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D5.0 – Floor and Wall Mounted Equipment

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FLOOR MOUNTED EQUIPMENT PRIMER

Introduction

This section will deal with the basics of the Kinetics Seismic Certification analysis for floor mounted equipment and the basic location and placement of the required isolators or restraints around the perimeter of the equipment. Also, there will be a general discussion concerning the required number and size of fasteners at each isolator or restraint location.

We will begin the discussion with seismic isolators and restraints that have three axis restraint elements. Table D5.1.1-1 is a listing of the common isolator and restraint models having tri-axial restraints offered by Kinetics Noise Control.

Table D5.1.1-1: Typical Kinetics Tri-axial Seismic Isolator and Restraint Models.

Isolator Models	Restraint Models
FHS	HS-5
FLS	HS-7
FLSS	KSMS
FMS	FMS
KRMS	--------
Titan	--------

Kinetics Seismic Certification Analysis Program

Figure D5.1.1-1 shows a typical arrangement for these types of devices around a typical piece of equipment. The piece of equipment in Figure D5.1.1-1 may be a generator on an inertia base located on a concrete housekeeping pad. The Kinetics Seismic Certification analysis program calculates the code values for horizontal and vertical seismic forces acting on the equipment. These seismic forces are applied at the center of gravity (***C.G***.) of the equipment. The horizontal seismic force may come from any direction. So, the program will cycle through a full ***360°*** to determine the worst case loading condition for the isolators or restraints. Then the program will compute the forces acting at each isolator or restraint location, and then compare these values to the allowable limits for the selected isolator or restraint model and size. These allowable limits are based on the strength of the isolator or restraint components as well as the strength of the attachment of the isolator to the structural steel framing of the building. One half of the lower of these two values then defines the allowable limit for the isolator or restraint. If the isolator or restraint is to be attached to concrete, the concrete anchors are evaluated separately. The Kinetics Seismic Certification program will print out the

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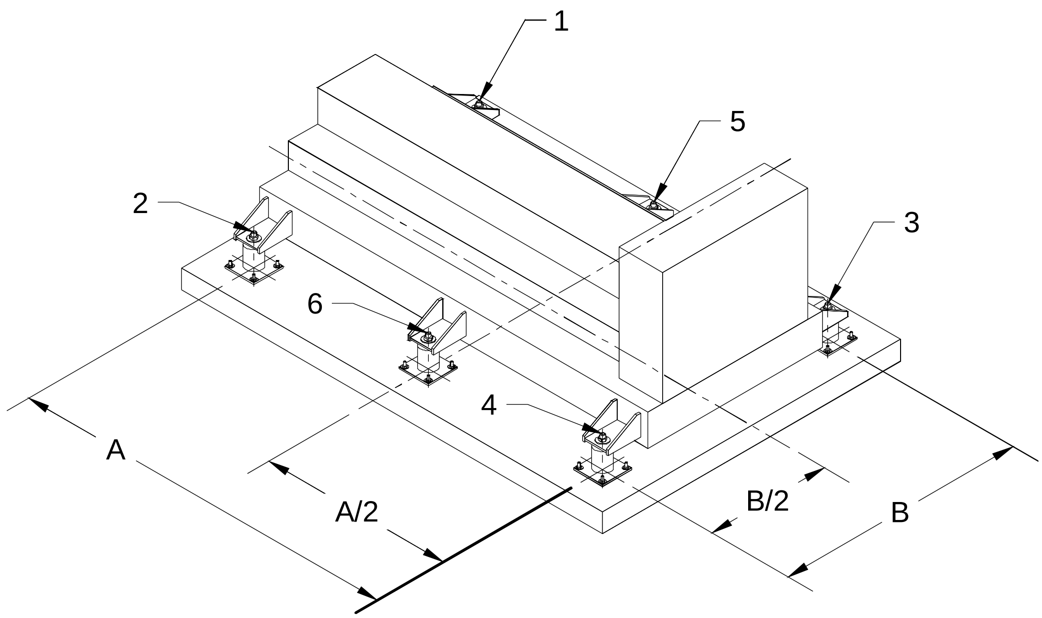
safety factor for each isolator or restraint, the safety factor for the bolts required to attach the isolator to the building's structural steel, and the safety factor for the concrete anchors that fit the holes in the isolator or restraint mounting plate. Also included in the information will be the number of bolts or anchors required for each isolator or restraint location.

Occasionally the anchorage to concrete is insufficient when using the anchor size, number, and spacing provided by the standard base plate on the isolator or restraint. In these cases the Kinetics Seismic Certification program will recommend a standard oversized base plate to be used with the isolators/restraints. For a discussion on the Kinetics Noise Control oversized base plates see Documents D5.2.1 and D5.2.2.

Figure D5.1.1-1: Typical Equipment and Isolator or Restraint Layout.



Isolator or Restraint Locations

The isolator or restraints are located of the geometric center lines of the equipment as indicated in Figure D5.1.1-1. On the Kinetics Seismic Certification sheet there is a schematic of the plan view of the equipment showing the general isolator or restraint locations. An example of this schematic is shown in Figure D5.1.1-2. The **ATTACHMENT POINT** numbers in Figure D5.1.1-2 correspond to the isolator or restraint numbers in Figure D5.1.1-1. Isolators or restraints ***5*** and ***6*** in Figure D5.1.1-1 are represented by the unnumbered **ATTACHMENT POINTS** in Figure D5.1.1-2. Note that the odd numbered isolators or restraints are always on one side of the equipment, and the even numbered Isolators or restraints are on the other. If there are more than three pairs of isolators or restraints, they should be spaced as evenly as possible along the length of the equipment between pair ***1 & 2***, and pair ***3 & 4*** starting with pair ***5 & 6*** closest to pair ***1 & 2***. This is further illustrated in Figures D5.1.1-3 through D5.1.1-5.

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These figures represent the plan view of a typical air handling unit that is restrained with Kinetics Noise Control Model **KSMS Seismic Equipment Brackets**. In these figures the terms ***L*** and ***W*** are the overall length and width of the equipment respectively. Dimensions ***A*** and ***B*** are the dimensions that establish the isolator/restraint locations. The variable ***N*** represents the number of isolators/restraints.

Figure D5.1.1-2: Seismic Certification Isolator or Restraint Location Schematic.

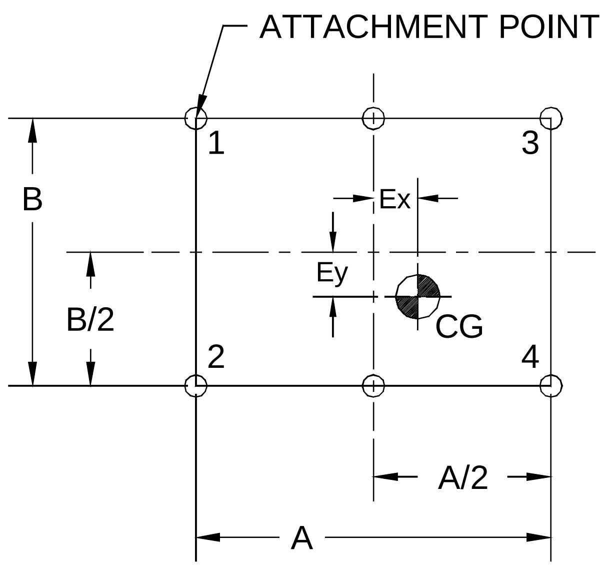

Figure D5.1.1-3: Typical of Four Isolator or Restraint Locations.

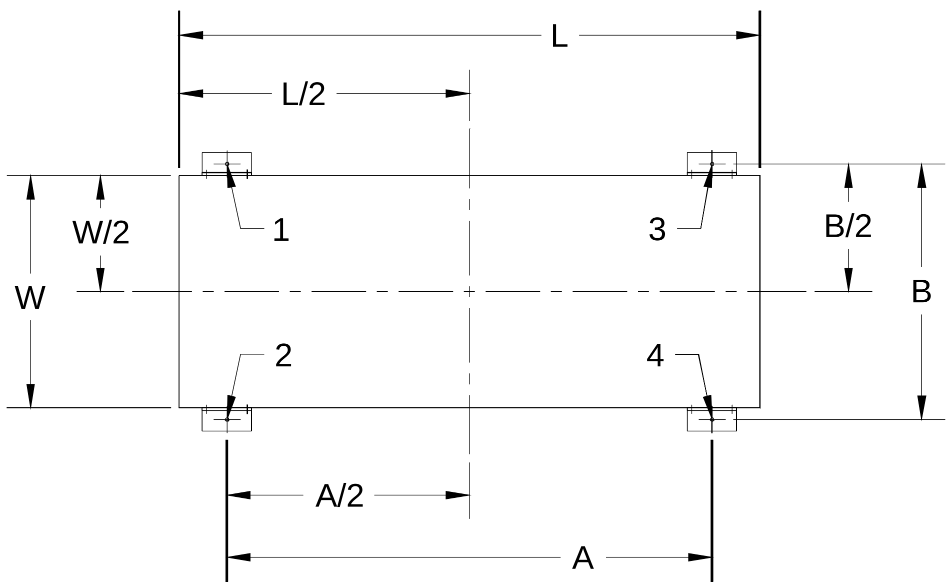

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Figure D5.1.1-4: Typical of Six Isolator or Restraint Locations.

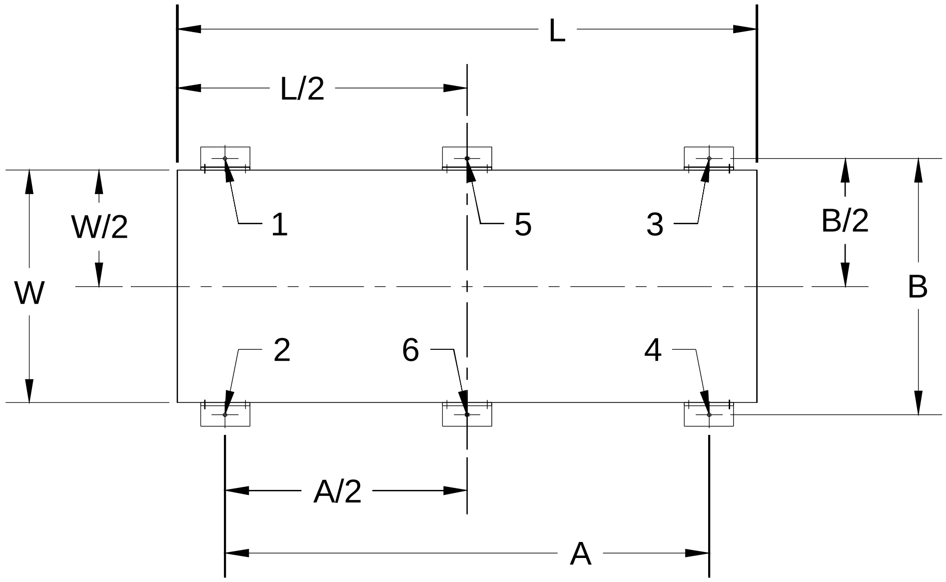
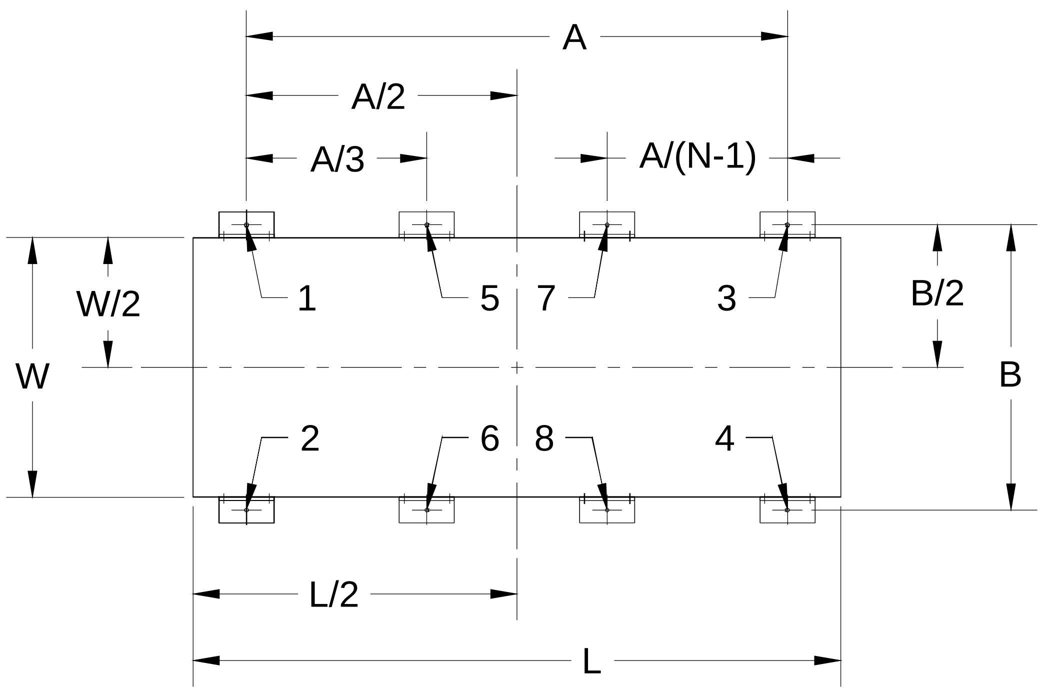


Figure D5.1.1-5: Typical of Eight or More Isolator or Restraint Locations.



Bolt/Anchor Number & Size and Weld Size & Length

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In general, the number of bolts or anchors used to attach the isolator/restraint to the building structure and their size are specified on the Kinetics Seismic Certification sheet. The bolts may be ***ASTM A-307***, ***SAE Grade 2***, or better. In some instances, they may be ***ASTM A-325, SAE Grade 5*** or better. *However care must be taken if **ASTM A-490** or **SAE Grade 8** bolts are used. These fasteners are made from highly heat treated steels and may behave in a brittle manner in service.* The concrete anchors certified by Kinetics Noise Control for use with isolators and restraints sold by Kinetics Noise Control are Model ***KCAB Seismically Rated Wedge – Type Anchors for Masonry,*** Model ***KUAB Seismically Rated Undercut Type Anchors,*** Model ***KCCAB Seismically Rated Cracked Concrete Type Anchors,*** Model ***KAAB Seismically Rated Adhesive Anchor Bolts,*** Model ***KSAB Seismically Rated Screw Type Anchors*** and Model ***KAST Seismically Rated Cast in Place Anchors.***.

In lieu of proper documentation, the appropriate bolt or anchor size may be determined by the size of the holes in the mounting plate or the oversized base plate. Table D5.1.1-2 will be useful in obtaining the proper bolt or anchor size.

Table D5.1.1-2: Bolt or Anchor Size vs. Hole Size

Hole Size (in)	Bolt or Anchor Size (in)
5/16	1/4
7/16	3/8
9/16	1/2
11/16	5/8
13/16	3/4
15/16	7/8
1-1/16	1
1-3/16	1-1/8
1-5/16	1-1/4

Unless otherwise specified by Kinetics Noise Control, all of the mounting holes in the isolator or restraint mounting plate or the oversized base plate are to be used with the appropriate sized fastener to attach the isolator or restraint to the building structure.

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If the isolator or restraint is to be attached to building structure by welding, the weld size and the linear length as well approximate locations will be specified on the Kinetics Seismic Certification sheet. The welds specified will have the same strength as the proper number and type of bolts for the most highly loaded isolator or restraint.

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FORCES TRANSFERRED BETWEEN THE EQUIPMENT & RESTRAINT

Introduction:

Due to the nature of certain seismically restrained isolators, and certain types of seismic restraints, the forces that are transferred between the equipment and the restraint, and the restraint and the ground are not what would be normally expected from the normal static force analysis. In this document we will discuss the basic types of restraints and isolators, and point out the effects that each will have on the magnitude of the forces transferred.

The newer building codes such as the ***IBC*** Code family and ***TI-809-04*** have mandated design seismic forces that are much larger in magnitude than were previously specified in the older model building codes. This means that the restraints that will be specified, oversized base plates that will be required, and the building structure required to support the equipment with its isolators, and/or restraints will all increase in size and capacity.

Basic Restraint Types:

The most basic types of restraints are those with built in clearance, and those without built in clearance. The following list shows the basic restraint types with the Kinetics Noise Control Models that apply to each.

1.) **Restraints with Built In Clearance: Tri-Axial Restraints – HS-5, HS-7, and FMS; Bi-Axial Restraints – HS-2; Single-Axis Restraint – HS-1.**

2.) **Restraints without Built In Clearance: KSMS**

The restraints with built in clearance are used primarily for three reasons. First this type of restraint is used when free standing steel coil springs are specified for isolation of the equipment. This allows the equipment to move, vibrate, slightly when operating without contacting the restraints. Second they may be used for equipment that is sitting on the floor and has no provisions to allow it to be attached solidly to the building structure, such as mounting feet or a structurally sound base. Third, certain models of this type of restraint, such as the ***HS-1***, may be added after the equipment has been installed and is operational, if there is enough space on the floor or housekeeping pad.

When restraints with built in clearance are used, the engineer, contractor, equipment supplier, and building owner need to be aware that impact forces greatly in excess of the basic code values for the horizontal and vertical seismic forces may be transferred between the equipment and the restraint. These built in clearances allow the equipment to be accelerated relative to the restraint. When the restraint is finally contacted, the equipment has generated an appreciable amount of kinetic energy that must be dissipated in the restraint. If the contact forces are stiff, the impact forces will be large. If the contact surfaces are relatively soft, the impact forces will be smaller in magnitude.

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In an effort to address this impact between the equipment and the restraint, the newer codes require that an ***Impact Factor*** of ***2:1*** be applied to the basic computed seismic force. Depending on the design of the restraint and the magnitude of a seismic event, this factor may or may not, be representative of the actual acceleration values encountered in service, however, it is a good point from which to begin.

The equipment manufacturers must to be cognizant of these impact forces as they will affect the reliability of their equipment. They must be considered when designing equipment that will be certified under the provisions of the ***IBC*** for continued operation after an earthquake for facilities that are categorized as essential or hazardous.

For restraints with built in vertical clearance, the forces that resist the overturning of the equipment are concentrated at the corner restraints. This sometimes leads to the necessity to select restraints and/or oversized base plates that seem to be larger than common practice would normally recommend.

The restraints without built in clearance used to mount rigid equipment will not have the impact force issues that the restraints with clearance have. Also, the forces that resist overturning are more-or-less evenly distributed between the restraints. These restraints are equivalent to solid mounting the equipment using the mounting feet provided by the equipment manufacturer. These restraints may also be used in conjunction with the pre-existing mounting feet on the equipment to provide additional restraint as required by the code provisions.

Basic Seismic Isolator Types:

The isolators that utilize steel coil springs fall into two basic types as shown below with Kinetics Noise Control models that typify each type.

1.) **Contained Spring Seismic Isolators: FHS with an Oversized Base Plate; FLS; FLSS; and FMS. In these isolators, when the equipment moves upward, and the vertical restraint is contacted, the spring force *<u>is not</u>* added to the loads in the bolts, anchors, or welds that attach the isolator to the building structure. The spring forces are, thus, tied up in the isolator housing.**

2.) **Uncontained Spring Isolators: FHS without an Oversized Base Plate, or any tri-axial restraint arrangement where the isolator is a separate component from the restraint and is supported directly by the building structure. In this type of isolator, when the equipment moves upward and contacts the vertical restraint, the spring force *<u>is</u>* added to the loads in the bolts, anchors, or welds.**

For all of the seismic isolator types listed above, the seismic restraint is a tri-axial type with built in clearance. As such, the previous discussion concerning restraints with built in clearance will apply to these products as well. Also, the forces that resist the overturning of the equipment will tend to be concentrated at the corner isolator locations in a similar fashion.

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The Kinetics Noise Control Model ***KRMS Seismic Neoprene Isolator*** falls in to the category of a restraint/isolator assembly without built in clearance. The vertical restraints forces are carried entirely though the housing to the bolts, anchors, or welds attaching the isolator to the building structure. So, it does not fall into either the category of restrained spring, or unrestrained spring. It exhibits the characteristics of both, and must be treated accordingly.

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ATTACHMENT OF EQUIPMENT TO RESTRAINTS

Introduction:

Restraints can be attached to equipment in a number of ways. The most obvious is by directly bolting the equipment mounting face or stud on the restraint devise to the equipment via a factory provided hole in the equipment. Unfortunately many pieces of equipment (particularly those not initially designed for seismic service) do not include mounting provisions. In some cases, several independent components make up the piece of equipment and often, if provided, holes are not well located or of appropriate size for direct connection to the restraint device.

Wherever the restraints are attached to the equipment, the equipment manufacturer must offer assurances that the application of seismically generated forces at these locations will not exceed the structural capabilities of the equipment. When reviewing the forces, the manufacturer must take into account shear, tensile and bending forces at the connection points.

D5.1.3.1 Equipment Directly Bolted to Restraints:

Where equipment can be directly bolted to the restraints and where the pattern is reasonably appropriate, this is the most appropriate method to use. The installer should refer to the certification that was performed on that particular piece of equipment and ensure that the number of attachment points and geometry used are consistent with the mounting pattern on the equipment. If the computation addressed several similar pieces of equipment, the spacing used would have been the smallest of all of those included in the analysis (as this would be the worst case). As such, if the actual bolt pattern found on the equipment is larger than that used in the analysis, mounting using the larger pattern is quite acceptable and would not negate the analysis.

It is further assumed, when performing an analysis or certification, that the hardware used matches the holes or studs in the restraint device. It is not permitted to downsize this hardware relative to that originally intended for the restraint. If the hole in the equipment is larger than the restraint hardware, it must be "fitted" to the bolt used in the restraint. This can be done by welding a washer plate to the equipment, adding a sleeve or using a grommet such as the Kinetics "TG" grommet. The hole size cannot exceed the nominal hardware diameter by more than 1/8".

If the hole in the equipment is smaller than the size required by the restraint, it must either be enlarged (with the equipment manufacturer's knowledge and permission) or the equipment must be fitted with an appropriately sized adapter to allow the use of the larger hardware.

D5.1.3.2 Equipment Welded to Restraints:

In many instances, there is no provision for bolt down attachment of the equipment, the arrangement is not conducive to seismic restraint or the bolt attachment provisions are simply inadequate. In these cases, welding is the most common method of attachment. Optional

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welding information is provided on Kinetics Noise Control's standard Certification document. Where this information is not provided, but the acceptable bolt size is known and bending forces are not significant, the following table can be used to size the weld based on the bolt size.

Table D5.1.3-1; Weld Length in Inches that are Equivalent to 1 Bolt

	Weld Equivalents to A307 Hardware					Weld Equivalents to A325 Hardware				
Bolt Dia	1/8 Weld	3/16 Weld	1/4 Weld	3/8 Weld	1/2 Weld	1/8 Weld	3/16 Weld	1/4 Weld	3/8 Weld	1/2 Weld
0.25	1.11	0.74	0.56	0.37	0.28	2.44	1.63	1.22	0.81	0.61
0.375	2.50	1.67	1.25	0.83	0.62	5.50	3.67	2.75	1.83	1.37
0.5	4.44	2.96	2.22	1.48	1.11	9.78	6.52	4.89	3.26	2.44
0.625	6.94	4.63	3.47	2.31	1.74	15.27	10.18	7.64	5.09	3.82
0.75	10.00	6.67	5.00	3.33	2.50	22.00	14.66	11.00	7.33	5.50
0.875	13.61	9.07	6.80	4.54	3.40	29.94	19.96	14.97	9.98	7.48
1	17.77	11.85	8.89	5.92	4.44	39.10	26.07	19.55	13.03	9.78

When using the above table (D5.1.3.1), each weld used should be approximately centered at the restraint location indicated in the analysis. In addition the leg **size** must not be larger in size than the thickness of either of the materials that are being welded together. Welds should be made to structural members within the equipment and should not be performed without the knowledge and approval of the equipment manufacturer.

D5.1.3.3 Intermediate Structure:

Intermediate structures are used for a number of reasons. First, they are used where the equipment is not structurally adequate for the direct attachment of the restraints. Second are cases where the equipment is "floated" on springs and there are multiple individual components that must be held in proper alignment with one another. Occasions when mass must be added to the system for stability can require an intermediate structure and lastly, when the type of restraint or isolator desired is not directly compatible with the type of mounting arrangement available on the equipment.

If an intermediate structure is fitted, this structure must be designed to withstand the full local restraint loads at their points of attachment and must interface with the equipment in such a fashion that the forces transmitted to the equipment are within the structural capabilities of the equipment. One of the biggest benefits of the use of intermediate frames is to distribute the high point loads (and often bending loads) that can be applied by the restraint components over several connections to the equipment. In the case of bending loads, intermediate structures can sometimes prevent them from being transmitted into the equipment at all.

D5.1.3.4 Cautions and Equipment Durability Design Factors:

When connecting restraints to equipment, they must be connected in such a way as to be "permanently" connected. They cannot be connected to removable panels, doors or covers.

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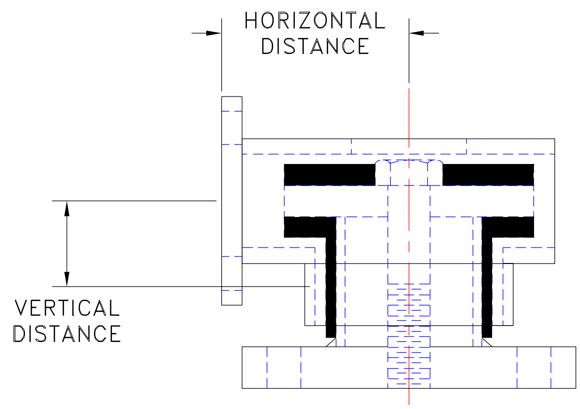
They also must not be located in such a way that they obstruct removable panels, doors or covers.

Care must be taken to ensure that the equipment has the capability to resist the seismic loads (particularly bending). Shear and Tensile forces can be obtained directly from Certification documents. These forces act at the center of the snubbing elements in the restraint device. Bending can be determined by factoring in the distance in the horizontal and vertical axis between the center of the snubbing element and the center of the mounting face or stud at the equipment surface.

The maximum moment that the equipment must be capable of withstanding is the sum of the horizontal and vertical moments. The Horizontal moment is the peak horizontal force from the analysis multiplied by the vertical distance from the snubber centerline to the center of the mounting surface face. This must be added to the peak vertical force multiplied by the horizontal distance between the snubber centerline and the center of the mounting surface face.

Figure D.5.1.2-1; Horizontal and Vertical Offsets



For floor mounted equipment, the peak vertical force is compressive however, depending on the restraint type, the springs in isolated systems may generate an uplift force on the restraint attachment hardware that is greater than would be predicted by a simple overturning analysis. Were appropriate, this must be taken into account. This occurs when the restraint is separate from the support system or if the spring force is not trapped within the isolator housing (For example an FHS without an oversized baseplate). The Kinetics Certification takes these factors into account when evaluating restraints, however if someone is looking to validate the numbers by hand, The peak vertical force to which the anchors would be exposed would equal listed the dead load (expressed as a positive number) plus the listed uplift force indicated in the standard certification document.

Below is listed some typical output data in which the worst case location is Loc 4. For it, the peak horizontal force would be 775 lb. If the restraint device in this instance included a fully contained spring coil (like an FLS) the peak vertical uplift force to which the anchors would be

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exposed would be the listed 728 lb. In the case of an FHS, the peak vertical load to which the anchors would be exposed would be *(The static load expressed as a positive number + the uplift load.* In this case, it works out to be 1704 lb.

Table D5.1.3-2; Vertical Load Components

Output Data				
Certification Loads (Seismic) (lb)	Loc 1	Loc 2	Loc 3	Loc 4
Static Load	**-552**	**-685**	**-787**	**-976**
Max Uplift Load at Loc:	**728**	**728**	**728**	**728**
Max Horiz Load at Loc:	**439**	**544**	**625**	**775**
Effective Corner Wt	**-553**	**-686**	**-787**	**-976**
Calculated Restraint Safety Factors (Must be greater than or equal to 1)				
	Loc 1	Loc 2	Loc 3	Loc 4
Restraint SF if Welded to Steel	**2.04**	**1.86**	**1.73**	**1.53**
Restraint SF if Bolted to Steel	**2.04**	**1.86**	**1.73**	**1.53**
Restraint SF if Anchored to Concrete	**.36**	**.34**	**.32**	**.29**
Anchor/Attachment Bolt Size/Qty	**0.375 / 2**	**0.375 / 2**	**0.375 / 2**	**0.375 / 2**
Min Anchor Embedment Req'd	**3"**	**3"**	**3"**	**3"**

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ATTACHMENT OF RESTRAINTS TO STRUCTURE

Introduction:

Unlike the connection between restraints and equipment (which is almost always a metal to metal connection), the connection to structure can be made to a wide variety of materials. The most frequent connection is to concrete, but connections to structural steel, wood and gage materials are also common. As the structural connection has the potential to be the weakest link in the anchorage chain, proper treatment is critical.

In addition to being critical to the anchorage of the equipment, the structural connection also has the potential to impact the durability of the structure. Because of this, all connections to structure should be reviewed with the engineer of record prior to installation to ensure that the attachment method chosen cannot result in a structural weak spot that can cause an unintended failure in the building or other dangerous situation.

Of particular concern are the following:

1) Connections to structural steel involving drilling holes or otherwise weakening the structure.
2) Connections to post-tensioned concrete slabs involving drilling into the slab.
3) Bolt or screwed connections to the narrow edge of wooden beams.
4) Any connections to gage material.

Connections to Concrete

Because of the brittle nature of concrete, it is particularly susceptible to failures that result from the pounding loads generated by earthquakes. As a result, the anchors selected must be sized conservatively. While cast in place anchors are preferable from a loading standpoint, the ability to properly locate them at the time of the pour is very low and they are rarely used in equipment mounting applications. If this hurdle is overcome, they can be sized using conventional anchor sizing procedures as identified in the current version of ACI 318 or through the use of the Kinetics Seismic Certification Program.

Most commonly, post-installed anchors are used. While these can be installed at the time the equipment is placed, they do not have the same positive grip as to the cast in place anchors. As a result, reduced capacities based on ICBO/ICC tests must be used and frequently factors are added to increase the design forces used in the analysis to further ensure that the anchors will remain functional.

In past versions of the IBC, wedge type anchors had been preferred. These anchors are relatively easy to install, continue to expand as they are exposed to tensile loads and offer added confidence that they will continue to function, even in cracked concrete. On the newer versions of the IBC however, many different types of anchors have been tested and approved and depending on the application, one type may have better performance characteristics than another.

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Unless directed otherwise or for cases where very large anchors are required and in places where they qualify, Kinetics Noise Control will design around seismically approved wedge type anchors.

In the early IBC codes (2000/2003), the codes dictate that undercut anchors be used for hard mounted equipment of greater than 10 hp. The later versions of the code allows the use of approved, properly selected adhesive anchors in their place. This requirement does not exist for isolated equipment. If used, undercut anchors require that a hole be drilled and then be modified to include an oversized pocket at their base. These pockets can be created with a special tool or in some cases, can be cut with the anchor itself. These pockets offer a more positive lock for the bolt than can be obtained with a wedge type anchor.

When using post-installed concrete anchors, all anchors are to be embedded, spaced and located far enough away from the edge of a slab to meet their rating requirements. Generally speaking, they must also retain 1" or more cover of concrete between the bottom of the hole and the opposite face of the concrete. For slabs on grade, this value should increase to at least 1-1/2". Because of this requirement, the size of the thickness of the concrete has a direct impact on the maximum permitted anchor size. Generally these limitations restrict the use of anchors larger than 3/8" when the popular floor slab thickness of 4" is used. If a larger anchor is required, some special treatment of the floor slab is needed.

All anchors are rated for installation into a single, uninterrupted layer of concrete. Because of this, unless poured at the same time and as one piece with the floor slab, the added thickness of a housekeeping pad cannot be added to the floor slab thickness when determining the maximum allowed anchor embedment. Instead, the housekeeping pad by itself, must be adequately thick to accommodate the anchors and must be tied with an array of smaller anchors to the structural floor. There is more information on designing housekeeping pads in the appendix of this manual.

Because post-installed anchors are dependent on friction for their capacity, it is critical that they are torqued to the appropriate level. Also, because anchors of similar sizes as manufactured by different manufacturers do not possess equal capacities, it is not permissible to substitute away from those that were assumed in the evaluation and certification process. All Kinetics Certifications are based on the use of Kinetics Noise Control provided anchors, torqued in conformance with the anchor torque data provided in the submittal information and also available in the product section of this manual.

An optional attachment method is to drill through a floor slab above grade and install the restraint device using bolts and nuts. If this is done, any factors that may have been used in the analysis to derate the anchors, can be ignored and the attachment can be treated as a through bolted connection.

A second option is to cast an oversized embedment plate into the floor in the approximately location of the required restraint device. This plate can be interfaced with the steel reinforcement in the slab to ensure that it will not pull out. When the equipment is installed at

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some later time, the restraints can be welded to the embed plate and the entire restraint arrangement can be treated as though it was attached to concrete.

Connections to Structural Steel

There are two different types of steel structures to which equipment may attach. The first is a purpose built structure that was designed specifically to support the equipment being restrained and the second is a structure whose primary design intent is based on the capacity of the building envelope to withstand building design loads.

In the first case, attachment holes are common and have typically been accounted for in the design of the structure. The use of bolts to attach the equipment is common practice, but should be coordinated with the structure's designer.

In the second case however, the attachment of equipment is frequently an afterthought. While the structure would globally have been designed to have adequate capacity for both its intended building function and equipment support, the addition of holes or of the locally generated stress concentration caused by the holes can weaken it to the point that serious building structural issues can emerge. Under no circumstances should the structure be modified in such a way that it would be weakened without prior review of the structural engineer of record. Connections to the building structure are normally accomplished by welding components to the structure. These components can include holes or other bolting provisions. If the attachment process involves the removal of fire proofing material on the steel, it must be replaced prior to completion.

When sizing holes to match the bolts in a restraint, they are not permitted to exceed the nominal hardware size by more than 1/8". Thus the largest hole permitted for a 5/8" bolt is 3/4". Slotting this hole for alignment is not permitted and if required, the hole must be repaired to limit the clearance to 1/8" prior to the installation of hardware. All bolts are to be tightened in conformance with normal practice.

Connections to Wood

There are a wide variety of wood sections to which people attach equipment. These range from heavy timber members and engineered lumber to roof sheeting. When seismically restraining equipment, connections should be made to structural grade or "engineered" lumber only.

Where possible, the preferred connection is with a through-bolt that penetrates the wood member and bears against a load spreading washer plate (or fishplate) on the back side of the wood to prevent crushing.

Where it is necessary to screw into the wood, lag screws inserted into properly drilled holes can be used providing the following rules are followed:

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1) The edge distance from the center of the screw hole to the edge of the wooden member in which it is inserted must be at least 1-1/2 bolt diameters.

2) The end distance (from the bolt to the end of the wooden member in the direction of the grain's axis) must be at least 7 bolt diameters.

3) Spacing between bolts must be at least 4 bolt diameters.

4) Embedment must be adequate for the design loads expected.

Of these items, the first 3 are relatively straightforward. The last item is more ambiguous and needs further explanation. The bolt capacity is a function of many factors and should be sized specifically for the application under review. The density and type of the wood, the angle of the screw relative to the grain and the redundancy of the connections all have significant impact on the rating of the connection. In order to achieve the full rated capacity of the restraint device (if connected with lag screws), the limiting capacity of the screw must be a metal failure in the screw itself. In general, this means that for a reasonably dense grade of structural lumber and a screw mounted at 90 degrees to the grain axis, an embedment depth of 9 diameters is needed to achieve full capacity. Further information on the design of lag screw connections is available in the NDS/ASD *National Design Specification for Wood Construction Manual* published by American Forest and Paper Association / American Wood Council or Section A7.3 in the Appendix portion of this manual.

As with connections to steel, it is mandatory that the structural engineer of record is aware of and approves connections to wood structures because of possible adverse effects that the connections might have on the ability of the structure to carry primary building loads.

Connections to Gage Materials

The most common applications that involve connections to gage materials involve curbs and roof mounted equipment. In these cases, if light equipment is involved (like mushroom fans), connections directly to sheet metal can frequently be adequate. In order to be successful however, the connections need to be made up of a series of small fasteners spaced evenly around the component being anchored. In general, applications involving screws larger than #10 cannot be directly connected to gage materials.

Where these connections can be made, it is also mandatory that the gage materials themselves are also attached to larger structural elements with a series of smaller connections. Again these must be designed such that the can transfer any seismic loads forced into them by the equipment back into the structure without damage.

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OVERSIZED BASEPLATES - HOW THEY WORK & WHY USE THEM

Introduction

The normal design philosophy for Kinetics Noise Control, when designing a new seismic isolator or restraint, is to size the components to allow the smallest package when the isolator or bracket is to be attached to the structural steel of the building. This means that the mounting fasteners and the footprint of the isolator or bracket optimized for the attachment to steel. As a result, the maximum capacity of the isolator or bracket can not be utilized when it is to be attached to concrete using either wedge type anchors or even the undercut type concrete anchors.

An isolator or bracket that is designed to optimize the capacity of the concrete anchors would have a footprint and fastener requirement that would be way too large for efficient attachment to structural steel. Also, we at Kinetics Noise Control feel that it would be prohibitively expensive to design one complete line of isolators or brackets for attachment to steel, and another complete line of isolators or brackets for attachment to concrete. Therefore, we design to optimize the isolator or bracket for attachment to structural steel, and employ the appropriate oversized base plate for an application that specifies attachment to concrete.

The oversized base plate is typically a square piece of steel plate with four anchor holes in it. The isolator or bracket is welded more-or-less to the center of the plate with the recommended amount of weld for attaching the isolator or bracket to structural steel. This oversized base plate allows us to use an anchor size larger than would be allowed by the mounting holes in the isolator or bracket. Also, the oversized base plate will allow us to space the anchors far enough apart to take full advantage of the allowable loads published for the concrete anchors. A typical wedge type concrete anchor, when loaded, tends to produce a cone shaped stress field where the point of the cone is at the embedded end of the anchor, and the large end of the cone is at the surface of the concrete. When the anchors are too close together, the cone shaped stress fields will interact and reduce the allowable capacities of the anchors.

Basic Analysis for Oversized Base Plates

Shown in Figure D5.2.1-1 is a typical oversized base plate with an isolator or bracket attached to it at the center of the plate. In this figure, L is the length and width of the base plate and t is the thickness of the base plate. The variable d represents the anchor size, or diameter, to be used with the base plate. The height H is the distance from mounting surface of the isolator or bracket to the center of the restraint. The seismic force is represented by F_h for the horizontal component of the seismic force, and F_v for the vertical component of the seismic force. The force component F_h is assumed to act at the center of the restraint, and the force component F_v acts act the center of the base plate. There will be three analyses, one for $F_v = 0$, one for $F_h = 0$, and on where $F_h = F_v$.

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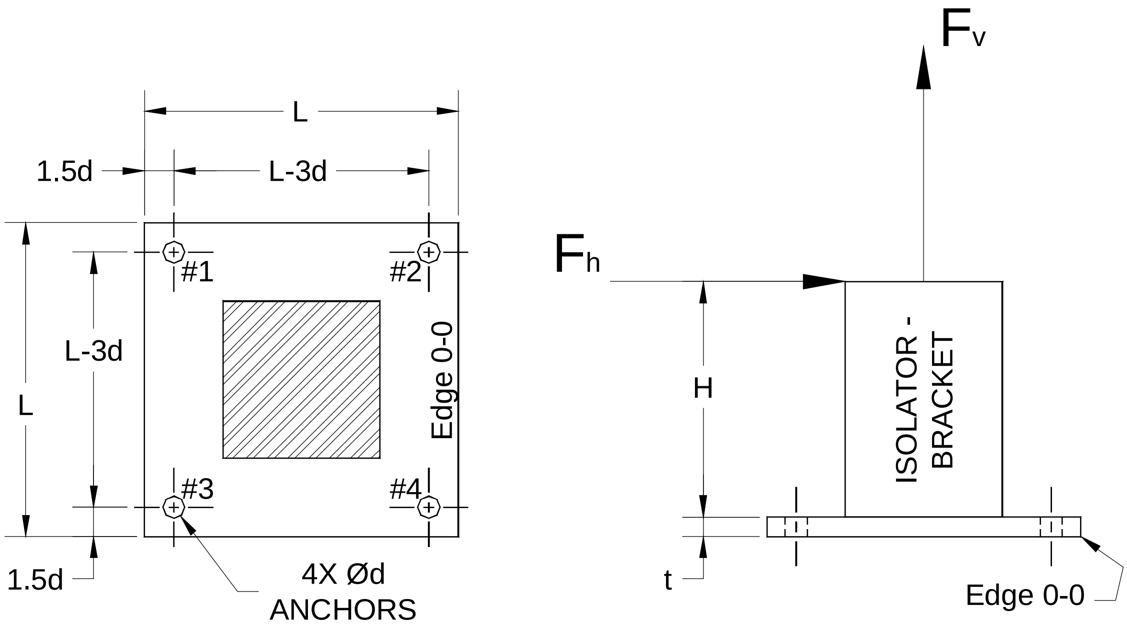
Figure D5.2.1-1; Typical Oversized Base Plate



Case 1: $F_v = 0$

In this case, the base plate will tend to tip around Edge 0-0. The analysis is based on the following assumptions.

1.) The base plate acts as a rigid member.
2.) The loads are such that there will be no concrete failure.
3.) The deflections and rotations of the base plate will be small.
4.) The tension in anchors ***#1*** and ***#3*** will be equal, $T_1 = T_3$.
5.) The tension in anchors ***#2*** and ***#4*** will be equal, $T_2 = T_4$.

Sum moments about Edge 0-0 to determine the tension in the anchors. Counter clockwise moments will be positive (+).

$$\Sigma M_{0\text{-}0} = 0 = 2*T_1*[L-(1.5*d)]+2*T_2*(1.5*d)-F_h*(H+t) \quad \text{(Eq. D5.2.1-1)}$$

And;

$$F_h*(H+t) = 2*T_1*[L-(1.5*d)]+2*T_2*(1.5*d) \quad \text{(Eq. D5.2.1-2)}$$

It is clear that anchors ***#1*** and ***#3*** will be more highly loaded than anchors ***#2*** and ***#4***. So, we will ultimately need to determine the tension in anchors ***#1*** and ***#3***. Through the assumptions it is possible to relate the tension in anchors ***#2*** and ***#4*** to the tension in anchors ***#1*** and ***#3*** in a linear fashion as follows.

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$T_2 = T_1*\{(1.5*d) / [L-(1.5*d)]\}$ **(Eq. D5.2.1-3)**

Substitute Equation D5.2.1-3 into Equation D5.2.1-2, simplify and solve for T_1.

$F_h*(H+t) = 2*T_1*[L-(1.5*d)]+2*T_1*\{(1.5*d)^2 / [L-(1.5*d)]\}$ **(Eq. D5.2.1-4)**

$F_h*(H+t)*[L-(1.5*d)] = 2*T_1*[L-(1.5*d)]^2+2*T_1*(1.5*d)^2$ **(Eq. D5.2.1-5)**

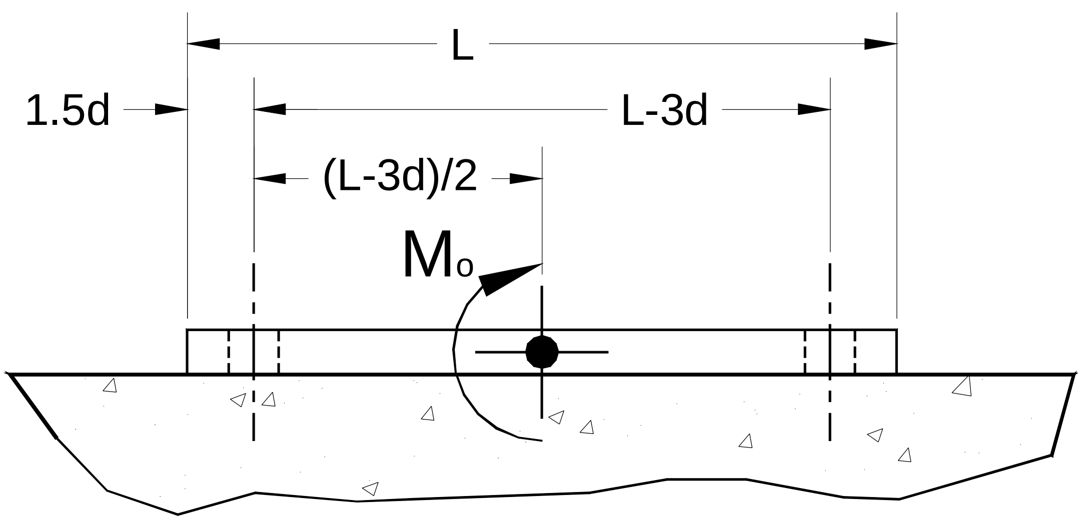
$T_1 = F_h*(H+t)*[L-(1.5*d)] / \{2*[(L-(1.5*d))^2+(1.5*d)^2]\}$ **(Eq. D5.2.1-6)**

The anchors will also be loaded in shear. Let's assume that all of the anchors are loaded equally in shear. The shear load on each anchor, P_1, will be as follows.

$P_1 = F_h / 4$ **(Eq. D5.2.1-7)**

The base plate thicknesses were selected in order to make the anchors the limiting components for values of ***H*** up to and including ***20*** inches. The stress in the base plate is estimated by assuming that the base plate is a beam with both ends fixed, and a couple M_o applied to the center of the beam, as shown in Figure D5.2.1-2.

Figure D5.2.1-2; Assumed Base Plate Loading Arrangement for Case 1



Because the isolator or bracket will be rather large, the center of the base plate will not be subjected to a great deal of bending. The maximum bending will occur at the anchor holes. The maximum applied moment in the at the anchor holes is;

$M = M_o / 4$ **(Eq. D5.2.1-8)**

The applied moment may be approximated as;

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$M_o \approx F_h*H$ **(Eq. D5.2.1-9)**

Then;

$M = F_h*H / 4$ **(Eq. D5.2.1-10)**

In general, the bending stress, s_b, in the base plate is given by;

$s_b = M*c / I$ **(Eq. D5.2.1-11)**

In this equation, ***c*** is the distance from the neutral axis to the outer fibers of the beam, and ***I*** is the area moment of inertia of the beam cross-section. For all of the cases presented in this document, ***I*** and ***c*** have the following values.

$I = L*t^3 / 12$ **(Eq. D5.2.1-12)**

And;

$c = t / 2$ **(Eq. D5.2.1-13)**

The final form of the bending stress equation will be as follows.

$s_b = 3*F_h*H / (2*L*t^2)$ **(Eq. D5.2.1-14)**

The allowable bending stress, s_A, is;

$s_A = 0.6*S_y$ **(Eq. D5.2.1-15)**

S_y is the yield strength of the base plate.

The factors of safety for the anchors and the base plate are now computed. For each case they must be greater than or equal to ***1.00***. For the anchors, the factor of safety is;

$F.S. = \{1 / [(T_1 / T_A)^{5/3}+(P_1 / P_A)^{5/3}]\} \geq 1.00$ **(Eq. D5.2.1-16)**

In the above equation, T_A and P_A are the allowable tension and shear loads for the anchors being used. The factor of safety for the base plate is given by;

$F.S. = s_A / s_b \geq 1.00$ **(Eq. D5.2.1-17)**

Case 2: $F_h = 0$

Since the base plate has been assumed to be rigid and the deflections have been assumed to be small, there will be little or no prying action on the anchors due to the vertical component of the seismic force F_v. Also, since $F_h = 0$, there will be no shear forces acting on the anchors. The

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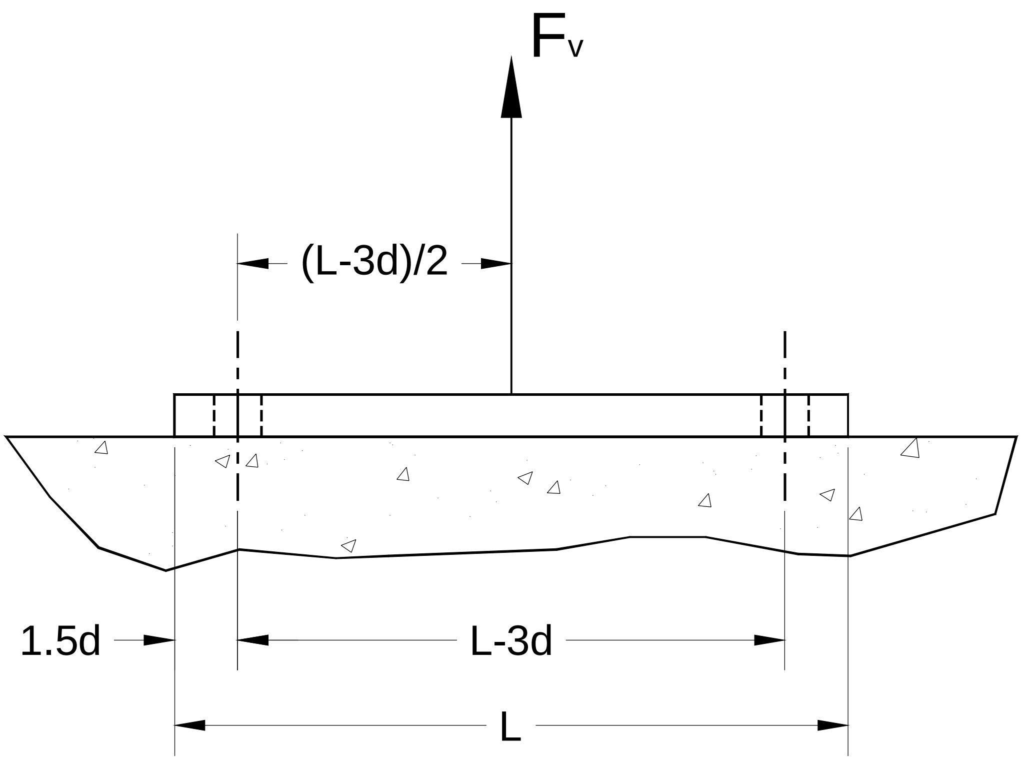
vertical component of the seismic force will be equally distributed between the four anchors, and;

$T_1 = F_v / 4$ and $P_1 = 0$ **(Eq. D5.2.1-18)**

The maximum bending will occur at the anchor holes. The base plate loading for Case 2 is shown in Figure D5.2.1-3.

Figure D5.2.1-3; Assumed Base Plate Loading Arrangement for Case 2



The maximum applied moment in the at the anchor holes is;

$M = F_v*(L-3*d) / 8$ **(Eq. D5.2.1-19)**

Substitute Equations D5.2.1-12, D5.2.1-13, and D5.2.1-19 into Equation D5.2.1-11 to obtain the maximum bending stress in the base plate.

$s_b = 3*F_v*(L-3*d) / (4*L*t^2)$ **(Eq. D5.2.1-20)**

Case 3: $F_h = F_v = F_c$

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This is the combined loading case that helps determine the final shape of the capacity envelope for the base plate. Again, we will sum moments about Edge 0-0 to determine the maximum tension in the bolts. All of the assumptions that applied to Case 1 will apply for Case 3.

$$\Sigma M_{0\text{-}0} = 0 = 2*T_1*[L-(1.5*d)]+2*T_2*(1.5*d)-F_c*(H+t)- F_c*L/2 \qquad \textbf{(Eq. D5.2.1-21)}$$

And;

$$F_c*(2*H+2*t+L)/2 = 2*T_1*[L-(1.5*d)]+2*T_2*(1.5*d) \qquad \textbf{(Eq. D5.2.1-22)}$$

Substitute Equation D5.32.1-3 into Equation D5.2.1-22, solve for T_1.

$$F_c*(2*H+2*t+L)/2 = 2*T_1*[L-(1.5*d)]+2*T_1*\{(1.5*d)^2 / [L-(1.5*d)]\} \qquad \textbf{(Eq. D5.2.1-23)}$$

$$F_c*(2*H+2*t+L)*[L-(1.5*d)]/2 = 2*T_1*[L-(1.5*d)]^2+2*T_1*(1.5*d)^2 \qquad \textbf{(Eq. D5.2.1-24)}$$

$$T_1 = F_c*(2*H+2*t+L)*[L-(1.5*d)] / \{4*[(L-(1.5*d))^2+(1.5*d)^2]\} \qquad \textbf{(Eq. D5.2.1-25)}$$

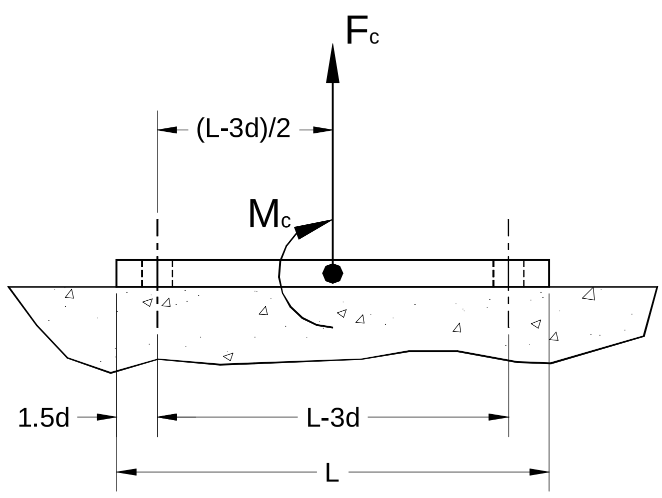
The anchors will be also be loaded in shear, and this shear load may be estimated using Equation D5.2.1-7.

The maximum bending will occur at the anchor holes in this case as well. The base plate loading for Case 3 is shown in Figure D5.2.1-4. The maximum bending moment at the bolt holes will be,

$$M = M_c/4+F_c*(L-3*d)/8 \qquad \textbf{(Eq. D5.2.1-26)}$$

$$M_c = F_c*H \qquad \textbf{(Eq. D5.2.1-27)}$$

Figure D5.2.1-4; Assumed Base Plate Loading Arrangement for Case 3



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$$M = F_c*H/4+F_c*(L-3*d)/8 \qquad \text{(Eq. D5.2.1-28)}$$

$$M = (F_c/8)*[2*H+L-3*d] \qquad \text{(Eq. D5.2.1-29)}$$

Substitute Equations D5.2.1-29, D5.2.1-12, and D5.2.1-13 into Equation D5.2.1-11 to obtain the bending stress in the base plate.

$$s_b = 3*F_c*(2*H+L-3*d) / (4*L*t^2) \qquad \text{(Eq. D5.2.1-30)}$$

The results of this analysis are presented and their applications are discussed in Document D5.2.2.

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The oversized base plate is typically a square piece of steel plate with four anchor holes in it. The isolator or bracket is welded more-or-less to the center of the plate with the recommended amount of weld for attaching the isolator or bracket to structural steel. This oversized base plate allows us to use an anchor size larger than would be allowed by the mounting holes in the isolator or bracket. Also, the oversized base plate will allow us to space the anchors far enough apart to take full advantage of the allowable loads published for the concrete anchors. A typical wedge type concrete anchor, when loaded, tends to produce a cone shaped stress field where the point of the cone is at the embedded end of the anchor, and the large end of the cone is at the surface of the concrete. When the anchors are too close together, the cone shaped stress fields will interact and reduce the allowable capacities of the anchors.

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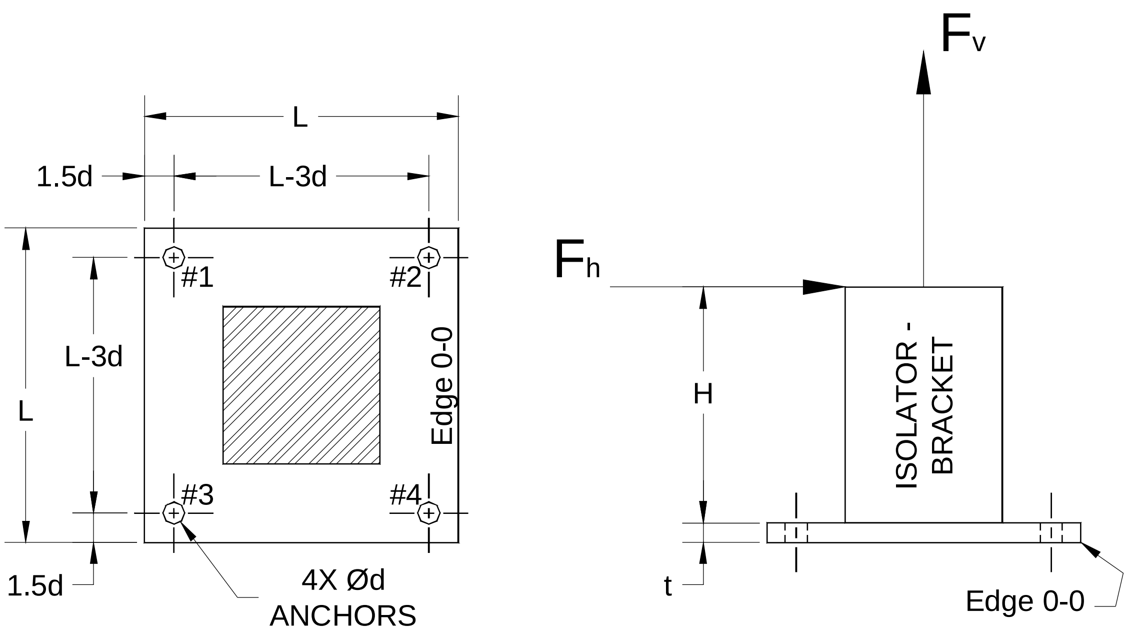
Figure D5.2.1-1; Typical Oversized Base Plate



Case 1: $F_v = 0$

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Sum moments about Edge 0-0 to determine the tension in the anchors. Counter clockwise moments will be positive (+).

$$\Sigma M_{0\text{-}0} = 0 = 2*T_1*[L-(1.5*d)]+2*T_2*(1.5*d)-F_h*(H+t) \qquad \textbf{(Eq. D5.2.1-1)}$$

And;

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It is clear that anchors ***#1*** and ***#3*** will be more highly loaded than anchors ***#2*** and ***#4***. So, we will ultimately need to determine the tension in anchors ***#1*** and ***#3***. Through the assumptions it is possible to relate the tension in anchors ***#2*** and ***#4*** to the tension in anchors ***#1*** and ***#3*** in a linear fashion as follows.

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$T_2 = T_1*\{(1.5*d) / [L-(1.5*d)]\}$ **(Eq. D5.2.1-3)**

Substitute Equation D5.2.1-3 into Equation D5.2.1-2, simplify and solve for T_1.

$F_h*(H+t) = 2*T_1*[L-(1.5*d)]+2*T_1*\{(1.5*d)^2 / [L-(1.5*d)]\}$ **(Eq. D5.2.1-4)**

$F_h*(H+t)*[L-(1.5*d)] = 2*T_1*[L-(1.5*d)]^2+2*T_1*(1.5*d)^2$ **(Eq. D5.2.1-5)**

$T_1 = F_h*(H+t)*[L-(1.5*d)] / \{2*[(L-(1.5*d))^2+(1.5*d)^2]\}$ **(Eq. D5.2.1-6)**

The anchors will also be loaded in shear. Let's assume that all of the anchors are loaded equally in shear. The shear load on each anchor, P_1, will be as follows.

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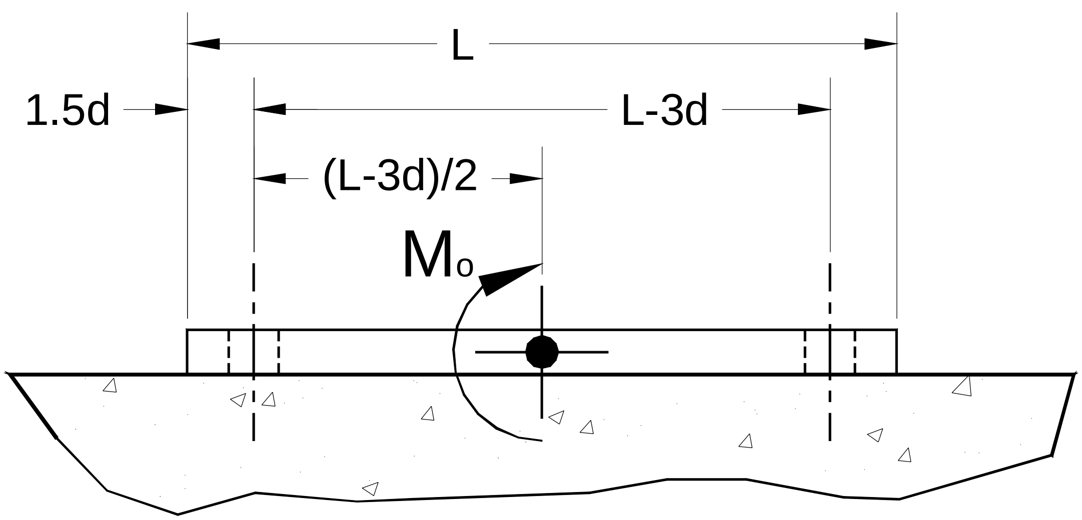
The base plate thicknesses were selected in order to make the anchors the limiting components for values of ***H*** up to and including ***20*** inches. The stress in the base plate is estimated by assuming that the base plate is a beam with both ends fixed, and a couple M_o applied to the center of the beam, as shown in Figure D5.2.1-2.

Figure D5.2.1-2; Assumed Base Plate Loading Arrangement for Case 1



Because the isolator or bracket will be rather large, the center of the base plate will not be subjected to a great deal of bending. The maximum bending will occur at the anchor holes. The maximum applied moment in the at the anchor holes is;

$M = M_o / 4$ **(Eq. D5.2.1-8)**

The applied moment may be approximated as;

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$M_o \approx F_h*H$ **(Eq. D5.2.1-9)**

Then;

$M = F_h*H / 4$ **(Eq. D5.2.1-10)**

In general, the bending stress, s_b, in the base plate is given by;

$s_b = M*c / I$ **(Eq. D5.2.1-11)**

In this equation, ***c*** is the distance from the neutral axis to the outer fibers of the beam, and ***I*** is the area moment of inertia of the beam cross-section. For all of the cases presented in this document, ***I*** and ***c*** have the following values.

$I = L*t^3 / 12$ **(Eq. D5.2.1-12)**

And;

$c = t / 2$ **(Eq. D5.2.1-13)**

The final form of the bending stress equation will be as follows.

$s_b = 3*F_h*H / (2*L*t^2)$ **(Eq. D5.2.1-14)**

The allowable bending stress, s_A, is;

$s_A = 0.6*S_y$ **(Eq. D5.2.1-15)**

S_y is the yield strength of the base plate.

The factors of safety for the anchors and the base plate are now computed. For each case they must be greater than or equal to ***1.00***. For the anchors, the factor of safety is;

$F.S. = \{1 / [(T_1 / T_A)^{5/3}+(P_1 / P_A)^{5/3}]\} \geq 1.00$ **(Eq. D5.2.1-16)**

In the above equation, T_A and P_A are the allowable tension and shear loads for the anchors being used. The factor of safety for the base plate is given by;

$F.S. = s_A / s_b \geq 1.00$ **(Eq. D5.2.1-17)**

Case 2: $F_h = 0$

Since the base plate has been assumed to be rigid and the deflections have been assumed to be small, there will be little or no prying action on the anchors due to the vertical component of the seismic force F_v. Also, since $F_h = 0$, there will be no shear forces acting on the anchors. The

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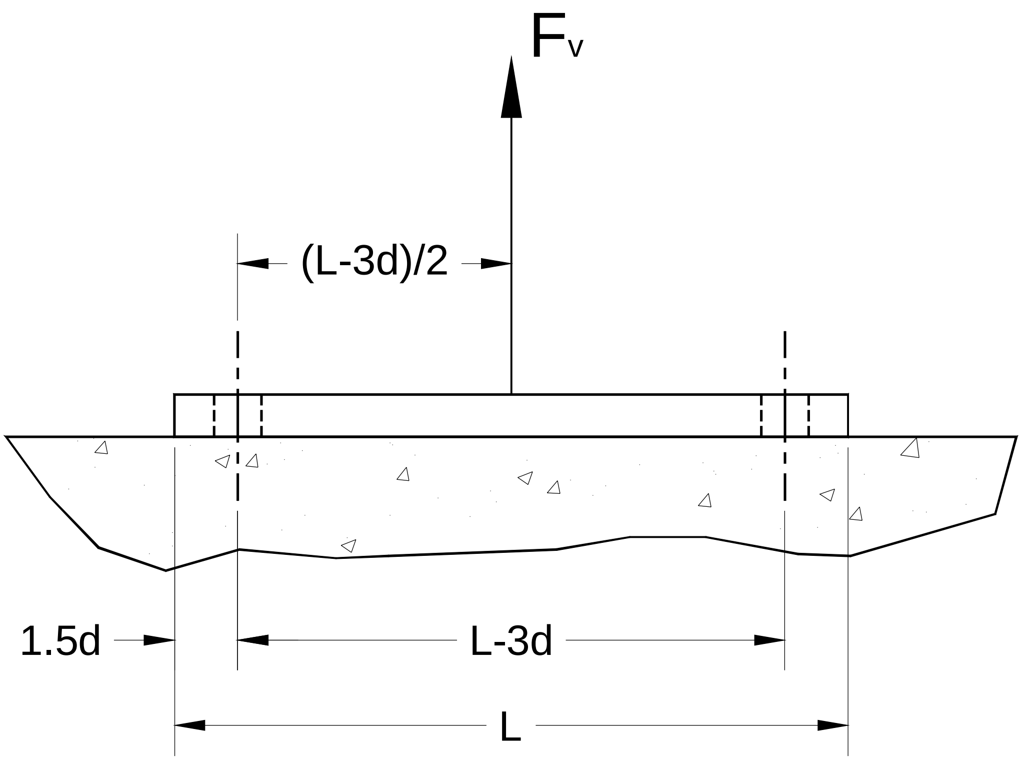
vertical component of the seismic force will be equally distributed between the four anchors, and;

$T_1 = F_v / 4$ and $P_1 = 0$ **(Eq. D5.2.1-18)**

The maximum bending will occur at the anchor holes. The base plate loading for Case 2 is shown in Figure D5.2.1-3.

Figure D5.2.1-3; Assumed Base Plate Loading Arrangement for Case 2



The maximum applied moment in the at the anchor holes is;

$M = F_v*(L-3*d) / 8$ **(Eq. D5.2.1-19)**

Substitute Equations D5.2.1-12, D5.2.1-13, and D5.2.1-19 into Equation D5.2.1-11 to obtain the maximum bending stress in the base plate.

$s_b = 3*F_v*(L-3*d) / (4*L*t^2)$ **(Eq. D5.2.1-20)**

Case 3: $F_h = F_v = F_c$

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This is the combined loading case that helps determine the final shape of the capacity envelope for the base plate. Again, we will sum moments about Edge 0-0 to determine the maximum tension in the bolts. All of the assumptions that applied to Case 1 will apply for Case 3.

$$\Sigma M_{0\text{-}0} = 0 = 2*T_1*[L-(1.5*d)]+2*T_2*(1.5*d)-F_c*(H+t)- F_c*L/2 \quad \text{(Eq. D5.2.1-21)}$$

And;

$$F_c*(2*H+2*t+L)/2 = 2*T_1*[L-(1.5*d)]+2*T_2*(1.5*d) \quad \text{(Eq. D5.2.1-22)}$$

Substitute Equation D5.32.1-3 into Equation D5.2.1-22, solve for T_1.

$$F_c*(2*H+2*t+L)/2 = 2*T_1*[L-(1.5*d)]+2*T_1*\{(1.5*d)^2 / [L-(1.5*d)]\} \quad \text{(Eq. D5.2.1-23)}$$

$$F_c*(2*H+2*t+L)*[L-(1.5*d)]/2 = 2*T_1*[L-(1.5*d)]^2+2*T_1*(1.5*d)^2 \quad \text{(Eq. D5.2.1-24)}$$

$$T_1 = F_c*(2*H+2*t+L)*[L-(1.5*d)] / \{4*[(L-(1.5*d))^2+(1.5*d)^2]\} \quad \text{(Eq. D5.2.1-25)}$$

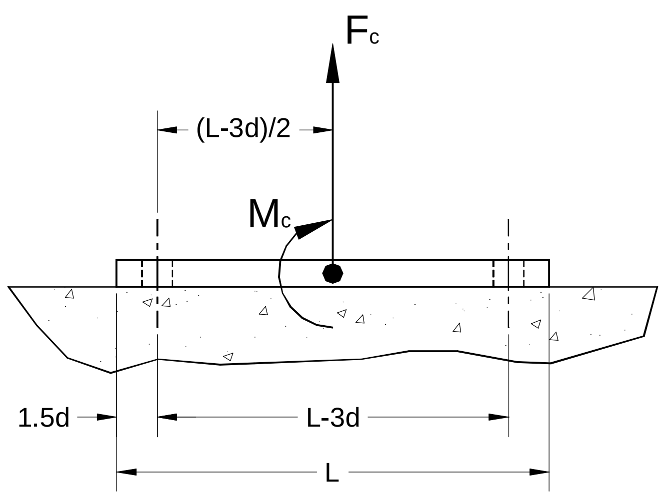
The anchors will be also be loaded in shear, and this shear load may be estimated using Equation D5.2.1-7.

The maximum bending will occur at the anchor holes in this case as well. The base plate loading for Case 3 is shown in Figure D5.2.1-4. The maximum bending moment at the bolt holes will be,

$$M = M_c/4+F_c*(L-3*d)/8 \quad \text{(Eq. D5.2.1-26)}$$

$$M_c = F_c*H \quad \text{(Eq. D5.2.1-27)}$$

Figure D5.2.1-4; Assumed Base Plate Loading Arrangement for Case 3



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$$M = F_c*H/4+F_c*(L-3*d)/8 \qquad \text{(Eq. D5.2.1-28)}$$

$$M = (F_c/8)*[2*H+L-3*d] \qquad \text{(Eq. D5.2.1-29)}$$

Substitute Equations D5.2.1-29, D5.2.1-12, and D5.2.1-13 into Equation D5.2.1-11 to obtain the bending stress in the base plate.

$$s_b = 3*F_c*(2*H+L-3*d) / (4*L*t^2) \qquad \text{(Eq. D5.2.1-30)}$$

The results of this analysis are presented and their applications are discussed in Document D5.2.2.

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