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D9.0 – Electrical Distribution Systems

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SEISMIC FORCES ACTING ON ELECTRICAL DISTRIBUTION SYSTEMS

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

Most electrical distribution systems are suspended from the deck above on fixed hanger rod systems. They may be supported singly or there may be several pieces of conduit or buss ducts attached to a common trapeze. On some occasions the conduit may run vertically or may be mounted to the floor.

D9.1.1 Suspended Systems

Most codes do not require that electrical distribution 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 systems 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 pieces of conduit, 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 conduit runs 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 the system supports and their restraints. Supports for these systems are typically sized to carry approximately a 10 ft length of conduit or duct (in the case of trapezes, multiple pieces of conduit each approx 10 ft long). Seismic restraints, on the other hand, are normally spaced considerably further apart with the spacing varying by restraint type, restraint capacity, conduit size, 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. (Note when using these tables that conduit should be assumed to be similar in weight and performance to the equivalent pipe size.)

To illustrate this difference, consider a simple example of a single piece of conduit 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 conduit 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.

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

D9.1.2 Riser Systems

Where conduit is 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 local anchorage and the spacing between these anchors is not to exceed the maximum tabulated lateral restraint spacing indicated in the design tables in Chapter D4.

D9.1.3 Floor-Mounted Systems

The primary difference between floor- and ceiling-mounted electrical distribution systems is that the support loads in the distribution system 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

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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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BASIC PRIMER FOR SUSPENDED ELECTRICAL DISTRIBUTION SYSTEMS

Failures in electrical distribution systems resulting from earthquakes have historically resulted in loss of building services, are possible fire sources and carry with them the risk of occupant electrocution. While to date, the recorded instances of dollar damage to the building and its contents has been less than that of the building mechanical and electrical systems, the risk exists for serious damage and possible loss of life. In addition, failure of the building's mechanical and electrical systems can render the structure unoccupiable until the damage is corrected, and result in major problems for the tenants and/or owners.

As with the piping and duct systems, requirements for the restraint of electrical distribution systems have also become much more stringent.

Within a building structure, there are multitudes of different kinds of electrical systems, each with its own function and requirements. These include building power, communication, system monitoring, HVAC control to name a few. Requirements for the systems vary based on the criticality of the system and those systems with which it interacts. Code mandated requirements for the restraint of electrical distribution 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 the system. 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 electronics that are not directly associated with building operating systems may have their own set of requirements that should be addressed separately. High voltage electrical systems, whether building or process related should be restrained per code requirements. If there are no applicable special requirements, all systems should be restrained in a similar fashion to the building mechanical systems. This manual will not address any special requirements.

Building electrical systems must be restrained per code. Refer to the code review chapter (D2) of the manual for applicable design requirements.

In many cases, conduit 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

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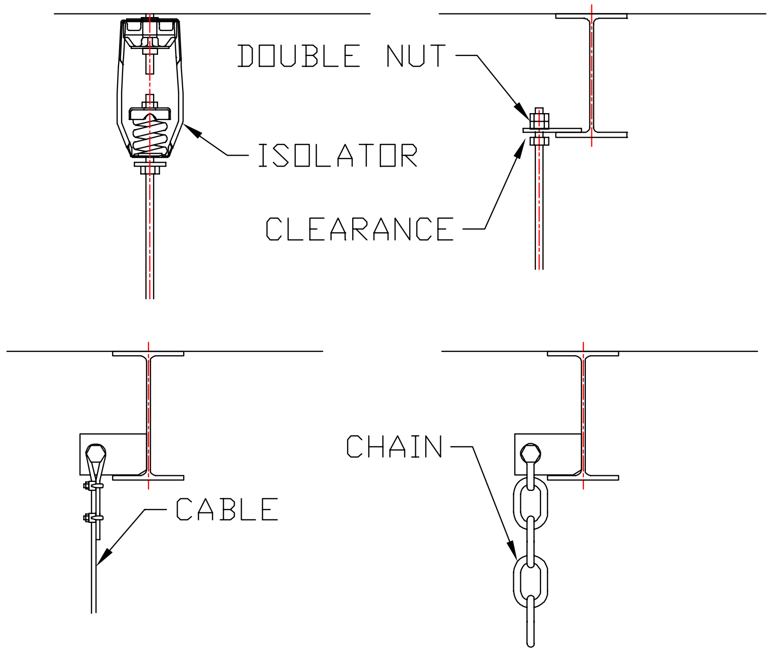
the installation of a "non-moment generating connection" at the top anchorage point. This term is often confusing and deserves further clarification. A "non- moment generating connection" is one that will allow the supported pipe to swing freely in any direction if acted on by an outside force. Some examples of "non-moment generating connections" are illustrated below.



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PROS AND CONS OF STRUTS VERSUS CABLES

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

In general, distribution systems restrained by struts will require only 1 brace per restraint location while systems 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 conduit or distribution ducts 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 distribution run 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. And third, they are easily set to the proper length.

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 a cable-restrained and strut-restrained piece of conduit.

Figure D9.3-1; Cable Restrained Conduit

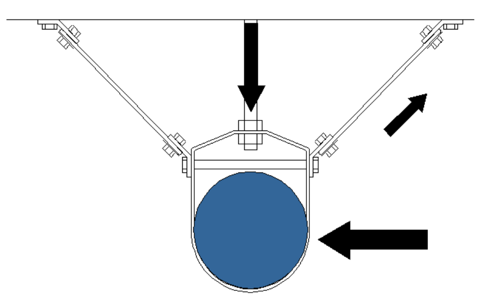

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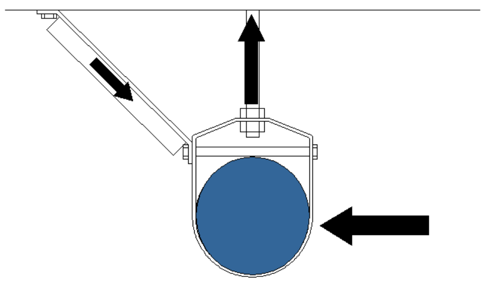
Figure D9.3-2; Strut Restrained Conduit



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. 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 0.5W. Using a 0.25g lateral design force (low seismic area), the total tensile load in a hanger increases to 0.75W 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 .94W for bracing on every support and 1.36W for bracing on every other support.

On the other hand, where 0.25g is applicable, buckling concerns in conduit 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 1.5W for 45 degree configurations and to 2.23W 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 D9.3-1; 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 ICC 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.

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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.

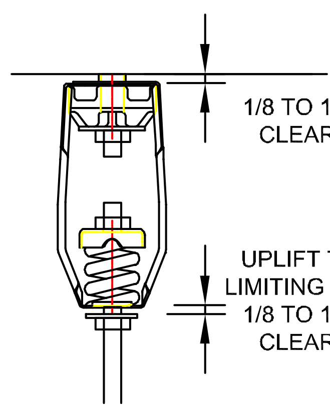
There is a wide range of variables involved in determining the need for rod stiffeners to resist this buckling load. Factors that impact this need are 1) the magnitude of the compressive force, 2) the weight load carried by the hanger rod, 3) the length of the hanger rod, 4) the diameter of the hanger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

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.

In rare instances, electrical distribution systems are isolated. In these cases and because uplift occurs, some attention must be given to the isolator itself. 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 D9.3-3; Installation for an Isolation Hanger in a Seismic Application



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REQUIREMENTS FOR DISTRIBUTION SYSTEM 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, conduit and other components used for electrical distribution 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.

D9.4.1-1 Definitions

Axial In the direction of the axis of the run.

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

Pipe or Conduit Clamp A heavy duty split ring clamp tightened against the conduit to the point that it can be used to control the axial motion of the conduit, tray or duct.

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

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

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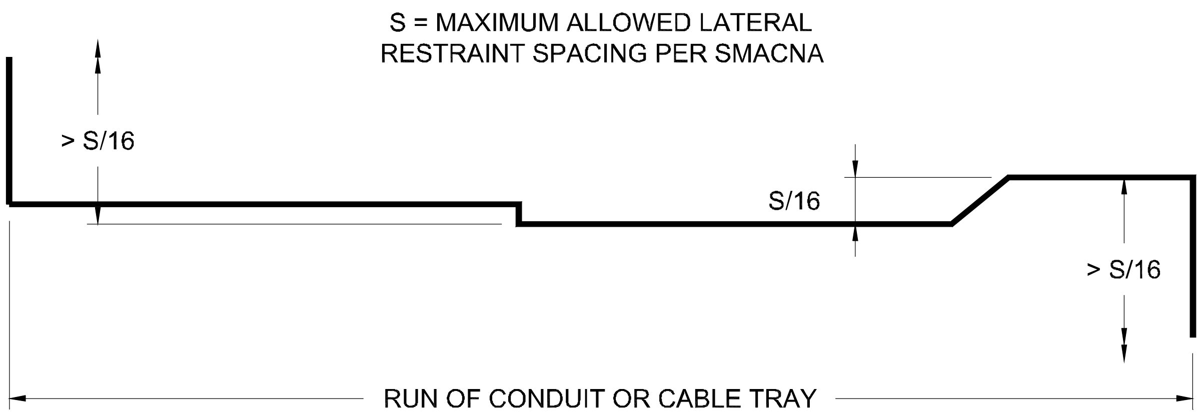
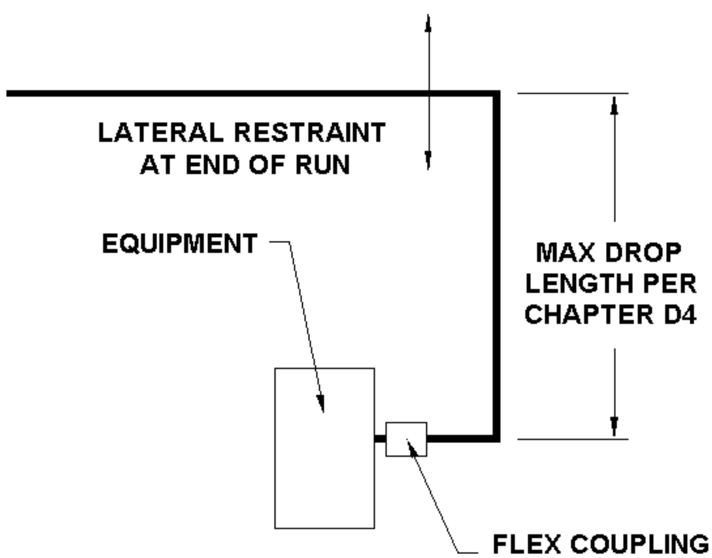
Figure D9.4.1-1; Definition of a "Run" of Duct



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 conduit that normally extends down from an overhead distribution system 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 conduit must be less than S/2. If over S/2, the length of conduit would be classified as a run.

Figure D9.4.1-2; Definition of a "Drop"



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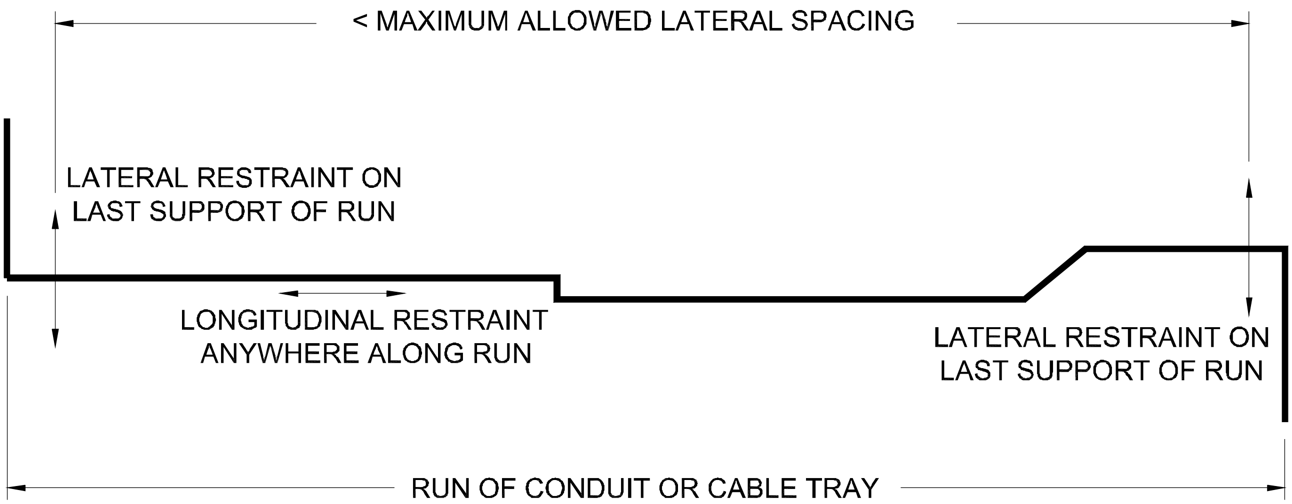
D9.4.1-2 Restraint Requirements

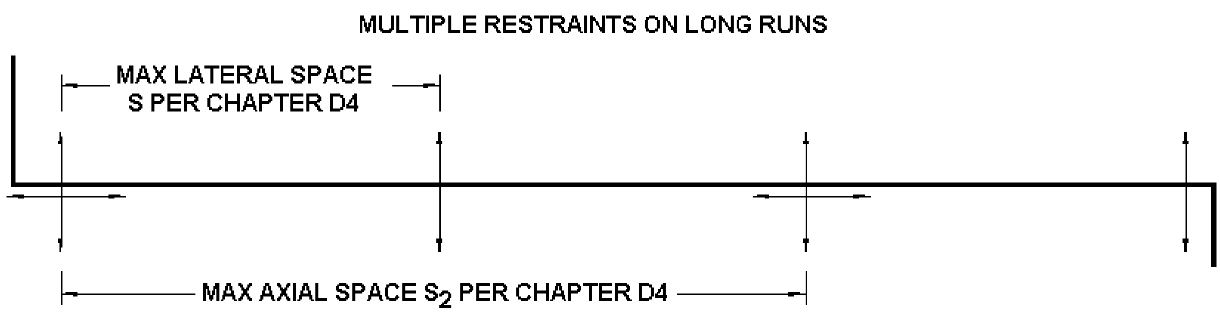
1) Full runs greater in length than S/2) must be restrained in both the axial and lateral direction. If the run is not a short run or a drop, it must, as a minimum, be laterally restrained at the last support location on each end.

Figure D9.4.1-2; Basic Restraint Requirements for a Typical "Run" of Conduit



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 D9.4.1-3; Basic Restraint Requirements for a Long "Run" of Conduit



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

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

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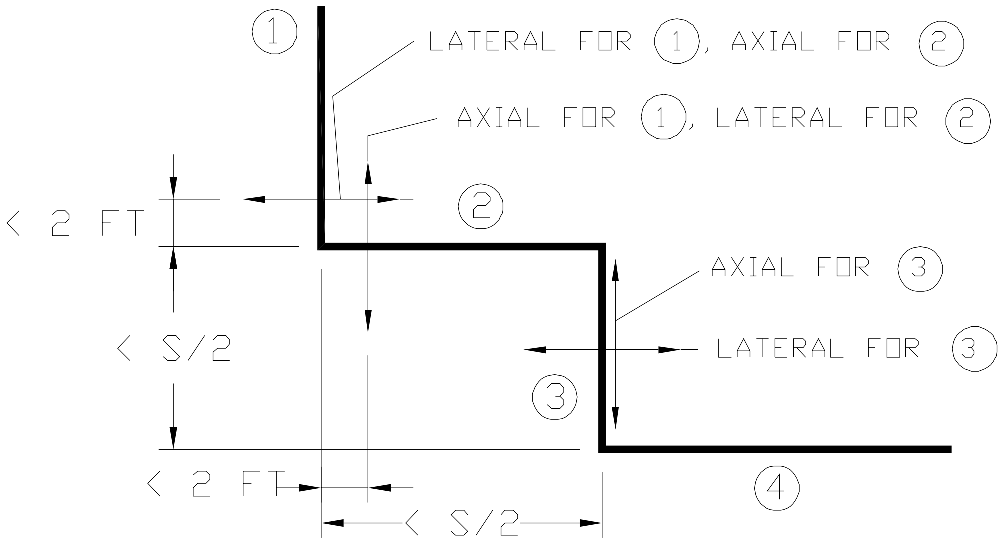
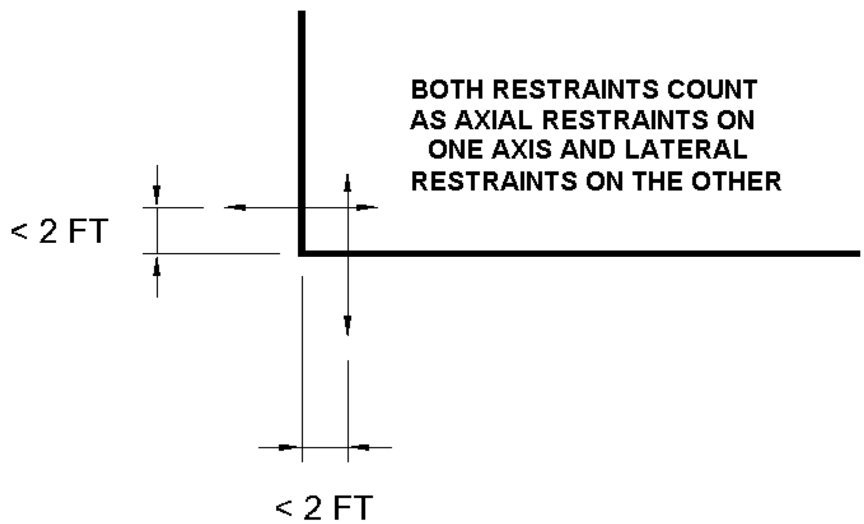
Figure D9.4.1-4; Basic Restraint Requirements for Multiple Short "Runs" of Conduit



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

Figure D9.4.1-5; "Double Duty" for Corner Restraints



6) Larger trays or conduit cannot be restrained with restraints located on smaller branch runs.

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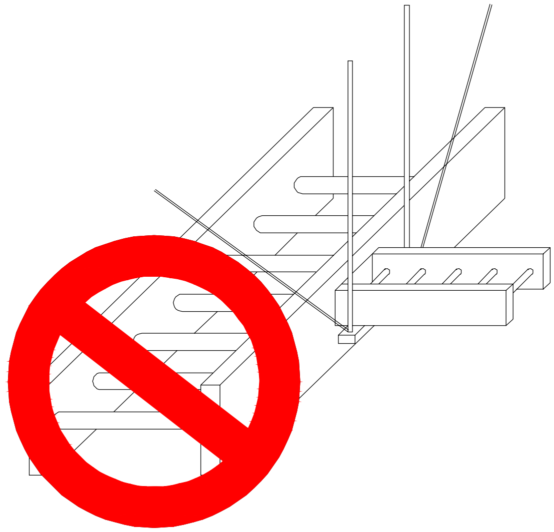
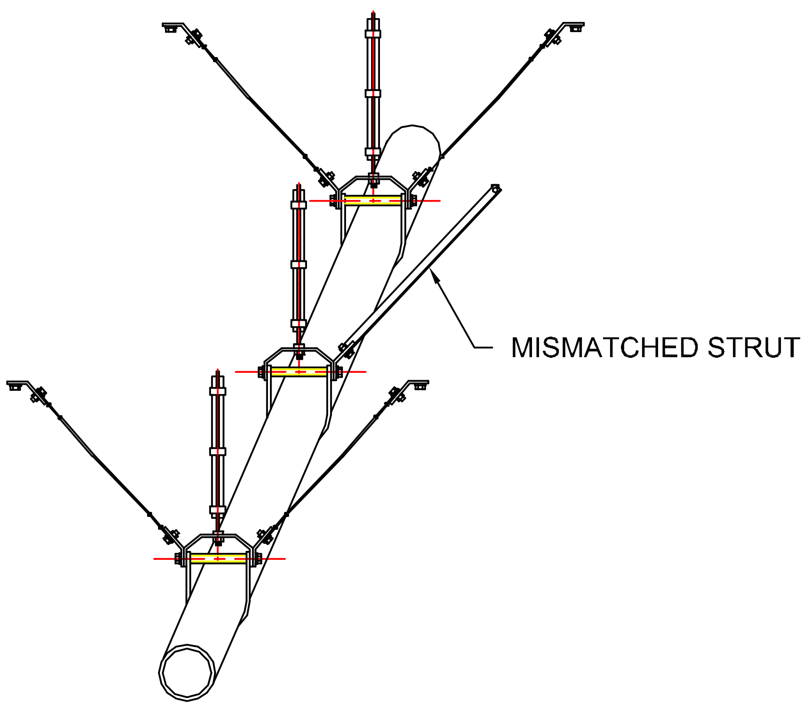
Figure D9.4.1-6; Do not Restrain Larger Electrical Runs with Restraints on Smaller Ones



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

Figure D9.4.1-7; Mismatched Struts and Cable Restraints



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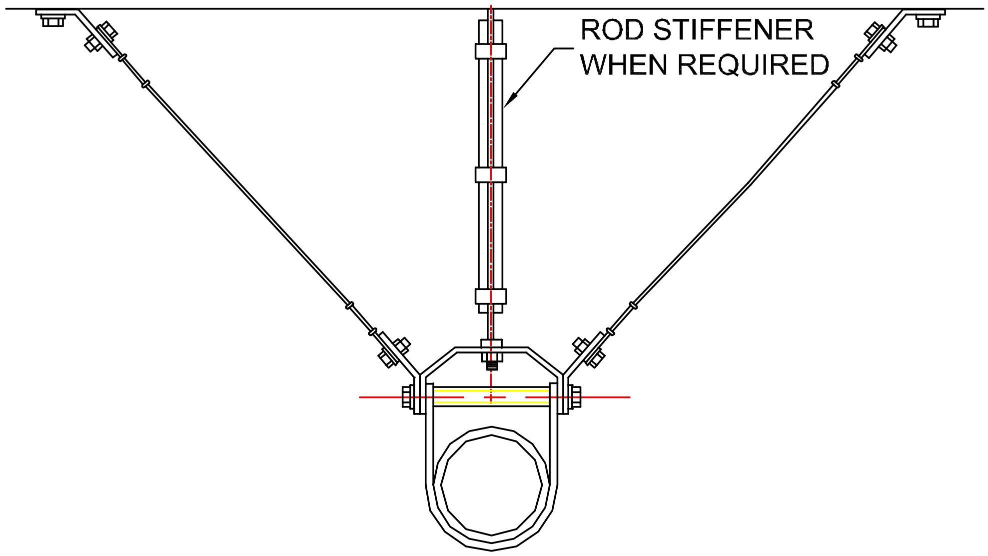
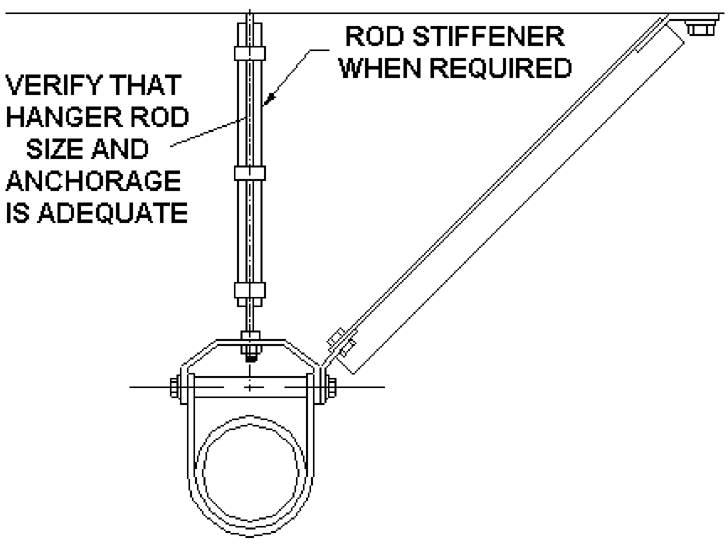
8) With longer hanger rods, rod stiffeners are likely to be required. Refer to the appropriate table in Chapter D4 to determine: (1) if needed, (2) what size stiffener material is appropriate, and (3) how frequently it needs to be clamped to the hanger rod.

Figure D9.4.1-8; Rod Stiffener



9) In addition to possibly requiring rod stiffeners, when struts are used to restrain conduit, the size of the hanger rod and its anchorage 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 D9.4.1-9; Hanger Rod Sizing (For Strut Applications)



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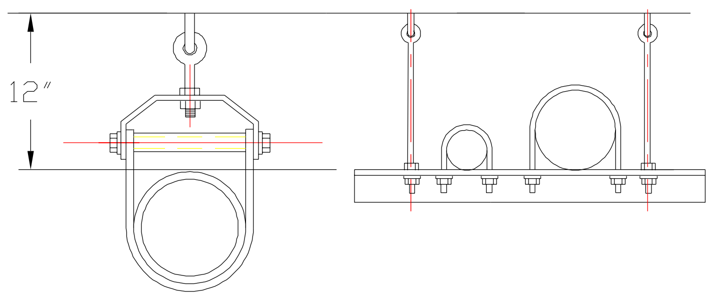
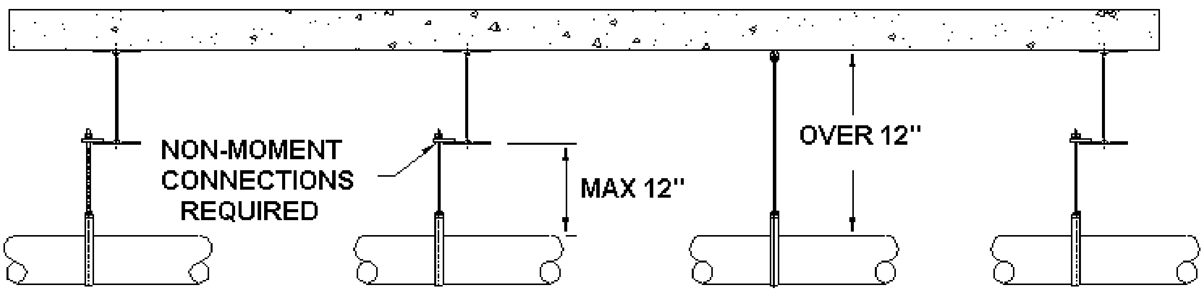
10) In some cases, it may be possible to locate the electrical distribution system close enough to the support structure (12”) to eliminate the need for restraint. (Refer to the building code review chapter (D2) to determine if this exemption is applicable.) If it is applicable, the 12” dimension is measured as shown below.

Figure D9.4.1-10; 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 D9.4.1-11; Run Fails the Consistency Requirement for 12” Exemption



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CEILING-SUPPORTED ELECTRICAL DISTRIBUTION SYSTEM 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.

It is assumed in this section that all conduit is rigid. For non-rigid conduit and if the conduit is large enough to require restraint, adequate hardware to accomplish this task is required at each support location.

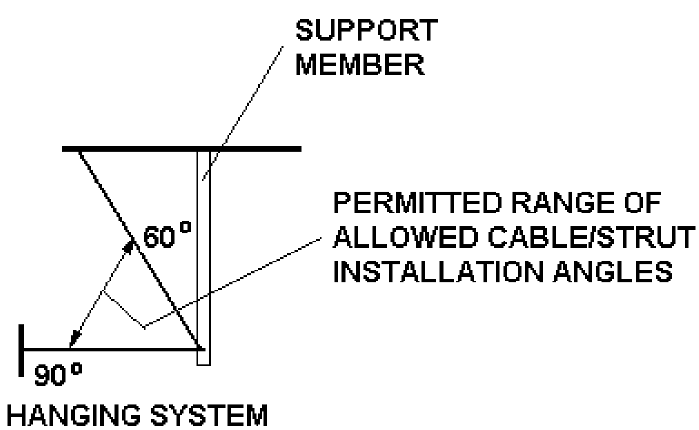
Details of the end connections and anchorage hardware are shown in subsequent sections of the manual. It is assumed in this manual that the restraint component is attached to a structural element capable of resisting the design seismic load.

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 run.</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 D9.4.2-1; Permissible Restraint Angles



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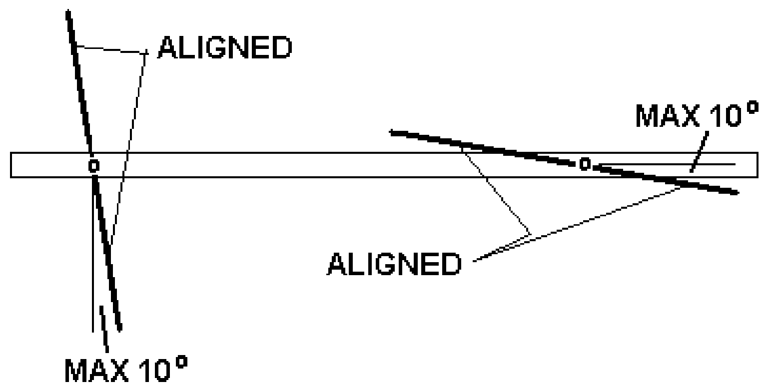
When installing restraints, lateral restraints should be installed perpendicular (±10 degrees) to the run in plan. Axial restraints should be in line with the run, ±10 degrees, again in the plan view. All restraint cables should be aligned with each other. See the sketch below.

Figure D9.4.2-2; Restraint Alignment



Lateral Restraint **Axial Restraint**

In general, when restraining electrical distribution systems and conduit the component actually being restrained is the system support device. This may be a clevis, a clamp, or a trapeze bar. Because the goal is to restrain the actual cable tray, duct or piece of conduit, it is necessary that the restrained element be connected 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 piece of conduit that is not clamped in place, it is obvious that the axial forces generated by the conduit cannot be restrained by the connection to the trapeze bar. Some other arrangement is needed.

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

When firmly connecting restraints to cable trays, ducts or conduit there are a few general rules that should be followed:

1) A conventional pipe or conduit clevis hanger cannot restrain a piece of conduit in the axial direction.
2) Trapeze-mounted ducts, trays and conduit should be tightly connected to the trapeze bar.

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3) If a tray or duct is used and it is mounted with the long dimension in the horizontal plane, the maximum spacing for restraints should be based on the allowable spacing for a pipe of a diameter equal to the tray's long axis dimension.
4) If a tray or duct is used and it is mounted with the short dimension in the horizontal plane, the maximum spacing for restraints should be based on the allowable spacing for a pipe of a diameter equal to the tray's short axis dimension.

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

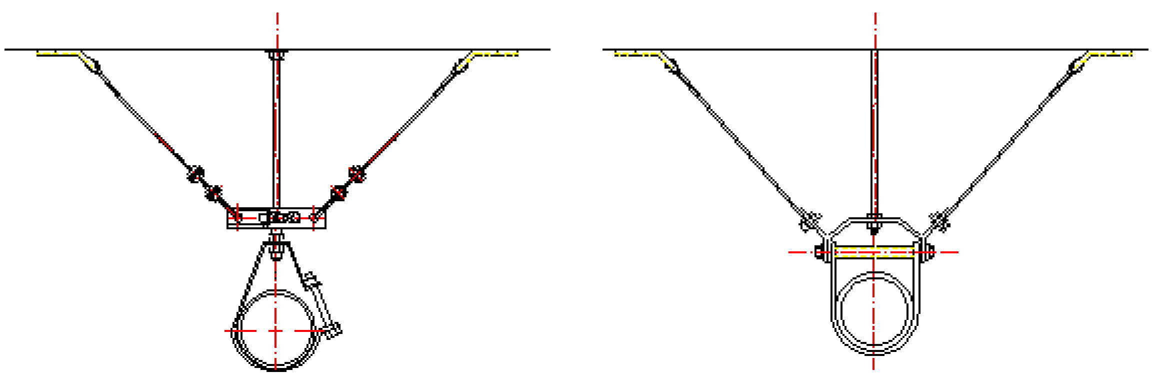
D9.4.2.1 Hanging Systems Restrained with Cables

Hanging systems may include supports for single or multiple conduit runs, buss ducts or cable trays. Single conduit runs can be supported using clevis hangers but wherever multiple items are used, they are normally supported on trapeze bars.

Lateral Restraint Examples

For a cable-restrained conduit supported by a hanger clevis, there are two options for non-isolated installations. Since the isolation of conduit is rare, it will not be addressed here, but would be similar to the isolated arrangements for piping and ductwork shown in the previous two chapters. These non-isolated options are shown below.

Figure D9.4.2-3; Lateral Cable Restraints used with a Gauge Material Ring Clamp



There are many options that exist for the arrangements of lateral restraints used in conjunction with trapeze-mounted systems. Shown below are several options for cable-restrained systems.

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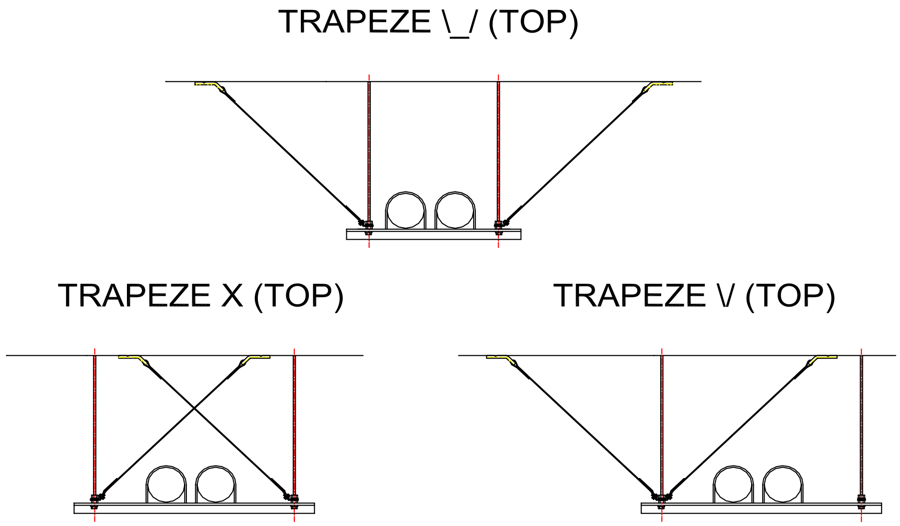
Figure D9.4.2-5; Lateral Cable Restraints Mounted to a Trapeze

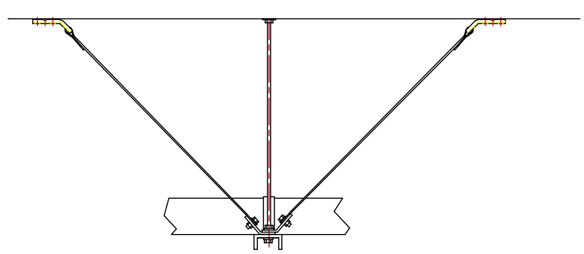


Axial Restraint Examples

Axial restraints cannot be connected to a standard clevis and be expected to work. This is because there is inadequate friction between the bracket and the conduit to transfer the forces in the conduit to the restraint. When axially restraining conduit, a trapeze or conduit clamp tightly attached to the conduit is the most common connecting device used. Details on these connections will be addressed in later sections.

Axial restraints offset from the centerline of restrained electrical run will generate additional bending forces in the tray or bus. Because of the nature of these components, unless restraints are fit on both sides, there will be an offset. Because these components are relatively fragile, the use of a single axial restraint offset from the center of the run is not recommended. For cases where multiple electrical runs are being supported on a common structure, the axial restraint should be between components in line with the approximate side-to-side center of gravity location.

Figure D9.4.2-6; Axial Cable Restraints



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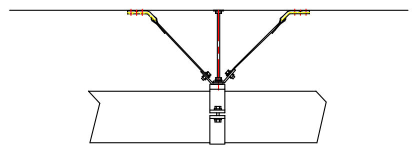
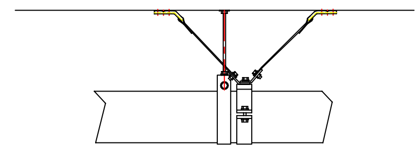
RISER CLAMP / SUPPORT



RISER CLAMP
ADJACENT TO SUPPORT



D9.4.2.2 Hanging Systems Restrained with Struts

As with cable restraints, hanging systems may include supports for single pieces of conduit, multiple conduit runs or a mixture of cable trays, ducts and conduit. Single conduit arrangements can be supported using a clevis or conduit hanger, but multiple components are normally supported on trapeze bars.

Lateral Restraint Examples

For a strut-restrained conduit supported by a hanger clevis there are two typical 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.

Figure D9.4.2-7; Typical Lateral Restraint Strut Arrangements for Clevis-Supported Conduit

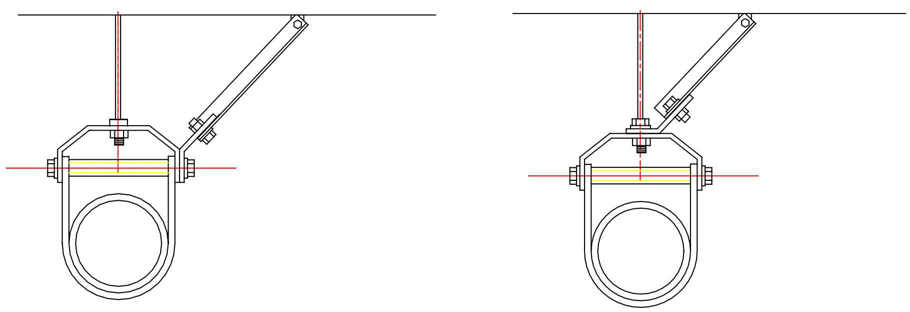


Figure D9.4.2-8; Shown below are 3 options for trapeze-supported conduit. All are equivalent.

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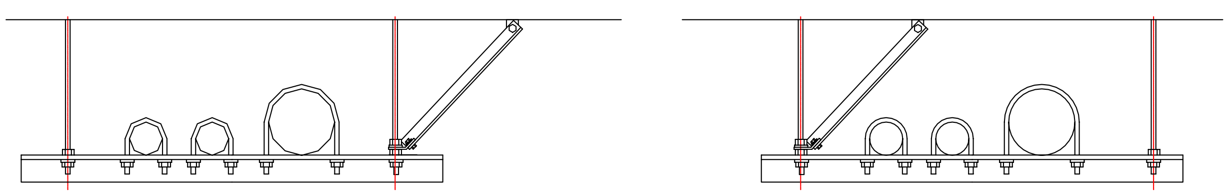

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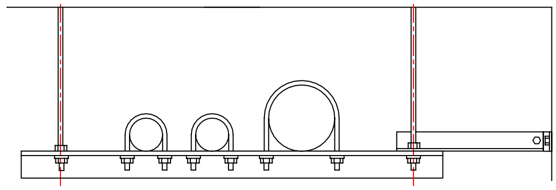


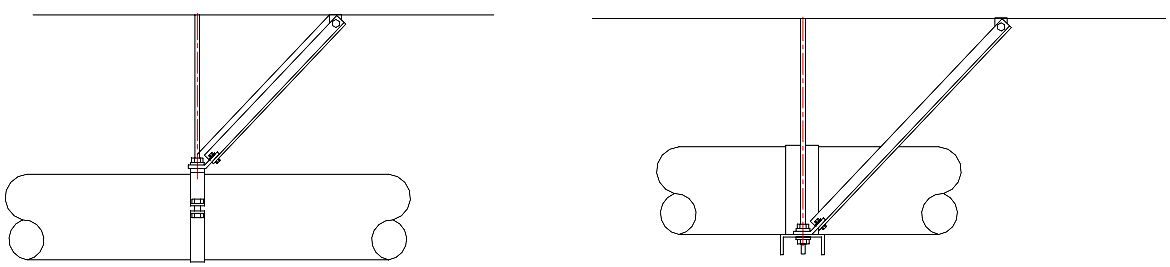
Axial Restraint Examples

As with cables, axial restraints using struts cannot be connected to a standard clevis and be expected to work. When axially restraining conduit, a trapeze or conduit clamp tightly attached to the conduit is the most common connecting device. It may however be possible to attach the restraint to a connector fitting in some cases.

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

As with the cable restraints, it must be recognized that axial restraints offset from the restrained run will generate additional bending forces in the duct, tray or conduit itself. This is true whether mounted to one end of a trapeze or along side a single piece of conduit rather than directly on its center. When the restraint is offset, the maximum permissible offset from the center of the conduit is not to exceed 1 times the conduit diameter. For duct or tray installations, the maximum offset (from the centerline) cannot exceed the width dimension of the tray or duct. For trapezed systems supporting multiple components, a single axial restraint should be located at the approximate center of the trapeze bar or pairs of axial restraints should be installed on each end of the trapeze bar.

Figure D9.4.2-10; Electrical Distribution systems axially restrained with Struts



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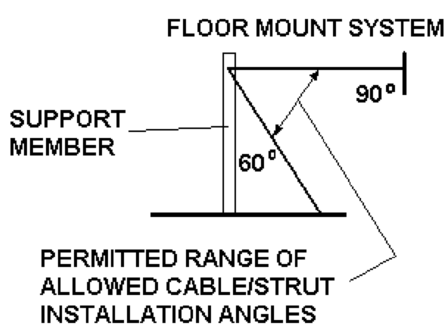
FLOOR OR ROOF SUPPORTED ELECTRICAL SYSTEM RESTRAINTS

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.

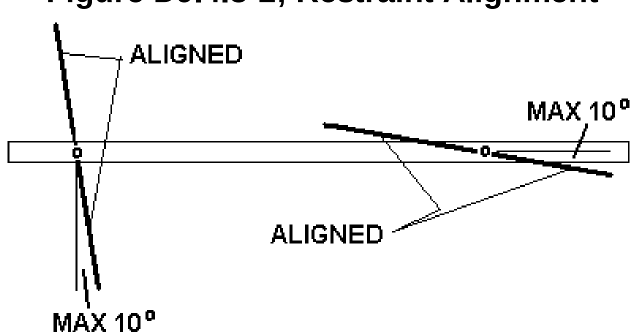
This manual addresses diagonal bracing oriented between horizontal and 60 degrees from the horizontal. Angles in excess of 60 degrees to the horizontal are not permitted.

Figure D9.4.3-1; Permissible Restraint Angles



When installing restraints, lateral restraints should be installed perpendicular (±10 degrees) to the conduit or tray in the plan view. Axial restraints should be in line with the conduit or tray (±10 degrees) again in the plan view. All restraint cables should be aligned with each other. See the sketch below.

Figure D9.4.3-2; Restraint Alignment



Lateral Restraint **Axial Restraint**

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E-mail: sales@kineticsnoise.com
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In general, when restraining conduit or trays, the component actually being restrained is the support device for the system. For floor-mounted equipment this would normally be either a fabricated frame or a trapeze bar. Because the goal is to restrain the actual conduit or tray, it is necessary that the restrained element be connected to the conduit or tray 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 conduit or tray that is not clamped tightly to it, it is obvious that the axial forces generated by the conduit or tray cannot be restrained by the connection to the trapeze bar and some other arrangement is needed.

With respect to firmly connecting restraints to conduit or tray, there are a few general rules that should be followed:

1) For Axial restraints, conduit clamps must be heavy duty and must be tightly clamped against the conduit itself.
2) If the pipe is wrapped or covered with a material that can reduce the clamps ability to grip it, the material must be removed or hardened to the point that positive clamping action can be assured.
3) Trapeze-mounted conduit or trays should be tightly clamped or bolted to the trapeze bar.

In addition, when sizing restraint components that affect multiple components, the total weight of all of the restrained componentry must be considered.

D9.4.3.1 Floor or Roof mounted Systems Restrained with Cables

Floor- or roof-mounted systems may include supports for single runs of conduit, multiple runs, cable trays or bus ducts. Typically, simple box frames are fabricated to support these, no matter what they are.

Transverse Restraint Examples

For a cable-restrained support brackets there are four options normally encountered for non-isolated systems. As Electrical distribution systems are rarely isolated, for the purposes of this document, isolated systems will not be addressed. 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.

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Figure D9.4.3-3; Transverse Cable Restraints for Floor/Roof (Non-isolated)

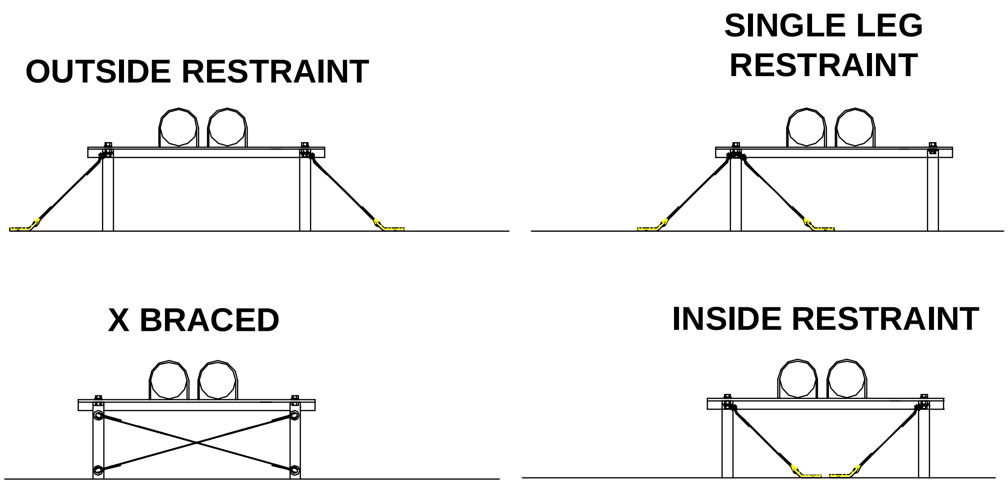
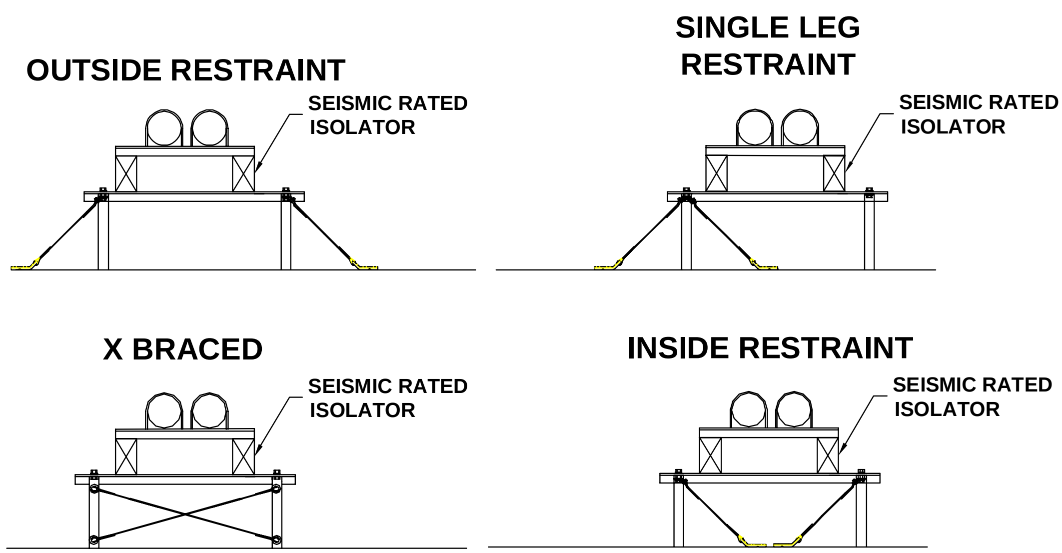


Figure D9.4.3-4; Transverse Cable Restraints for Floor/Roof (Isolated)



Longitudinal Restraint Examples

When longitudinally restraining conduit, a trapeze or clamp tightly fitted to the conduit is the most common connecting device between the restraint strut and a single piece of conduit. When connecting to a cable tray or bus duct, bolts or tray clamps are typically used. Details on these connections will be addressed in later sections.

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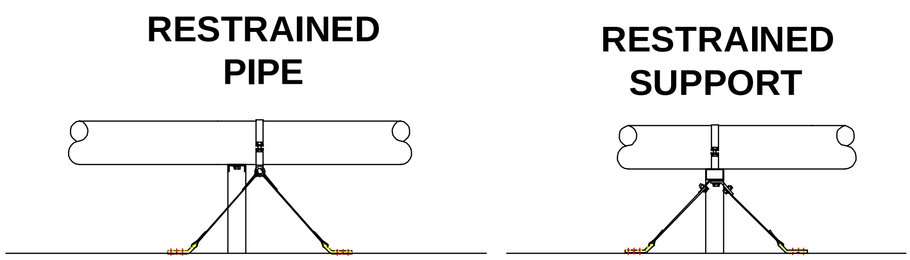
If the details of the connection are ignored at this point, general Longitudinal restraint arrangements recognized in this manual are illustrated below.

Note: Longitudinal restraints offset from the restrained run will generate additional bending forces in the restrained system. This is true whether mounted to one end of a trapeze or along side a single piece of conduit rather than directly under its center. When the restraint is offset, the maximum permissible offset from the center of the conduit, tray or duct is equal to its diameter or width. For trapezed systems supporting multiple runs, a single Longitudinal restraint should be located at the approximate center of the trapeze bar or pairs of Longitudinal restraints should be installed on each end of the trapeze bar or support frame.

Figure D9.4.3-5; Longitudinal Cable Restraints



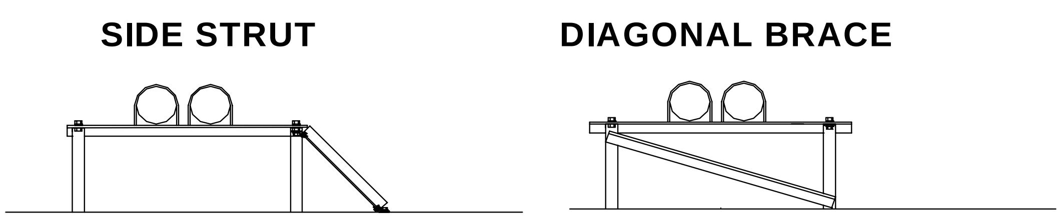
D9.4.3.2 Floor or Roof Mounted Systems Restrained with Struts

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

Transverse Restraint Examples

With struts there are three typical configurations as shown below.

Figure D9.4.3-6; Typical Transverse Restraint Strut Arrangements for Conduit



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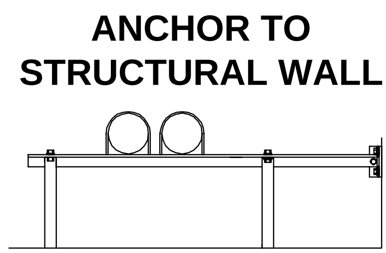


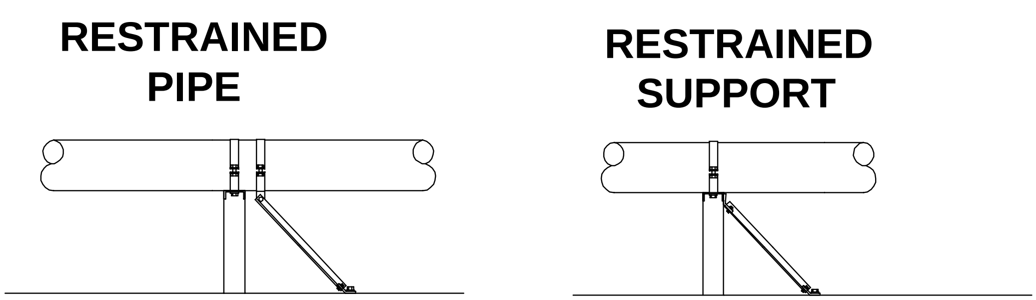
Longitudinal Restraint Examples

When longitudinally restraining conduit, a trapeze or clamp tightly fitted to the conduit is the most common connecting device between the restraint strut and a single piece of conduit. When connecting to a cable tray or bus duct, bolts or tray clamps are typically 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, it must be recognized that longitudinal restraints offset from the restrained conduit, trays or ducts will generate additional bending forces in the component. This is true whether mounted to one end of a trapeze or alongside a single piece of conduit rather than directly under its center. When the restraint is offset, the maximum permissible offset from the center of the conduit, tray or duct is equal to its diameter or width. For trapezed systems supporting multiple components, a single longitudinal restraint should be located at the approximate center of the trapeze bar or pairs of longitudinal restraints should be installed on each end of the trapeze bar or support frame.

Figure D9.4.3-8; Conduit Longitudinally Restrained with Struts



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TRANSFERRING FORCES (ELECTRICAL SYSTEM 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 gravity to ensure their continued long-term operation.

Exceptions:

A) Cable end connections (Swaged ends, U-bolts, and QuakeLocs can be used with appropriate installation procedures).
B) Properly installed heavy-duty riser clamps seated against steel pipes, heavy conduit or other compression resistant materials.
C) 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 or systems 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 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 .)*

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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 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.*

8) Connections between sections of conduit, trays or bus ducts can become critical factors 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 connecting materials and fittings, brazed connections, and plastic pipe.

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NON-MOMENT GENERATING CONNECTIONS

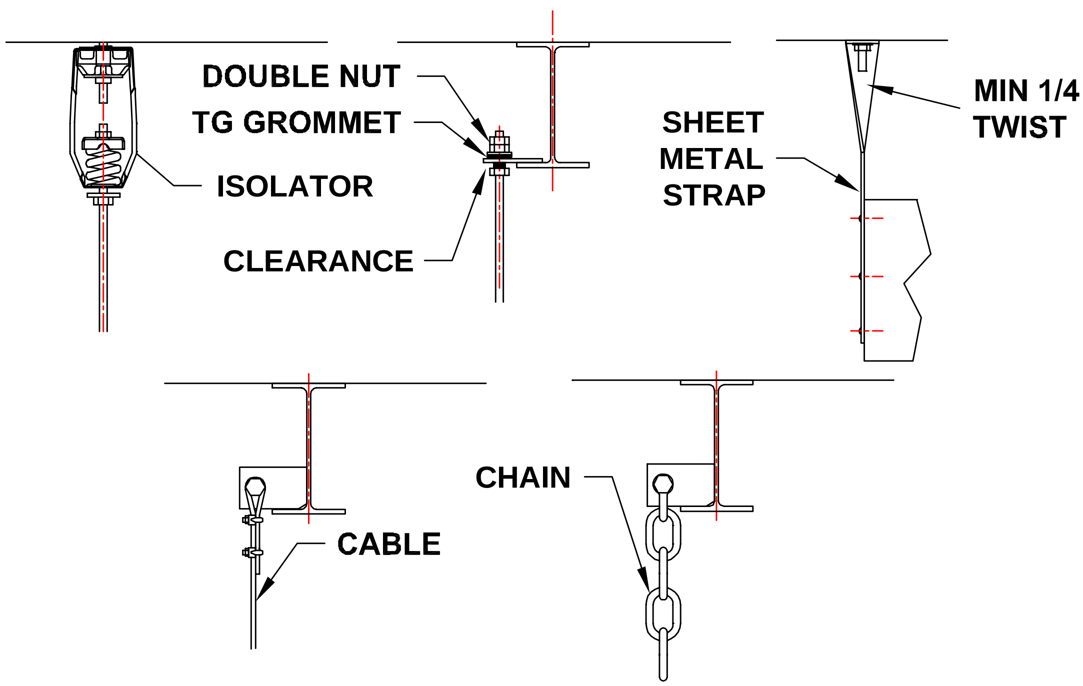
The IBC and 97 UBC codes allow the omission of seismic restraints for most piping, conduit and ductwork runs without regard to size but that are located within 12" of the structure. Refer also to section D2 of this manual for specific exemptions by code version. In order to qualify for this, the following 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".
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.



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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.

D9.6.1 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 electrical distribution system in question 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 D9.6-1; Trapeze-Mounted Conduit Restrained to Structural Wall or Column with a Horizontal Strut (Trays would be similar)

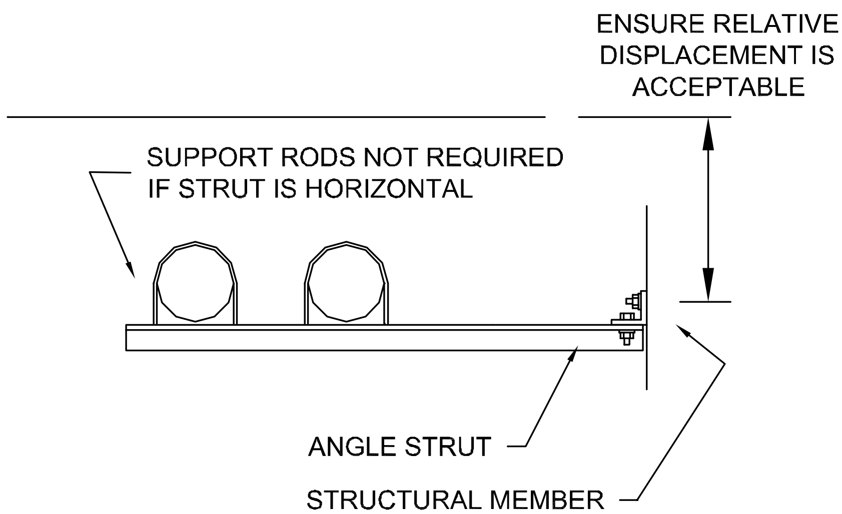

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Figure D9.6-2; Trapeze-Supported Bus Duct Restrained to Structural Wall or Column with an Sloping Strut

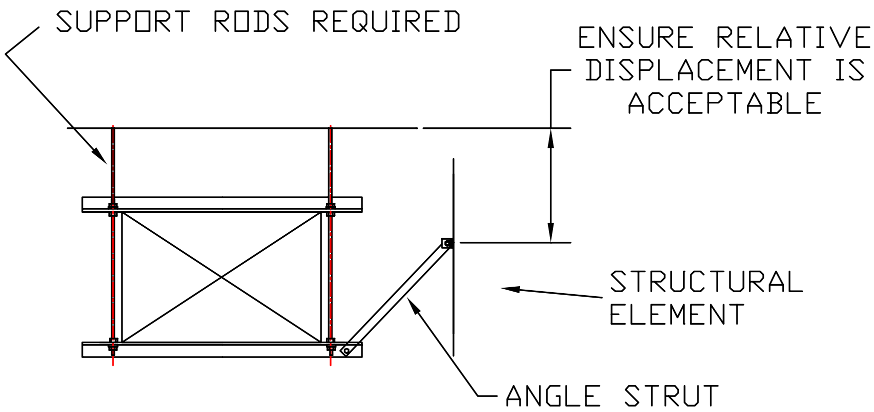
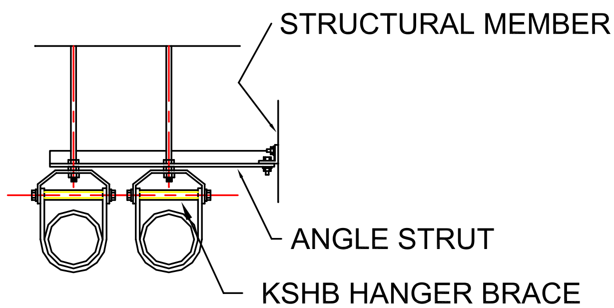


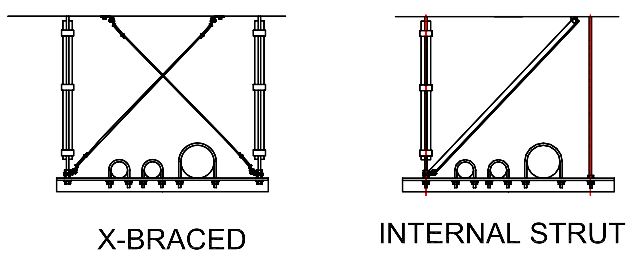
Figure D9.6-3; Clevis-Supported Conduit Restrained to Structural Wall or Column



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 D9.6-4; "X" or Diagonally Braced Restraint Arrangement



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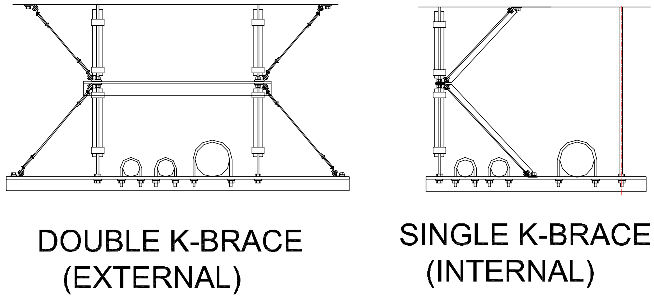
A "K" or double "K" brace can also be used. The "K" can either be located inside the support rods or outside the support rods, but in the case of a double "K", both sides must be identical (either inside or outside).

Figure D9.6-5; 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 D9.6-6; Wall Penetration Restraint (Cable)

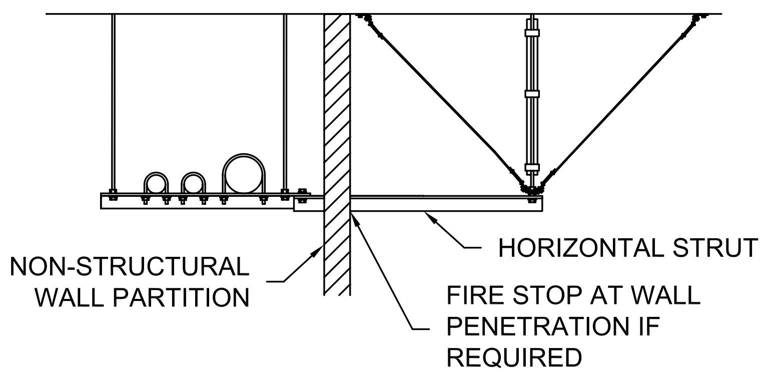
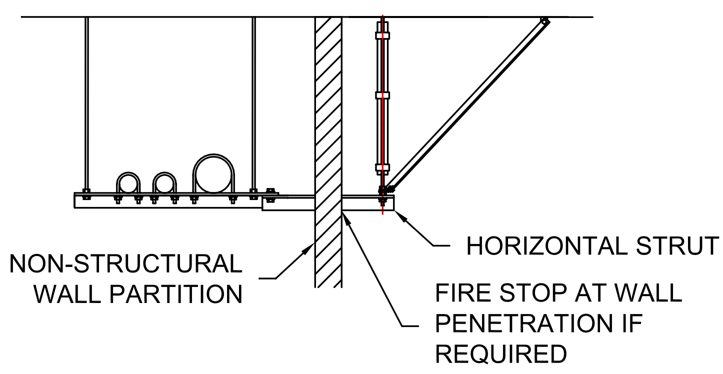


Figure D9.6-7; Wall Penetration Restraint (Strut)



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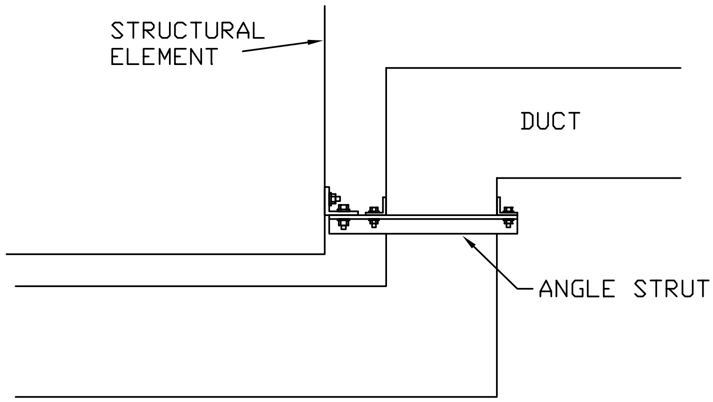
D9.6.2 Axial Restraint Strut at a Dogleg

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 bus ducts, 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.

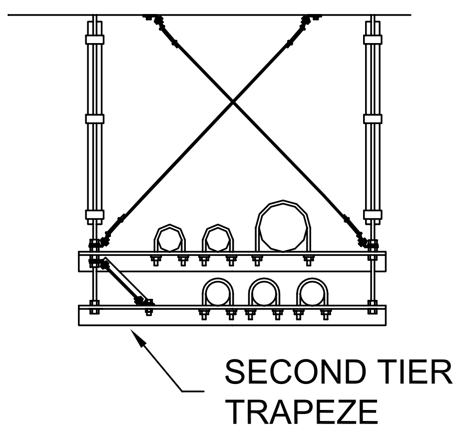
Figure D9.6-8; Axial Restraint Strut at a Dogleg



D9.6.3 Piggyback or Double-Tier Restraint

In congested areas, there is often a double layer of conduit 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 supported components must be similar in nature and ductility.

Figure D8.6-9; Piggyback or Double-Tier Restraint Arrangement



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D9.6.4 Restraints for conduits, ducts or trays 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 a system 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 system that is located either just above or just below its installed elevation. The system 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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