SECTION D10.0 – TABLE OF CONTENTS

D10.0 – SUSPENDED EQUIPMENT

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SEISMIC FORCES ACTING ON SUSPENDED EQUIPMENT

When subjected to an earthquake, Suspended equipment must resist all lateral forces, without regard to their direction. The restraint components for these systems must resist pullout and localized structural failures. Unlike piping and ductwork, there are rarely concerns about the buckling of the equipment. Generally the equipment is assumed to be rugged enough to maintain it shape throughout the seismic event.

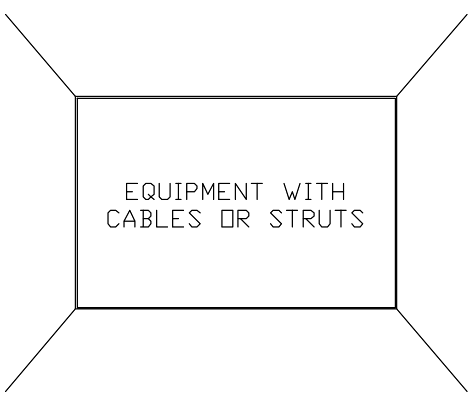
In most cases, equipment is suspended from the deck above on either fixed or isolated hanger rod systems. On more rare occasions the equipment may be bolted directly to the underside of the structure without the inclusion of hanger rods. For the later, the anchorage must be assumed to resist the seismic as well as gravity forces. When mounted on hanger rods, struts or cables are used to absorb the seismic forces.

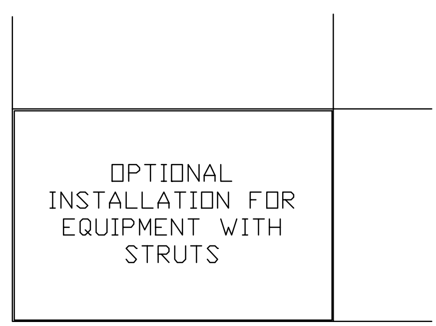
When working with suspended equipment, unlike piping and ductwork, the codes in general do not identify global exemptions. Refer to the code section for specific exemptions, but in general equipment less than 20 pounds in weight does not require the installation of “purpose built” seismic restraint componentry. Conventional attachment is assumed to be adequate.

When installing restraints on hanging equipment, it must be kept from moving in any horizontal direction. The use of cable restraints or struts can induce uplifting forces at their attachment point and if these overcome gravity forces, devices to resist this uplift are also required.

Whether restraining equipment with cables or struts, a minimum of 4 restraints are needed for each piece of equipment. Cables are typically connected to the equipment corners (approx) and run in a direction diagonal to the unit. When looking up at the equipment, each cable should be oriented at approximately 90 degrees to the cables on either side of it creating a “paddle wheel” look with 4 paddles.

When struts are used, they can be oriented like the cables or they can be oriented as shown below.





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The requirement for 4 struts is to prevent the rotation of the equipment that will occur if 2 struts are used that do not line up exactly with the equipment's center of gravity.
Ideally, the restraint members should be at as shallow an angle as possible (mostly horizontal). As the angle becomes steeper (the restraint member becomes more vertical), the vertical forces in the hanger rods 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 caused by the cable or strut can be greater than the downward weight load from the equipment. Depending on the support rod length and stiffness, this 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. The hanger rod and its anchorage for these applications must be designed to accommodate these combined loads. Hanger rod sizing information is also available in Section D4.4 of this manual.

Use of Graphs (Section D4.4) to select restraints for Equipment

The graphs in Section D4.4 can be used for restraint selection for equipment. To do this, simply reference the weight on the left hand horizontal axis and proceed from that point using the same procedure as is used for the selection of restraints for distributed systems.

A more detailed explanation of the use of these tables is in section D4.4 of the manual.

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BASIC PRIMER FOR SUSPENDED EQUIPMENT

Failures in piping systems equipment that interfaces with them 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 unoccupiable 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 and interfacing equipment have become much more stringent.

Within a building structure, there are multitudes of different kinds of systems, each with its own function and requirements, many of which interface with suspended equipment or are in the immediate proximity of this equipment. Significant effort must be expended to ensure that motion of the equipment induced by an earthquake will not damage surrounding systems or the equipment itself.

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, which can be researched further in Chapter D2, or by specification.

This chapter also does not address the sizing of restraint hardware. Section D10.1 and Section D4.4 include sections on sizing componentry based on the design seismic force and the weight of the system being restrained and should be consulted for this task.

Process equipment is not directly associated with building operating systems and often has its own set of requirements. If there are no applicable special requirements, this equipment should be restrained in a similar fashion to the building mechanical systems.

This manual will not address any special requirements for non-building processes.

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PROS AND CONS OF STRUTS VERSUS CABLES

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

When restraining equipment whether struts or cables are used, there is typically no difference in the number of restraints needed. This is unlike piping or ductwork where normally a single strut can replace 2 cable assemblies. The difference between equipment and piping/ductwork is that the equipment is small enough that in addition to swinging laterally from a seismic input, it can easily rotate. 2 struts acting at 90 degrees to one another cannot resist this rotation. Under some cases it can be resisted using 3 struts properly aligned, but unless carefully reviewed a minimum of 4 struts is recommended.

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

There are three significant advantages of cables, where they can be used. First, 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. Second, they are easily set to the proper length. And third, they are well suited to isolated equipment 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 equipment.

Figure D10.3-1; Cable Restrained

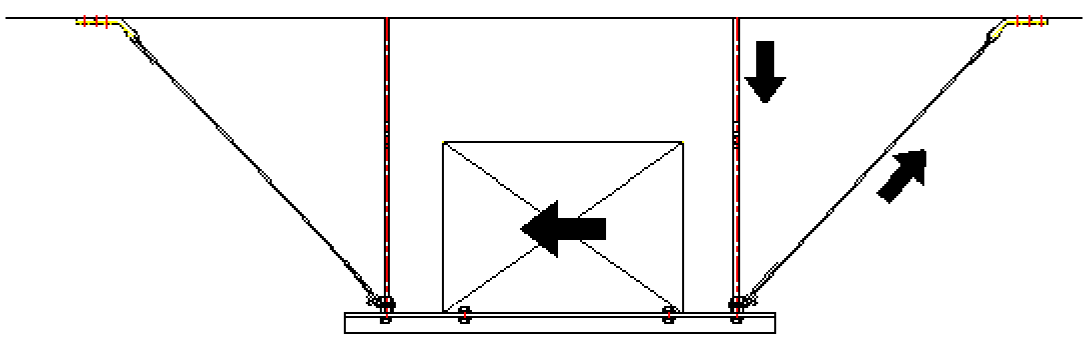

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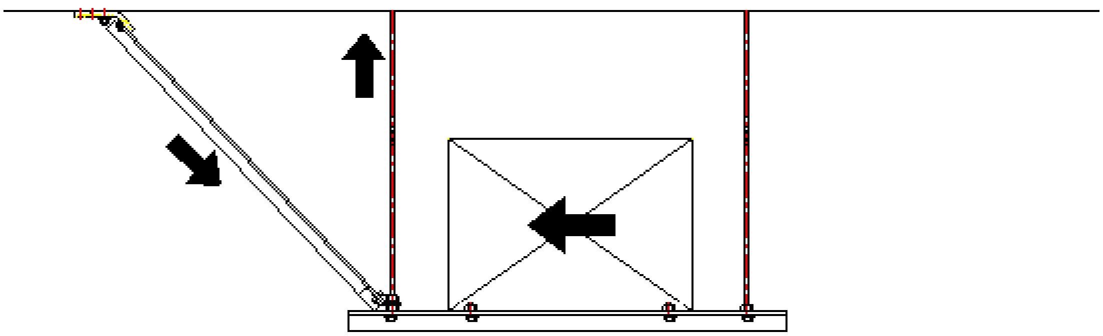
Figure D9.3-2; Strut Restrained



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 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.

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 hanger rods now must comply with all of the anchor requirements specified by ICC. This includes the use of pre-qualified anchors and embedment depths as specified in the pre-qualification documentation. 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 need are 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.

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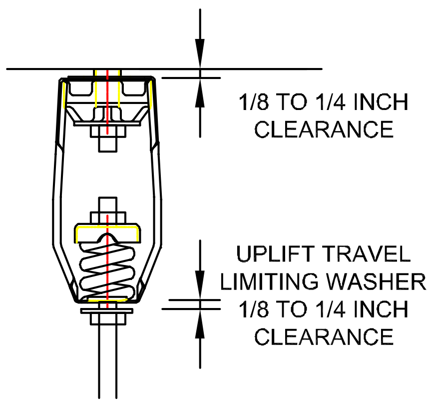
Charts are included in Section D4.4 of this manual that allow the user to determine if there is a need for a stiffener and to allow the uplift load to be determined. From this the weight load at the restraint point (typically approx. 20% of the equipment weight) can be deducted and the appropriate rod stiffener selected from the rod stiffener charts in that Section.

Because uplift can occur, 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).



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REQUIREMENTS FOR SUSPENDED EQUIPMENT RESTRAINTS DEFINITIONS AND LOCATING REQUIREMENTS

While SMACNA has developed a set of restraint placement criteria based on analytical review, practical experience, and historical analysis for piping and ductwork, their material does not address the restraint of equipment. The criterion presented in this manual is generally based on SMACNA concepts and criteria, except that it is modified to make it appropriate for use on equipment applications. The only exception to this is that the data has been extrapolated to higher seismic force levels and hardware capacity limited forces and is not limited by buckling issues as is the case with piping and ductwork.

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

In general, equipment is restrained on a unit by unit basis and the concept of "runs" as defined in the piping and ductwork sections of the manual are not appropriate. In places where there are long lengths of pipe or duct integral to the equipment (like radiant heaters), that portion of the equipment should be restrained in the same manner as piping or ductwork. More information on this can be found in the piping/ductwork Chapters of the manual on this.

Also, in some cases, small pieces of equipment may be "hard" mounted into the ductwork. Under some conditions (see the code section of the manual), these can be treated as part of the duct and properly restraining the duct will result in acceptable restraint of the equipment. This is not true if the equipment is connected to the duct using a flexible material.

Definitions

Lateral A horizontal force acting on the equipment in any direction.

Restraint A device that limits the motion of the equipment in any horizontal direction.

Rod Stiffener A component added to a hanger rod to prevent it from buckling

Restraint Requirements

1) Equipment must be restrained against a lateral force that can act in any direction. Multiple restraint components may be required to accomplish this task.

2) For long modularized equipment (20 ft or longer), additional restraints should be installed so the span between the restraints does not exceed 20 ft.

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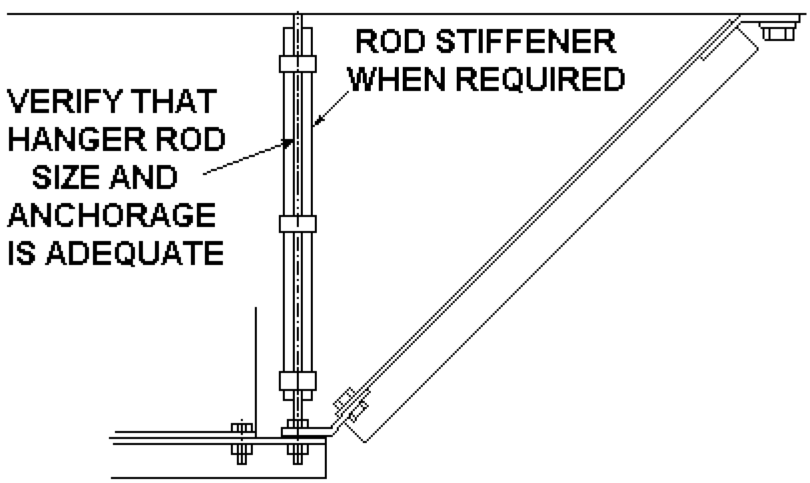
3) Restraints must be connected to substantial attachment points on the equipment or to equipment support members that are in turn connected substantially to the equipment. Hardware in size equal to that identified for the restraint attachment (Chapter D4) should be used to attach the equipment.

4) All restraints for a given piece of equipment must be the same. (You cannot mix struts and cables.)

5) With longer hanger rods, rod stiffeners are likely to be required. Refer to the appropriate table 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.

6) In addition to possibly requiring rod stiffeners, when struts are used to restrain equipment, the size of the hanger rod <u>and its anchorage</u> also become critical. Again refer to the appropriate table in Chapter D4 to determine the minimum allowable size for the hanger rod and anchor.

Figure 10.4.1-1 Rod Stiffener



7) There is no hanger rod length or component size based exclusion rules for equipment as there is for piping or ductwork with the following exception. If the equipment is hard connected to a duct, small enough to be considered part of the duct (see appropriate code section) and the duct is exempted by one of these rules, the equipment can also be considered to be exempted.

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SUSPENDED EQUIPMENT 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.

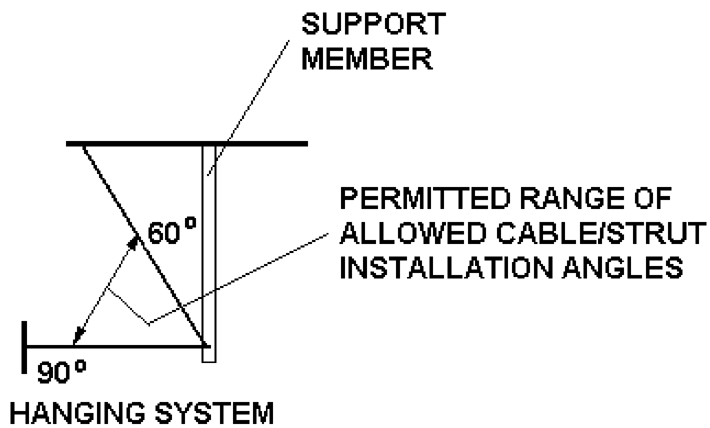
Details of the end connections and anchorage hardware are shown in subsequent sections of the manual. It is assumed in this manual that the restraint component is attached to a structural element capable of resisting the design seismic load.

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 different arrangements in different locations on the same job.

<u>The only significant caution here is that it is not permissible to mix struts and cables on the same piece of equipment.</u>

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 D10.4.2-1; Permissible Restraint Angles



When installing restraints, each individual restraint should be installed perpendicular (±10 degrees) to the adjacent restraint as viewed from underneath. In addition, the restraints should be approximately aligned with the center of gravity of the piece of equipment being restrained. Although it is typical to install restraints at each corner extending radially outward from the piece of equipment, this arrangement is not mandatory. See the sketches below.

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Figure D10.4.2-2; 4 Restraint Options, Restraint angles can vary 10 degrees from those shown

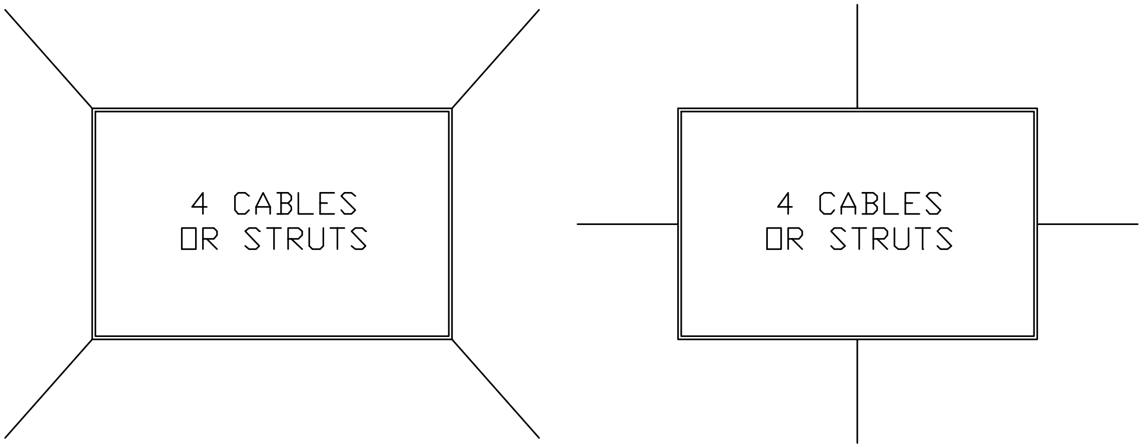


Figure D10.4.2-3; 8 Restraint Options, Restraint angles can vary 10 degrees from those

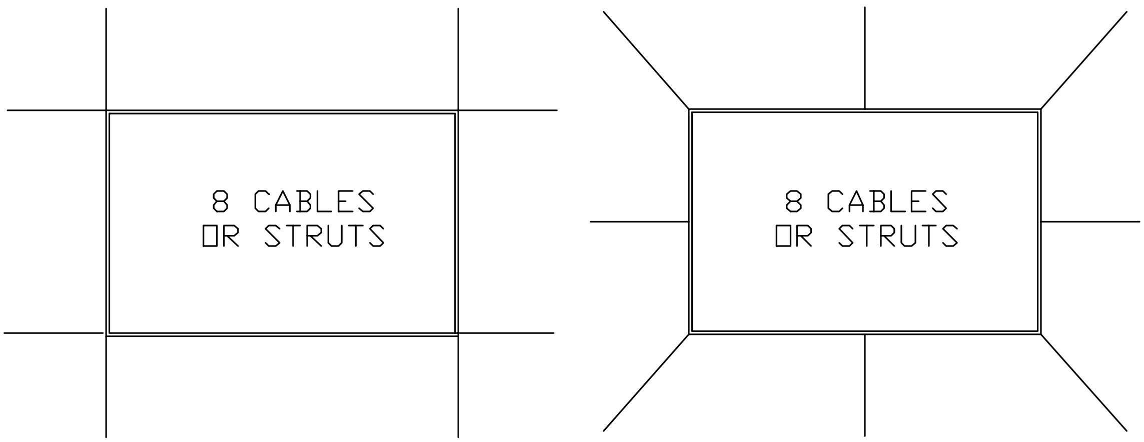
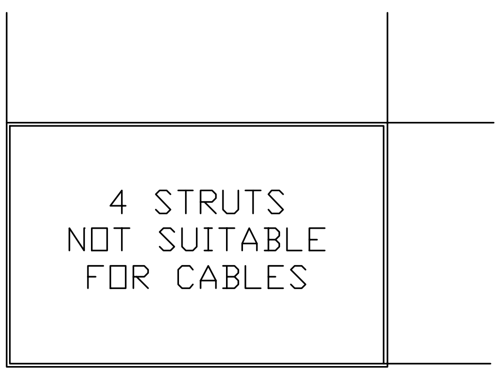


Figure D10.4.2-3; 4 Strut Arrangement, Restraint angles can vary 10 degrees from those



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In general, when restraining equipment, the component actually being restrained is the member that supports the equipment rather than the equipment itself. This is normally a trapeze bar. Because the goal is to restrain the actual equipment, it is necessary that the restrained element be connected to the equipment in such a way as to transfer the appropriate forces between the two.

Based on the Maximum Horizontal Force requirement, the appropriate size and quantity of fasteners to connect ducts to support/restraint members is as follows:

Force (Lbs)	250	500	1000	2000	5000	10000
#10 Screw	3	5	10	20		
Force (Lbs)			3	6	20	40

D10.4.2.1 Hanging Equipment Restrained with Cables

(Note on these and all sections below, the cables must be oriented in the plan view as identified earlier in this document.)

Restraint Examples

For some pieces of equipment that are intended to be suspended, mounting points are normally provided. An example is an axial flow fan. For these kinds of equipment the restraints and the supporting hangers are normally connected to these mounting points directly as shown below. This arrangement works with both isolated and non-isolated systems. Note that the isolators are 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 arrangement.

Figure D10.4.2-4; Fan with Cable Restraints (Non-Isolated)

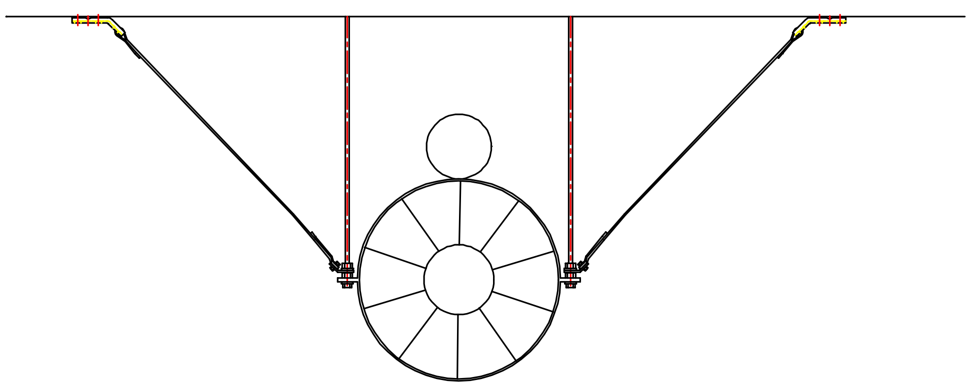

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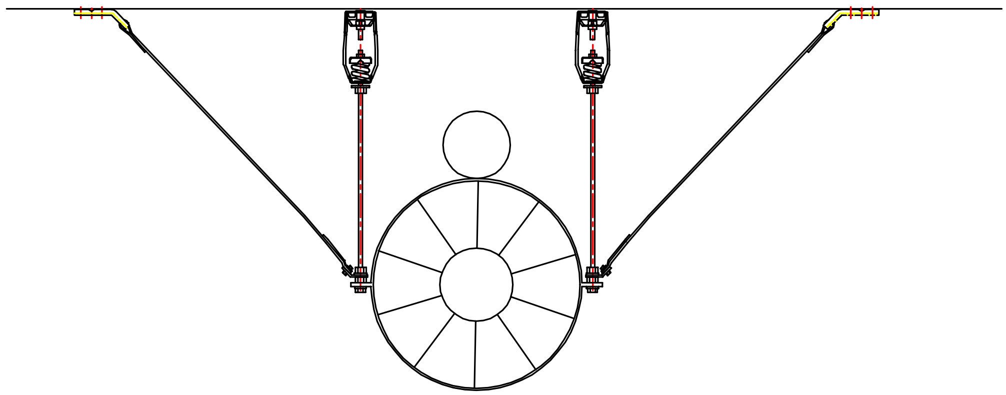
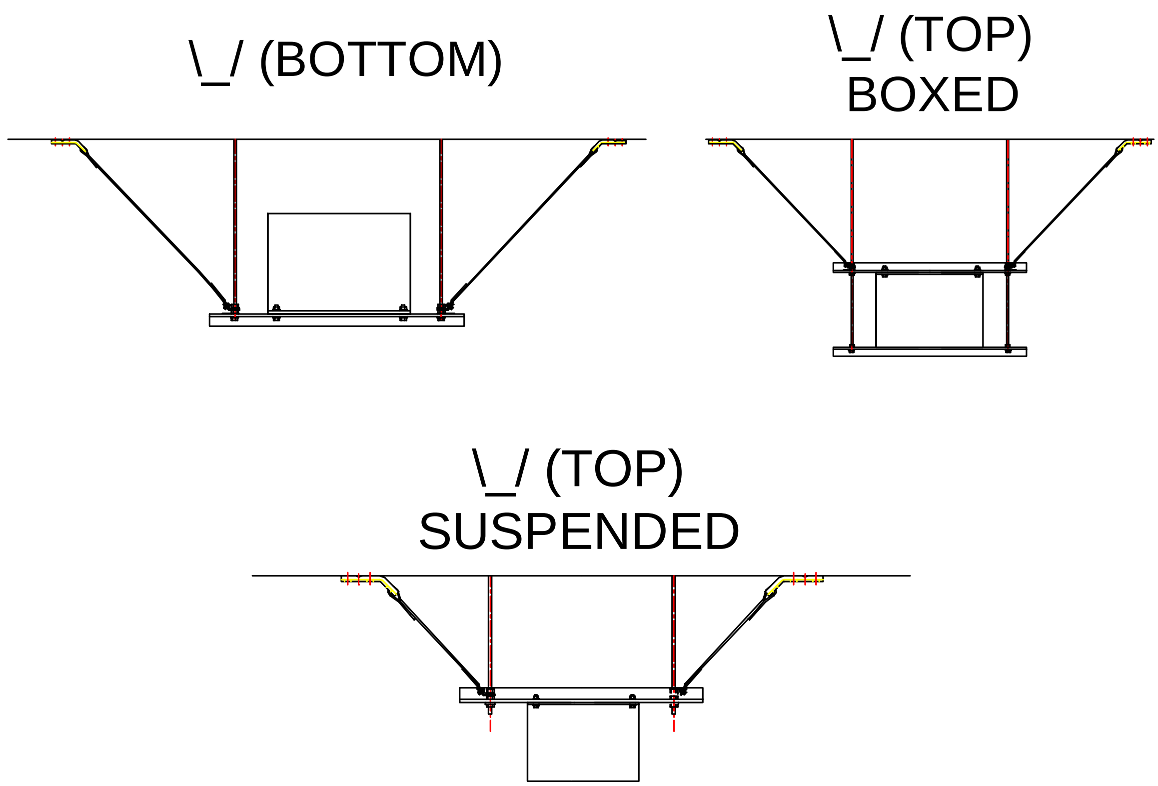
Figure D10.4.2-5; Fan with Cable Restraints (Isolated)



Most equipment however is mounted using a trapeze bar arrangement. There are many options that exist for the arrangements of restraints used in conjunction with trapeze-mounted systems. Shown below are several options for both non-isolated and isolated cable-restrained systems.

Figure D10.4.2-6; Typical Cable Restraint Arrangements Mounted to a Trapeze (Non-isolated)



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In addition to the conventional _/ mounting arrangement, where there is sufficient room above the equipment, and X type of arrangement shown below can often be an attractive alternative.

Figure D10.4.2-7; X Type Cable Restraint Arrangement Mounted to a Trapeze (Non-Isolated)

X (TOP)
BOXED

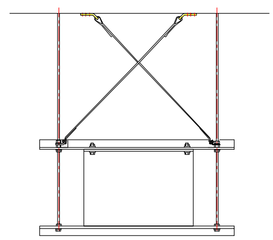
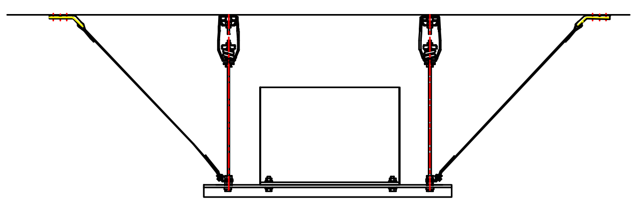
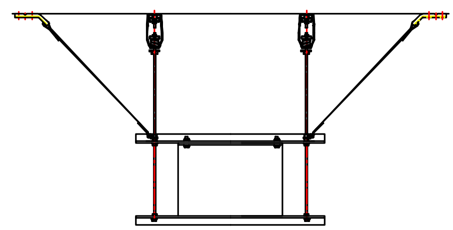


Figure D10.4.2-8; Typical Cable Restraint Arrangements Mounted to a Trapeze (Isolated)

_/ (BOTTOM)



_/ (TOP)
BOXED



_/ (TOP)
SUSPENDED

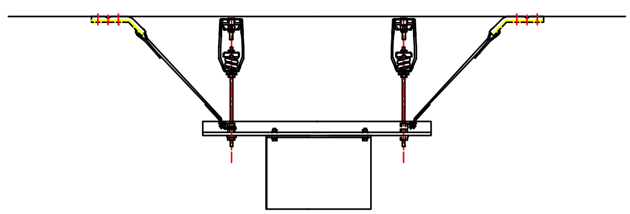


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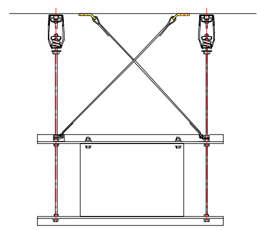
Figure D10.4.2-9; X Type Cable Restraint Arrangement Mounted to a Trapeze (Isolated)

X (TOP)
TRAPPED



D10.4.2.2 Hanging Equipment Restrained with Struts

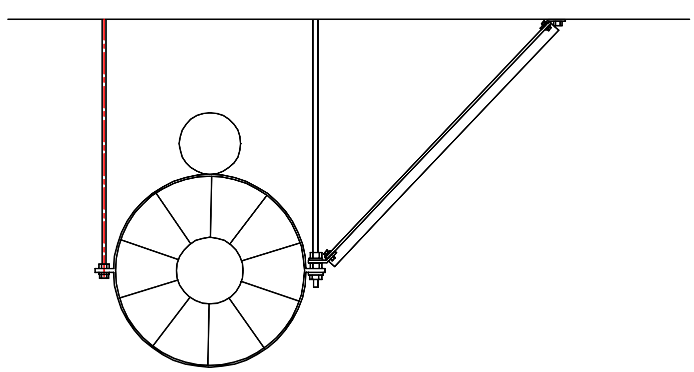
(Note on these and all sections below, the cables must be oriented in the plan view as identified earlier in the paper.)

It is recommended that struts not be used to restrain isolated equipment. Struts will generate hard connections between the equipment 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.

Restraint Examples

For a strut-restrained piece of equipment with integral attachment points located away from the top surface, there is only one common arrangement. It is to connect the restraint and the support to the attachment point as shown below.

Figure D10.4.2-10; Strut Restraint Arrangement for Axial Fan (Non-Isolated only)



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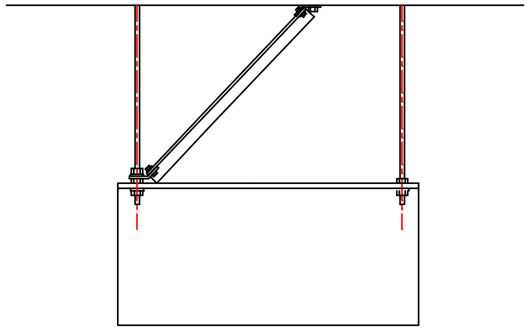
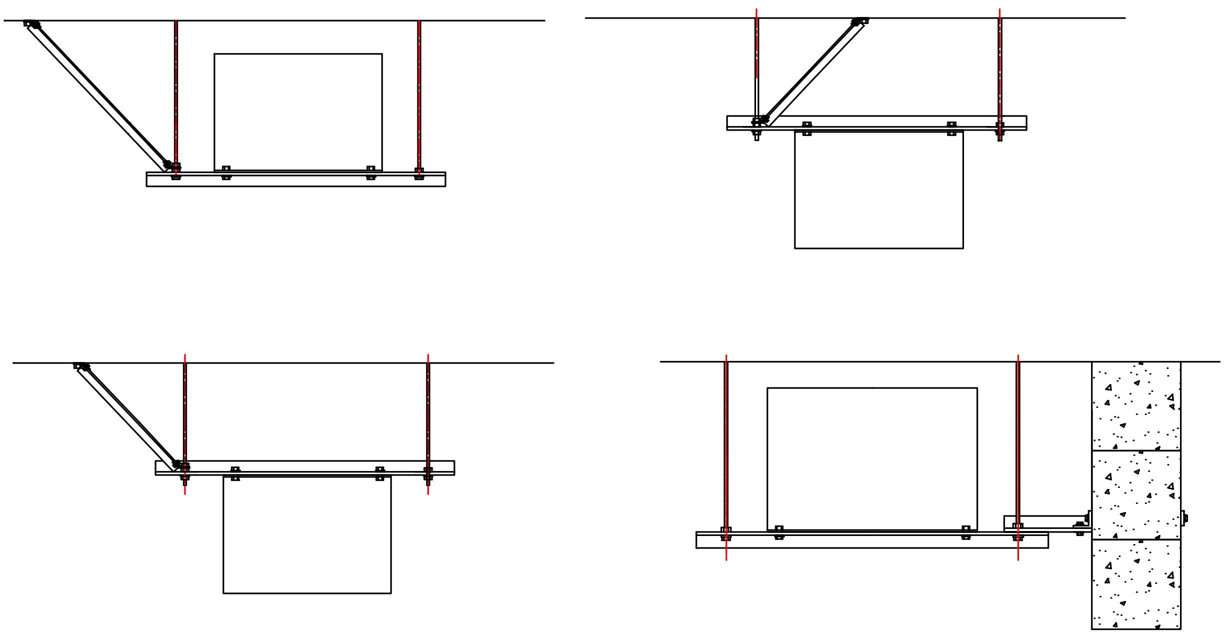
If the connection points for the equipment are on the top surface, the strut can be angled in the opposite direction as shown below.

Figure D10.4.2-11; Strut Angled over Top of Equipment (Non-Isolated only)



Shown below are 4 options for trapeze-mounted equipment. All are equivalent.

Figure D10.4.2-12; Typical Strut Restrained Equipment (Non-Isolated only)



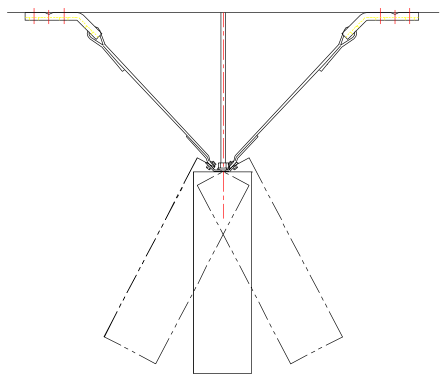
D10.4.2.3 Special Cases

Equipment Supported at 2 points

When equipment is supported on only 2 points, caution must be used to ensure that the restraints are connected in such a way as to prevent lateral motion of the equipment without allowing it to sway and put undo stress on the hanger rods. Classic examples of this type of equipment are Unit Heaters.

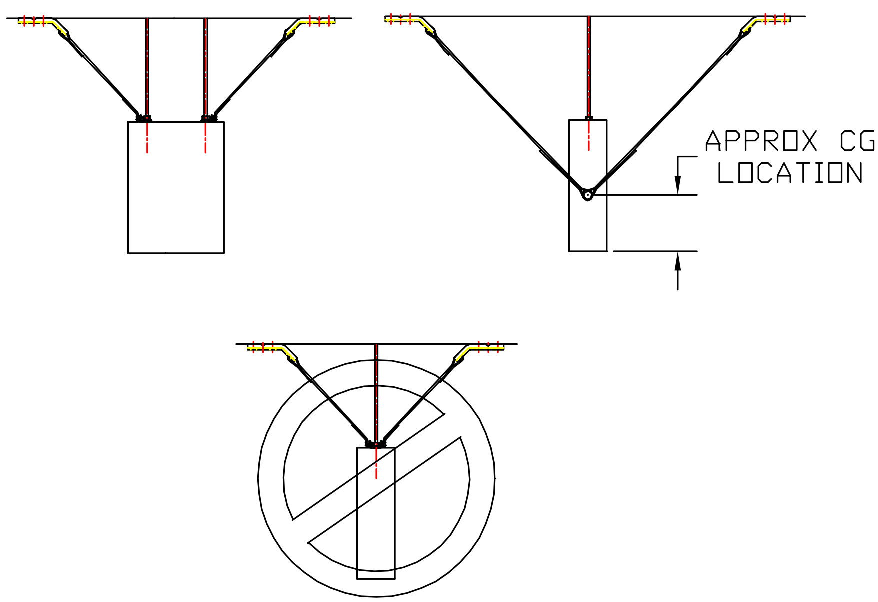
The condition of concern is illustrated below.

Figure D10.4.2-13; Possible Sway in Equipment Mounted on 2 Support Hanger Rods



In order to keep this swaying motion from occurring, it is necessary to ensure that on the axis where swaying can occur, the restraints connect to the equipment at its vertical center of gravity (approx). This is not necessary on the opposite axis. See Below.

Figure D10.4.2-13; Proper Restraint of Equipment Suspended by 2 Hanger Rods



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TRANSFERRING FORCES (SUSPENDED EQUIPMENT)

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, suspended systems in general are 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

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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 are not permitted. *(Rationale: Open joists are notoriously weak in their lateral axis. They are not designed to take loads, particularly on the lower cord, and 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.*

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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.

Note: The options shown below illustrate equipment viewed on a single axis, Equivalent restraint is however needed on both principle axies.

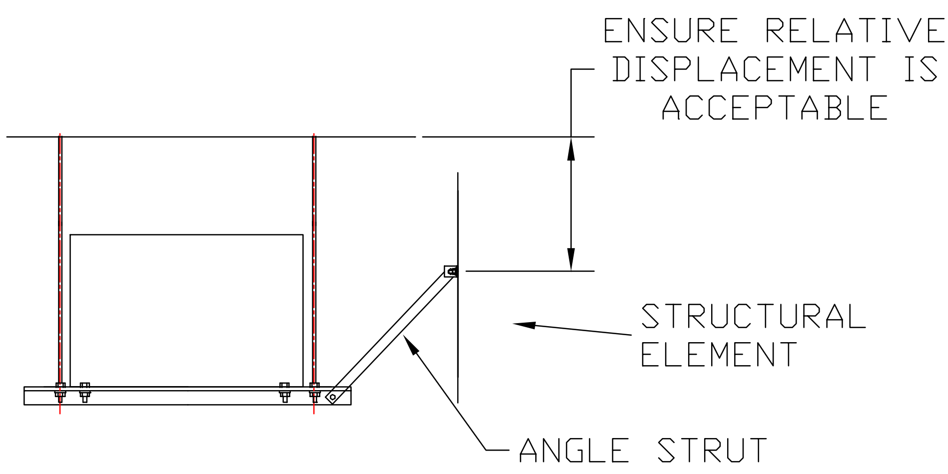
D10.6.1 Equipment Tight to Walls

Probably the most common issue in the field is how to deal with restraints where there is little room to slope cables or struts up to the ceiling structure. Frequently the walls are not structural and do not offer a surface to which to anchor.

When evaluating these kinds of spaces, the first issue is to determine if either of the walls bordering the space are structural. If they are, they can offer 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 lateral 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 D10.6.1; Trapeze-Mounted Equipment Restrained to Structural Wall or Column with a Strut



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.

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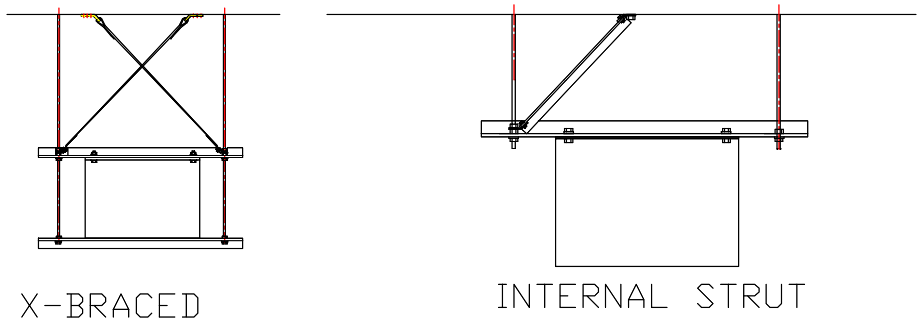
The first option is to restrain to the ceiling using “X” bracing or a diagonal strut.

Figure D10.6.2; “X” or Diagonally Braced Restraint Arrangements



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 D10.6.2; Single and Double “K” Brace Restraint Arrangement

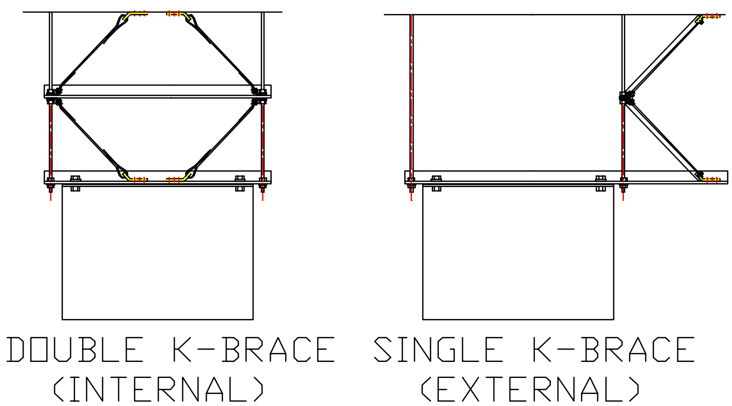


Figure D10.6.3; Wall Penetration Restraint (Cable)

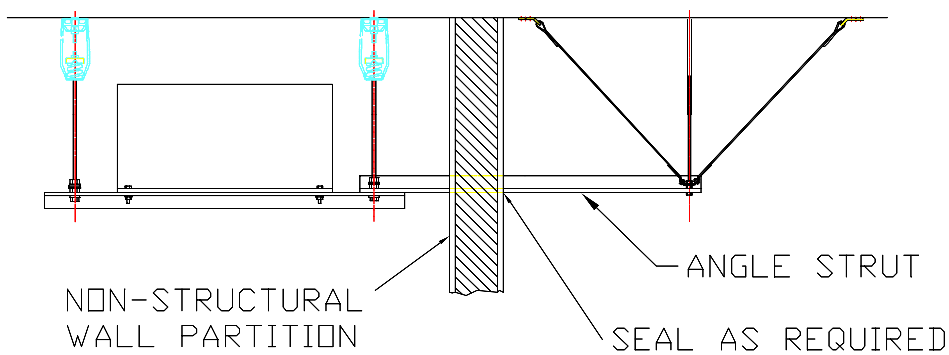


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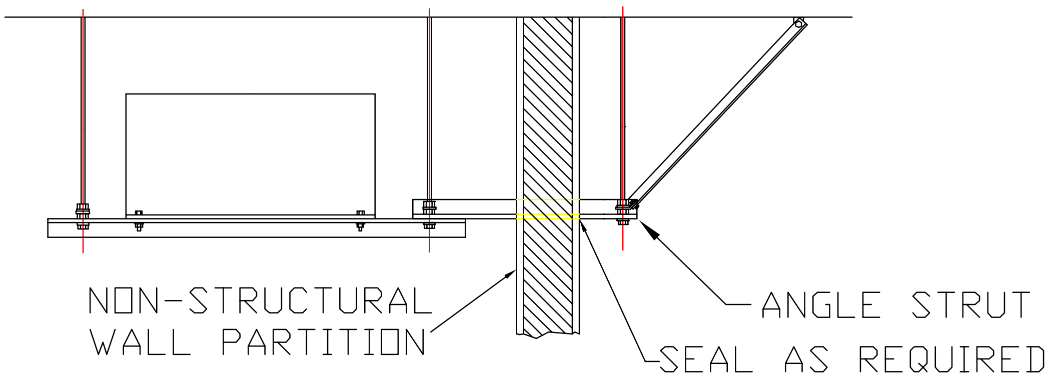
Figure D10.6.4; Wall Penetration Restraint (Strut)



D10.6.2 Piggyback or Double-Tier Restraint

In congested areas, It may be possible to restrain a piece of equipment as well as an associated distribution system with one set of restraints. Care should be used in doing this to ensure that the the components restrained together have similar properties. For example:

1) Ductwork can be restained with small AHU units or VAV boxes.
2) Pumps can be restrained with piping, valves or other piping components
3) Piping should not be restrained with AHU's
4) Ductwork should not be restrained with pumps.
5) Isolated systems must be restrained with other isolated systems
6) If piping or ductwork does not require restraint because of size or proximity to the ceiling, it cannot be connected to a piece of equipment that does.

When selecting restraints, the restraints must be adequate in capacity to resist the total load generated by both the equipment and distribution system. The graphs in Section D4.4 can be used for restraint selection for multiple components. To do this, simply reference the total weight on the left hand horizontal axis and proceed from that point using the same procedure as is used for the selection of restraints for distributed systems.

A more detailed explanation of the use of these tables is in section D4.4 of the manual.

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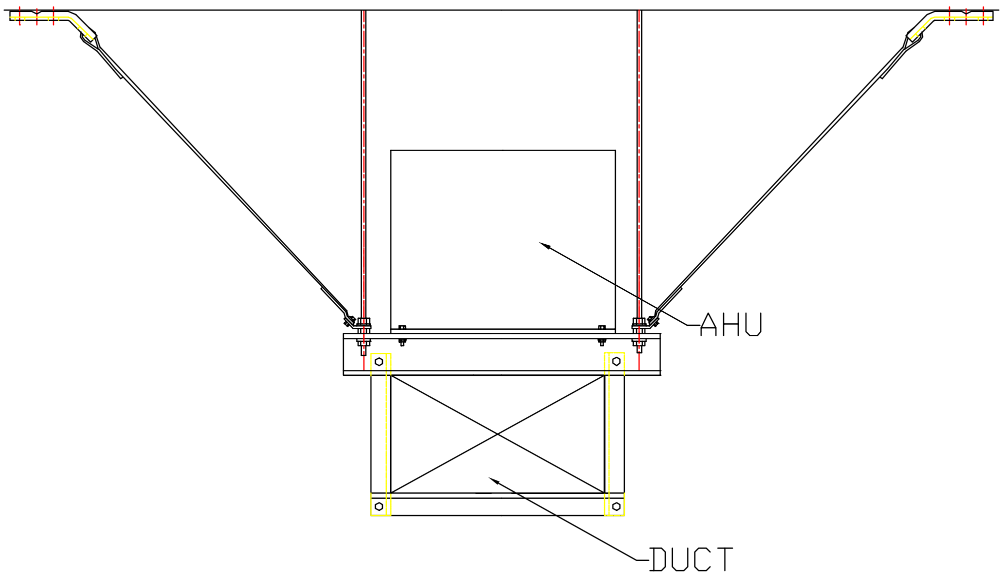
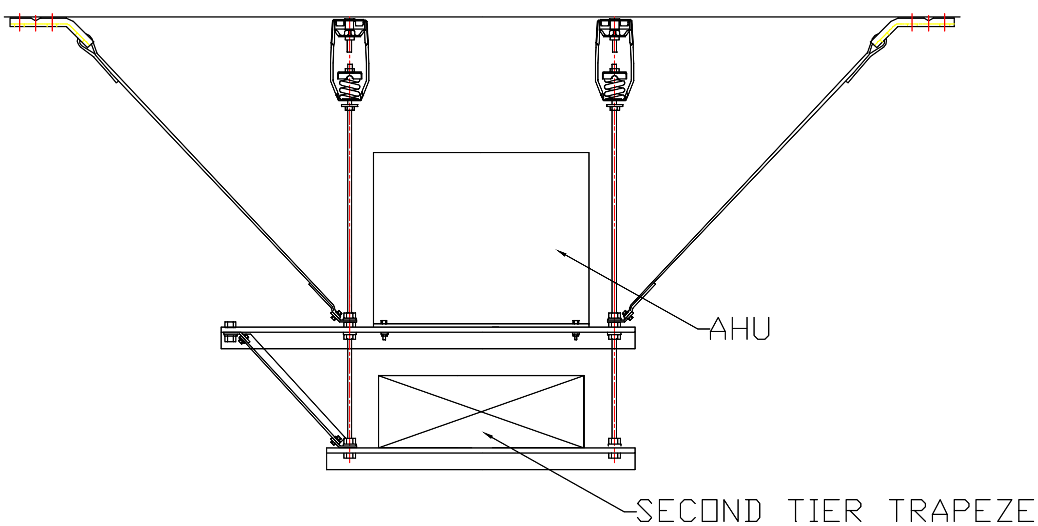
Figure D10.6.5; Piggyback Restraint Arrangement



It is possible under some conditions to brace one trapeze bar to the other, and then restrain the second trapeze bar to the structure. This is shown below:

Figure D10.6.6; Double-Tier Restraint Arrangement



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D10.6.3 Restraints for Equipment 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 equipment 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 equipment supports to fail. Neither of these outcomes is desirable.

About the only solution to this is to add a support structure for the equipment that is located either just above or just below the level of that equipment. The equipment 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 supporting structure.

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