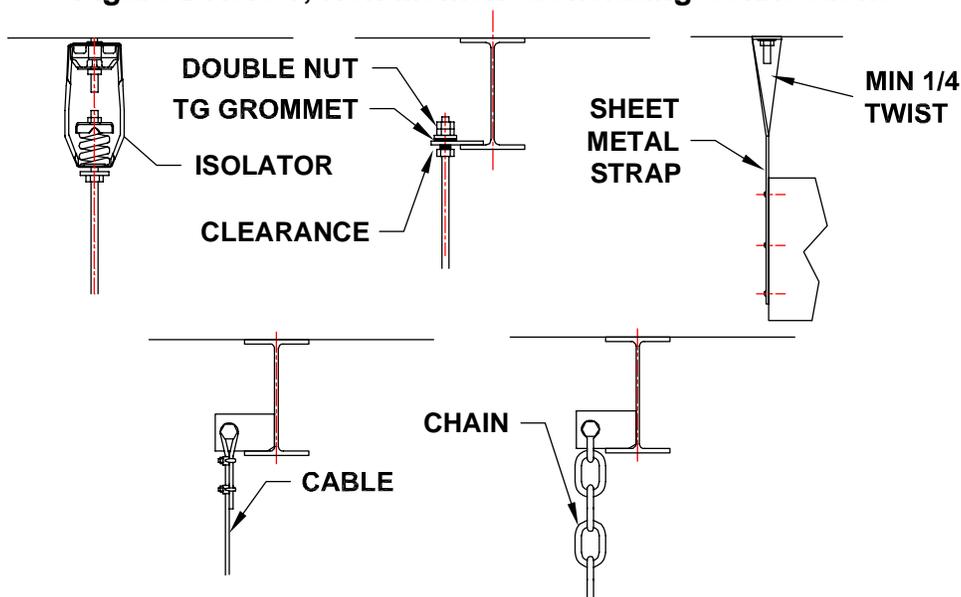
- 1)The length of **all** supports on the run measuring from the top anchorage point to the connection point to the trapeze bar or the top of a singly supported pipe or conduit run must not exceed 12" (6" for fire piping).
- 2)Unrestrained free travel of the supported system must be such that over the course of its movement, contact is not made with any other system, component or structural element that can result in damage to either the supported system or the object it hit.
- 3)The top connection to the structure must include a Non-Moment generating connection to prevent damage to the hanger rod or support strap.

A Non-Moment generating connection is any device that would allow a free flexing action of the hanger rod or support strap for an unlimited number of cycles without its being weakened. This motion must be permitted in any direction.

Shown below are typical examples of acceptable Non-Moment generating connections. Any other device that allows the same freedom of motion is equally acceptable.

A hanger rod rigidly embedded into the underside of a concrete structural slab is not.

Figure D7.5.5-1; Non-Moment Generating Connections



NON-MOMENT GENERATING CONNECTIONS

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CONNECTION OPTIONS FOR AWKWARD SITUATIONS

Almost every project will include some areas where installing restraints in a conventional fashion will be difficult. This segment of the manual offers options to consider when confronted with various situations.

D7.6.1 Long, Narrow Hallways

Probably the most common issue in the field is how to deal with transverse restraints in long, narrow hallways. Normally there is considerable congestion in these areas and not enough room to angle restraints up to the ceiling structure. Often the walls are not structural and do not offer a surface to which to anchor.

When evaluating halls, the first issue is to determine if either of the walls of the hall is structural. If either wall is structural, it offers a surface to which the restraints can often be attached. For structural walls, any relative displacement issues between the wall and the structure supporting the pipe must be identified. The maximum permitted relative displacement is ¼ inch, which for most structures correspond to a difference in elevation of approximately 2 feet (see also the Structural Attachment Section of this chapter).

Assuming the wall meets both of the above requirements, a transverse restraint can be run either directly over to the wall or up at a slight angle to the wall. Normally this would be done with a strut as shown below.

Figure D7.6-1; Trapeze-Mounted Piping Restrained to Structural Wall or Column with a Horizontal Strut

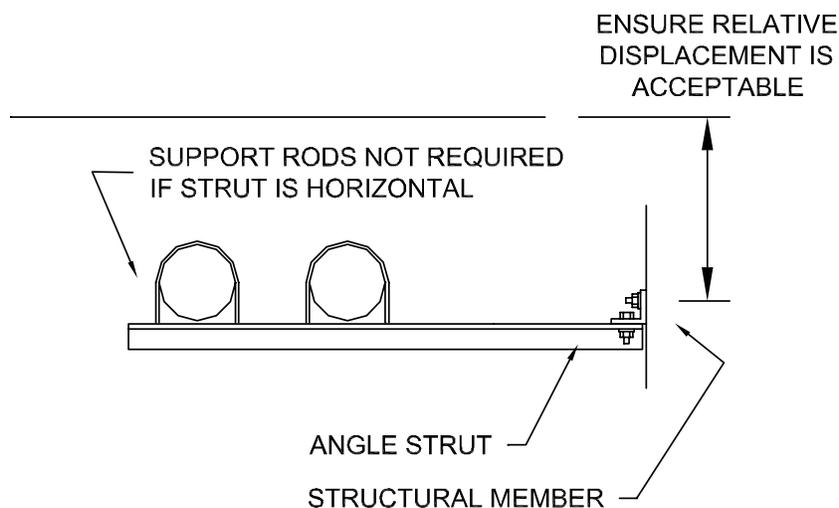


Figure D7.6-2; Trapeze-Supported Piping Restrained to Structural Wall or Column with an Sloping Strut

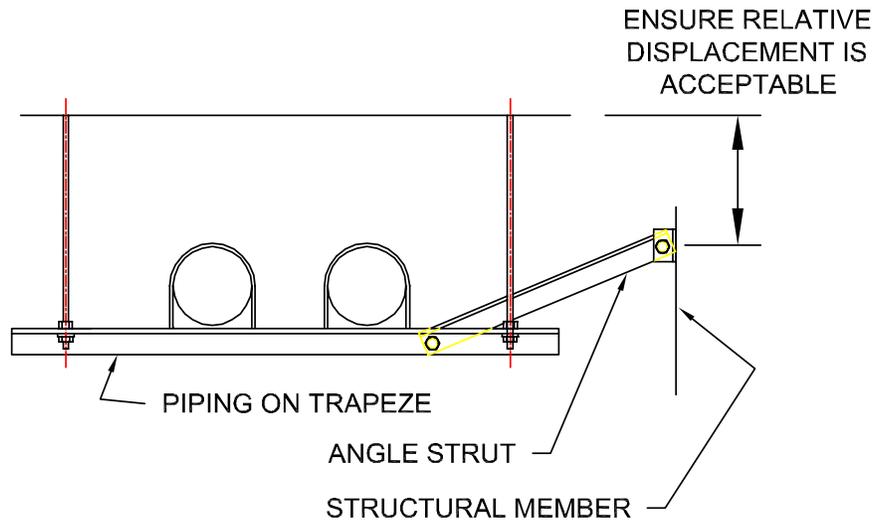
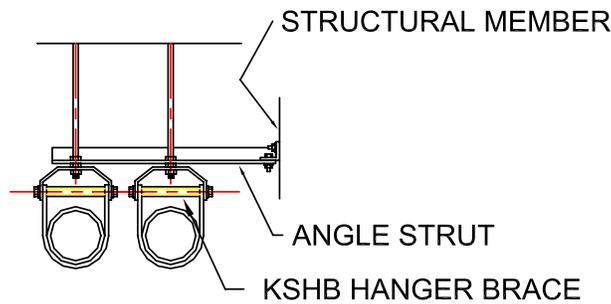


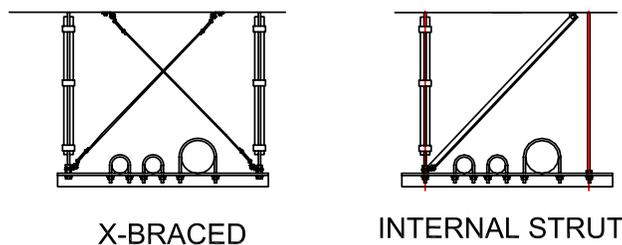
Figure D7.6-3; Clevis-Supported Piping Restrained to Structural Wall or Column



For the case where there are no nearby structural connection points or where the nearby structural elements are not suitable, there are several options that can be considered.

The first option is to restrain to the ceiling using “X” bracing or a diagonal strut.

Figure D7.6-4; “X” or Diagonally Braced Restraint Arrangement



CONNECTION OPTIONS FOR AWKWARD SITUATIONS

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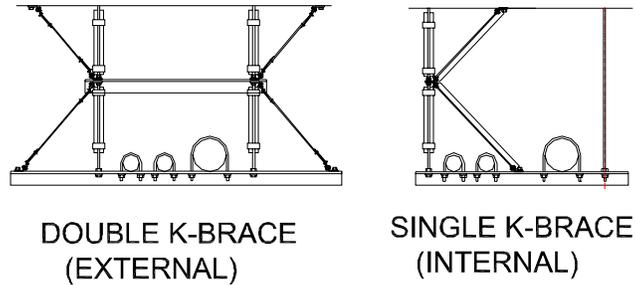
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A “K” or double “K” brace can also be used. The “K” can either be located inside the support rods or outside the support rods, but in the case of a double “K”, both sides must be identical (either inside or outside).

Figure D7.6-5; Single and Double “K” Brace Restraint Arrangement



In cases where only non-structural walls limit access for restraint, it is frequently possible to penetrate the non-structural wall and shift the lateral restraint device to the opposite side of the wall or partition as shown here.

Figure D7.6-6; Wall Penetration Restraint (Cable)

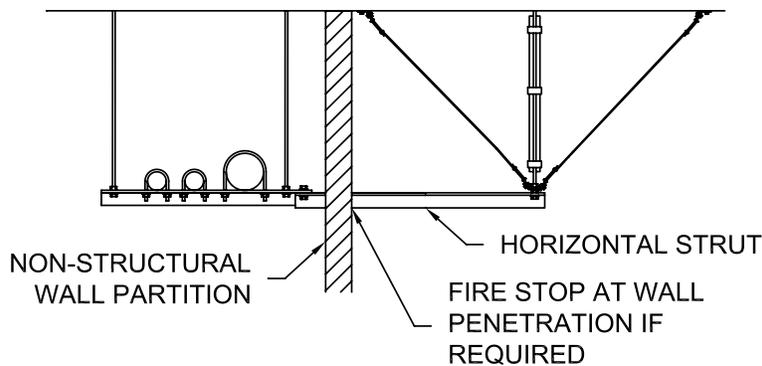
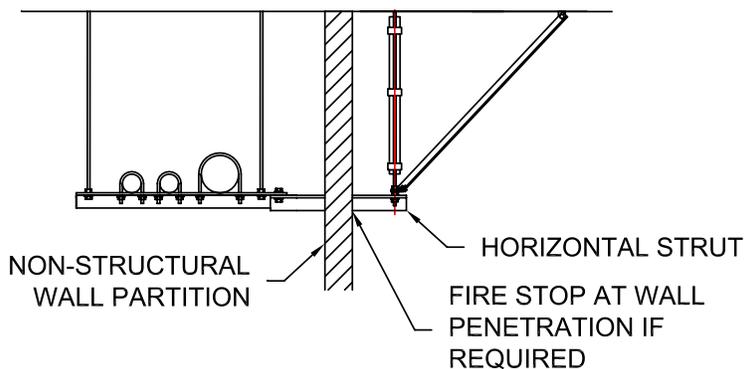


Figure D7.6-7; Wall Penetration Restraint (Strut)



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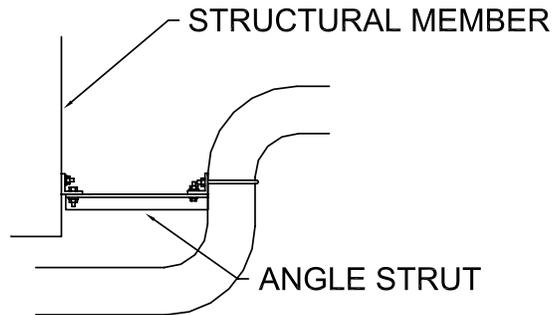
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D7.6.2 Axial Restraint Strut at a Dogleg

This arrangement is often a convenient way to connect an axial restraint and can occur both in the horizontal and vertical plane. Often it will be found that when installing piping, a jog has been added to a run to avoid running into a column or other structural member. Where this occurs, it offers an easy way to connect an axial restraint.

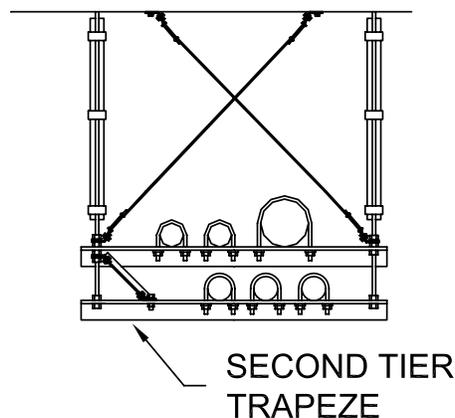
Figure D7.6-8; Axial Restraint Strut at a Dogleg



D7.6.3 Piggyback or Double-Tier Restraint

In congested areas, there is often a double layer of piping supported off a single trapeze arrangement. It is possible under some conditions to brace one trapeze bar to the other, and then restrain the second trapeze bar to the structure. If doing this, there are a couple of cautions. First, the restraint capacity for the second trapeze bar must be adequate to restrain the total load from both bars and, second, the piping must be similar in nature and ductility.

Figure D7.6-8; Piggyback or Double-Tier Restraint Arrangement



D7.6.4 Restraints for Piping Mounted Well Below the Support Structure

This situation is not easily handled. Past history has shown, and the code is quite clear, that it is not a good idea to support the pipe from one structural element and restrain it using another structural element that will undergo significantly different motions. Restraints fit in this fashion will likely fail or cause the supports for the system that is being supported to fail. Neither of these outcomes is desirable..

About the only solution to this is to add a support structure for the piping that is located either just above or just below the piping. The piping can then be both attached and restrained to this structure.

The structure can be supported off the floor, off the ceiling, or from structural walls or columns. The support structure must be rigid enough to absorb all of the seismic loads, and particularly the moments, with minimal deformation, transferring pure shear or tensile forces into the supports.

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