OVERVIEW OF ANALYTICAL METHODS USED

Unless otherwise specified, the analyses performed by Kinetics Noise Control are based on a worst case statically applied load and assume that the equipment being restrained is rigid. These assumptions are in compliance with code parameters and with the application of appropriate factors, address dynamic forces to the various structural elements involved as well.

Generally speaking, this analysis models a piece of restrained equipment as a rigid body with a lateral and possibly vertical load as defined by the code applied to its center of gravity. The application of these loads generates forces at the equipment restraints, which can eventually be reconciled to anchor loads. As the wave front angle for the earthquake is unknown, this analysis work must ensure that the design loads are applied in the directions which will generate the highest forces in the anchors.

There are several types of reactive loads that result from the analysis of a typical piece of equipment. A horizontal shear load, an imbalance load, a vertical uplift load, an overturning load and the static deadweight load. The interaction between these results in worst case combinations at each restraint point.

SHEAR LOAD ANALYSIS

The most obvious restraint loading that occurs during a seismic event is the horizontal force that is generated by the lateral load. In its simplest case this results in the lateral load being split among the restraints. If the center of gravity of the equipment is aligned with the geometric center of the restraints, the split will be equal as shown in Figure 1.

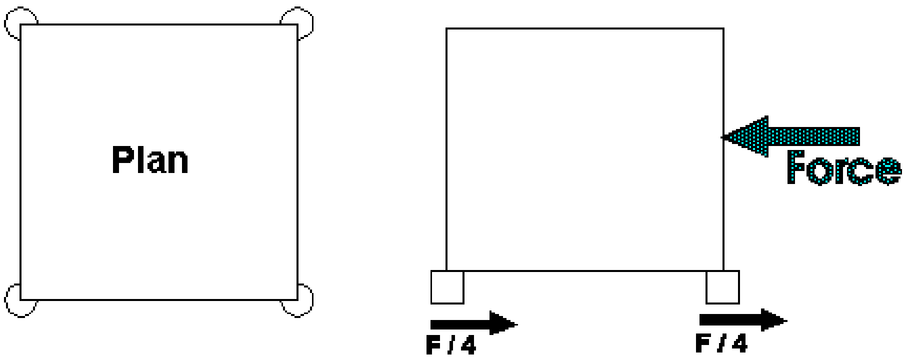


Figure 1

IMBALANCED LOAD ANALYSIS

More frequently, the unit center of gravity is not aligned with the geometric center. When this is the case, an imbalanced load is generated which needs to be combined with the shear loads previously discussed. Figure 2 shows that the method of analyzing this situation is to treat the horizontal shear load at each restraint as a function of the mass that is associated with them.

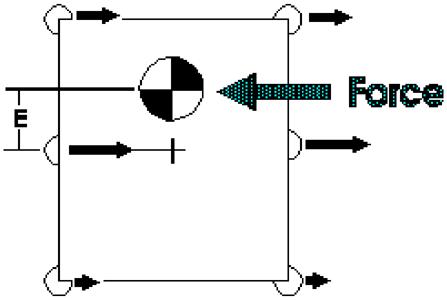


Figure 2

OVERTURNING LOAD ANALYSIS

The accurate modeling of overturning forces is critical in determining the vertical forces to which the restraints are exposed. In the simple case where the center of gravity is coincident with the geometric center of the system and with four restraints, the vertical components are a simple function of the height of the center of gravity and the restraint spacing (Figure 3).

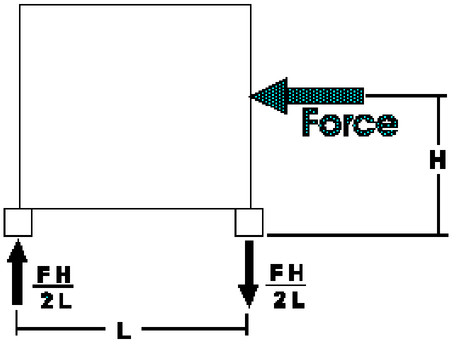


Figure 3

In the case of a system with more than four restraints, the number of points that can be considered to share the overturning load becomes a function of clearance that may be present. Note in Figure 4, that with no clearance, resistance to the overturning load will occur at every restraint location. The most common type of installation that exhibits this property is a rigidly bolted system.

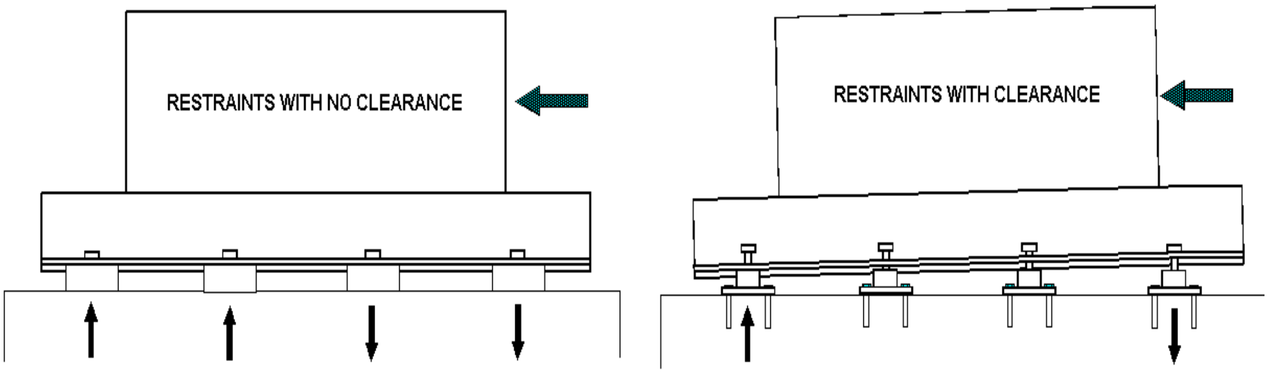


Figure 4

In systems that have more than four restraints and contain restraints that maintain an operating clearance, only the end restraints can be considered effective in resisting overturning loads. With this type of restraint, some elastomeric snubbing must be present to prevent impact loading and resulting force amplification. In some cases, if the snubbing pads are thick enough and the operating clearance small enough, some load sharing may be present, but in general this effect is minimal. This is clearly illustrated in Figure 4.

LOAD DIRECTION ANALYSIS

Because the direction of the seismic load is unknown, it is necessary to determine the worst case overturning load at each restraint point based on any possible load direction. The method used by Kinetics Noise Control is to set up a mathematical model of the equipment arrangement and then index the application angle of the design seismic force for the full 360 degrees of possible application angles in 1-degree increments. At each increment, the overturning load for each point is computed and the worst case load encountered at each restraint point is used in the analysis.

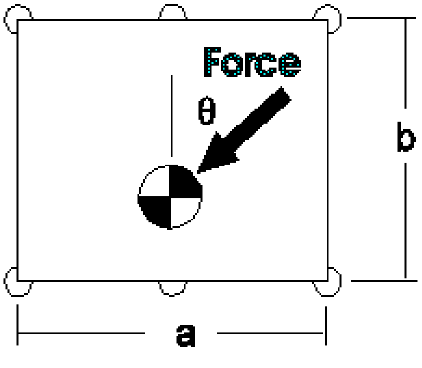


Figure 5

OTHER SIGNIFICANT FACTORS

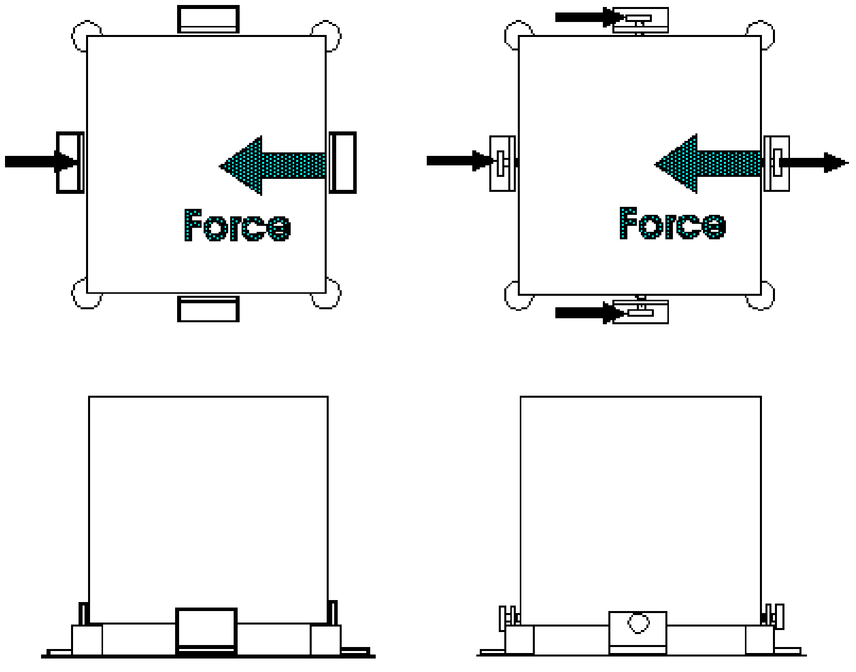
Before a mathematical model can be built, there are several other key hardware factors that need to be accounted for. These factors relate to specific snubber or system designs that can have a major impact on the final restraining loads.

SINGLE DIRECTION SNUBBERS

Figure 6A shows a system using four single direction lateral restraints. Because this type of restraint only restrains a single direction lateral load, they must be used in sets of four. Some versions of these include a vertical snubbing pad for uplift loads. Although these are then biaxial restraints, they behave very similarly. It is important to note that since each restraint only works in a single direction, that any restraint must absorb the entire lateral force by itself.

MULTI-DIRECTION SNUBBERS

In contrast to this, the same unit fitted with four multi-axial restraints will produce an average lateral load per restraint equal to 1/4 of the total load. This results in a series of restraints, which can be significantly smaller than what would be required for single direction components (Figure 6B).



(A) (B)

Figure 6

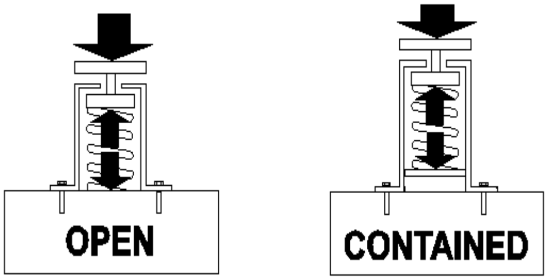
OPEN SPRING ISOLATORS

When restraining vertical loads, there are two distinct types of restraints that can be used. The first of these I will call an open or non-contained spring isolator. This is one in which the spring bears against the floor and the anchor bolts have the possibility of absorbing the spring load. An illustration of this is shown in Figure 7 (Labeled “OPEN”).

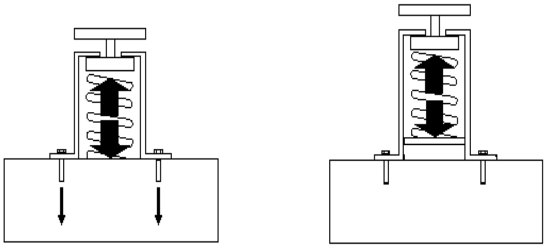
CONTAINED SPRING ISOLATORS

Another more common type of restrained spring isolator is one, which I will call a contained spring isolator. In this type, the spring load is contained within the restraint housing. The net result is that the anchor bolts, while still required to resist the equipment loading, do not have to absorb any additional loading that may be generated by the spring. This is shown in Figure 7 (Labeled “CONTAINED”).

To illustrate this point more clearly, The first illustration in Figure 7 shows the two types of isolators under normal load. Note that in either case the anchors are effectively unloaded. If the equipment weight is now suddenly removed, the situation occurs that is illustrated in the second illustration. In this case nearly all the spring load is transferred directly to the anchor bolts in the open case, but the anchors are still unloaded in the contained one.

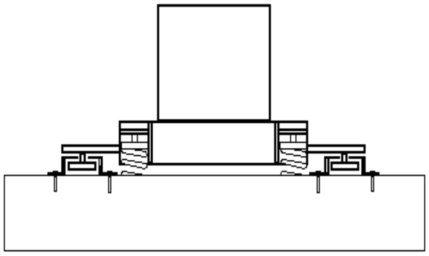


(A) WITH STATIC EQUIPMENT LOAD

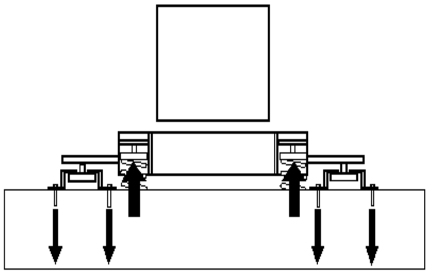


(B) WITH EQUIPMENT LOAD REMOVED

ISOLATOR / RESTRAINT COMBINATION



(A) BASE UNDER NORMAL LOAD



(B) BASE WITH "UPLIFT" LOAD

SEPARATE ISOLATOR / RESTRAINT

Figure 7

SEPARATE SNUBBERS

A quick review of systems which incorporate spring supports and independent snubbers will show that they perform in the same manner as those which use open spring isolators. These cases are illustrated in the right half of Figure 7.

MODEL GENERATION

Two static models are set up for a given piece of equipment. One would be an X-axis model and the other a Y-axis version. In these models, all translational, vertical and overturning loads are accounted for including factors for the center of gravity offsets in each of the two major axes. The input load can be considered to be applied in any direction and X and Y components are extracted from it.

Using the above concept and generating loads for each restraint point based on the load angle discussed earlier. The angle is incremented from 0 to 360 degrees, generating the resulting forces at each restraint point for each angle. The worst case force at each restraint location is then stored and used for the evaluation of the restraint at that location.

RESTRAINT ANALYSIS

Up to now, the analysis has been limited to the entire system. It now becomes necessary to use the loads developed for each restraint location to determine the adequacy of each restraint.

In general each restraint behaves like a small piece of equipment with its own horizontal, vertical and overturning components. Because these parameters are clearly defined for each restraint however, these factors can be boiled down to a capacity chart listing the maximum vertical, lateral and combined capacity of the restraint. These values are different for anchorage to concrete or attachment to steel. The previously computed forces are then compared to the restraint limits to ensure their adequacy.