An Introduction to Vibration Control in Buildings

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1. VIBRATION CRITERIA. Structural vibration in buildings, which results in feelable vibration, produces structural or superficial damage of building components or interferes with equipment operation is unacceptable. In addition large building components that vibrate can produce unacceptable sound levels.

1.1 VIBRATION CRITERIA FOR OCCUPANTS. Figure 1 shows the approximate occupant response to building vibration levels. An approximation of the "threshold of sensitivity" of individuals to feelable vibration is shown by the shaded area of Figure 1, labeled "barely perceptible." Other typical responses of people to vibration are indicated by the other zones in Figure 1. These reactions or interpretations may vary over a relatively wide range for different individuals and for different ways in which a person might be subjected to vibration (standing, seated, through the finger tips). The lower portion of the "barely perceptible" range is most applicable to commercial installations. Complaints of building vibration in residential situations can arise even if the vibration levels are slightly below the lower portion of the "barely perceptible" range. The choice of a vibration criteria, for annoyance due to feelable vibration, will be determined by the usage of the space and the perceived sensitivity of the occupants. There should not be a problem with perceptible vibration if the levels are 6 to 8 dB below the "barely perceptible" range of Figure 1.

1.2 VIBRATION CRITERIA FOR BUILDING STRUCTURES. High amplitude vibration levels can cause damage to building structures and components. When vibration is destructive to building components the vibration will be highly perceptible to the building occupants. A structural vibration velocity of 2.0 in/sec has commonly been used as an upper safe limit for building structures, and vibrations above this value will have adverse environmental impact. A vibration velocity of 1.0 in/sec should be used as a normally safe vibration upper limit with respect to structural damage. Vibrations with a velocity level greater than 1.0 in/sec should be avoided or special arrangements should be made with the owners of the exposed structure. Even with a vibration level of 1.0 in/sec superficial damage may occur in isolated instances. Superficial damage can consist of small cracking in brittle facades such as plaster. In order to ensure that the possibility of superficial damage is minimized a vibration criteria of 0.2 in/sec has been recommended. And finally for very old structures an even lower level of 0.05 in/sec is recommended. The manner in which the level is to be determined is a function of the type of vibration expected or experienced. For continuous vibration the RMS level should be used. For impulsive vibration the Peak value is to be used. In Figure 2 the vibration limits mentioned above have been plotted in terms of acceleration level in dB re 1 micro G.

1.3 VIBRATION CRITERIA FOR SENSITIVE EQUIPMENT. Building vibration may be disturbing to the use or proper operation of vibration-sensitive equipment, such as electron microscopes and other special chemical, medical, or industrial instruments or processes. Figure 3 shows vibration criteria for some sensitive equipment types. To achieve these low level vibration levels special building construction, mechanical equipment selection and isolation, and vibration isolation for the sensitive equipment are required.

1.4 VIBRATION CRITERIA FOR SOUND CONTROL. Vibrating building components will produce sound radiation which may be unacceptable. Figure 4 shows "NC-equivalent" sound level curves as a function of acceleration level of a large surface. These NC-equivalent curves show the vibration acceleration levels of a large vibrating surface (such as a wall, floor, or ceiling of a room) that will produce radiated sound having approximately the octave band sound pressure levels of the NC curves (shown elsewhere).

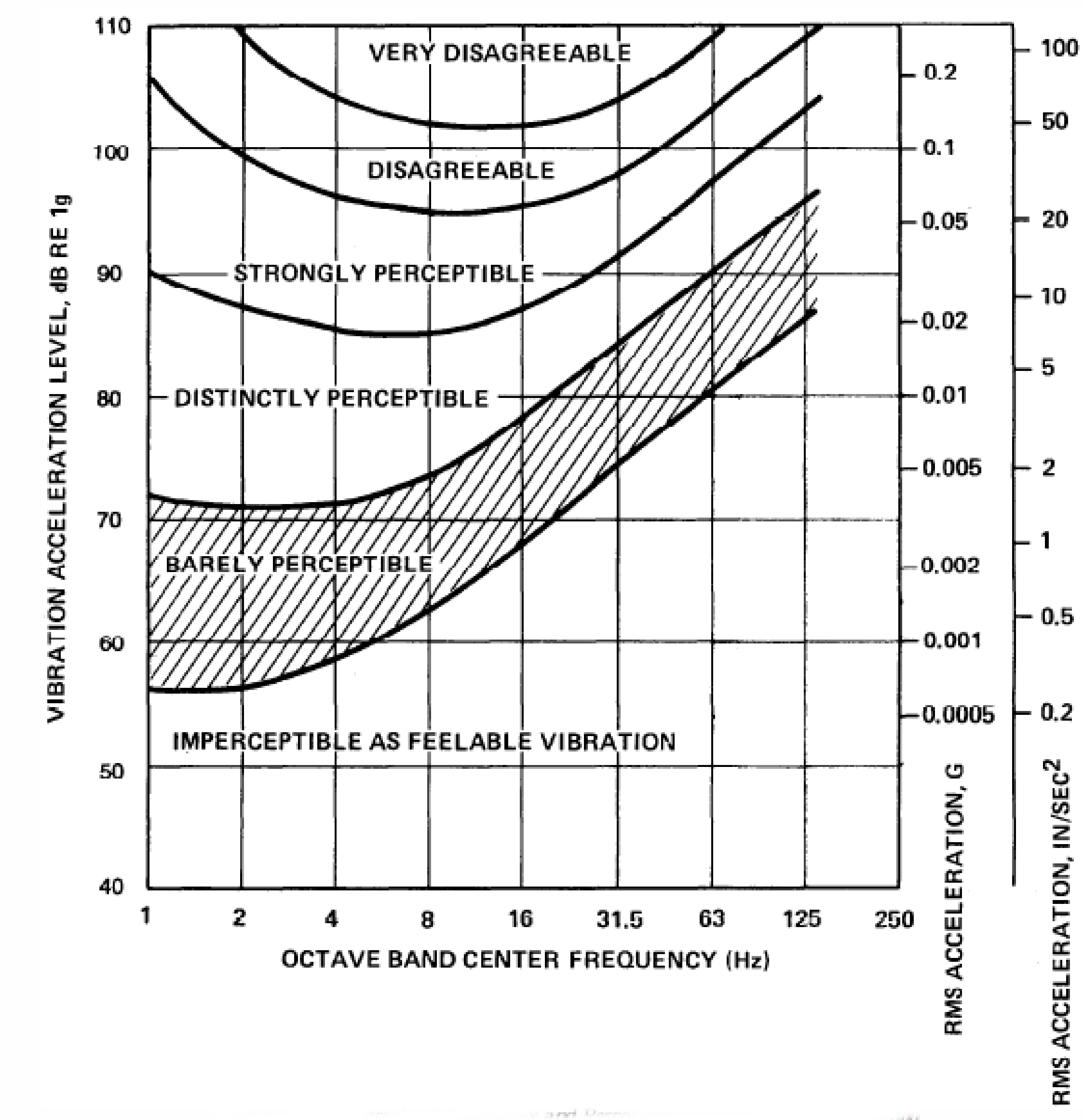


Figure 1

Approximate Sensitivity and Response of People to Feelable Vibration

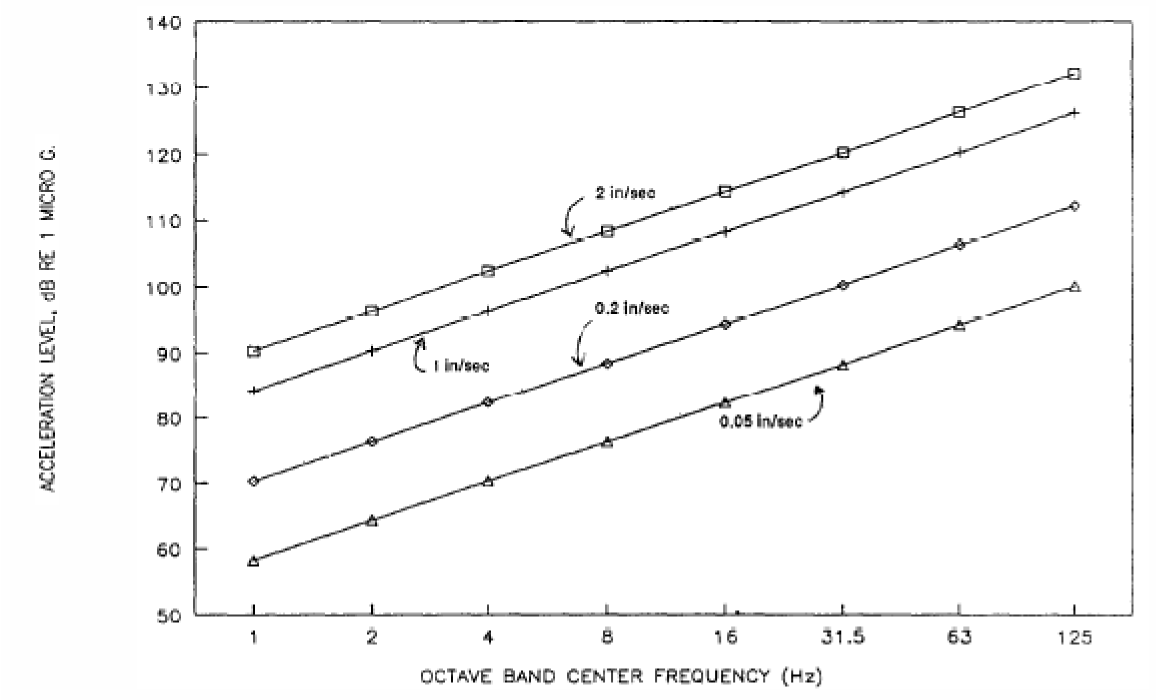
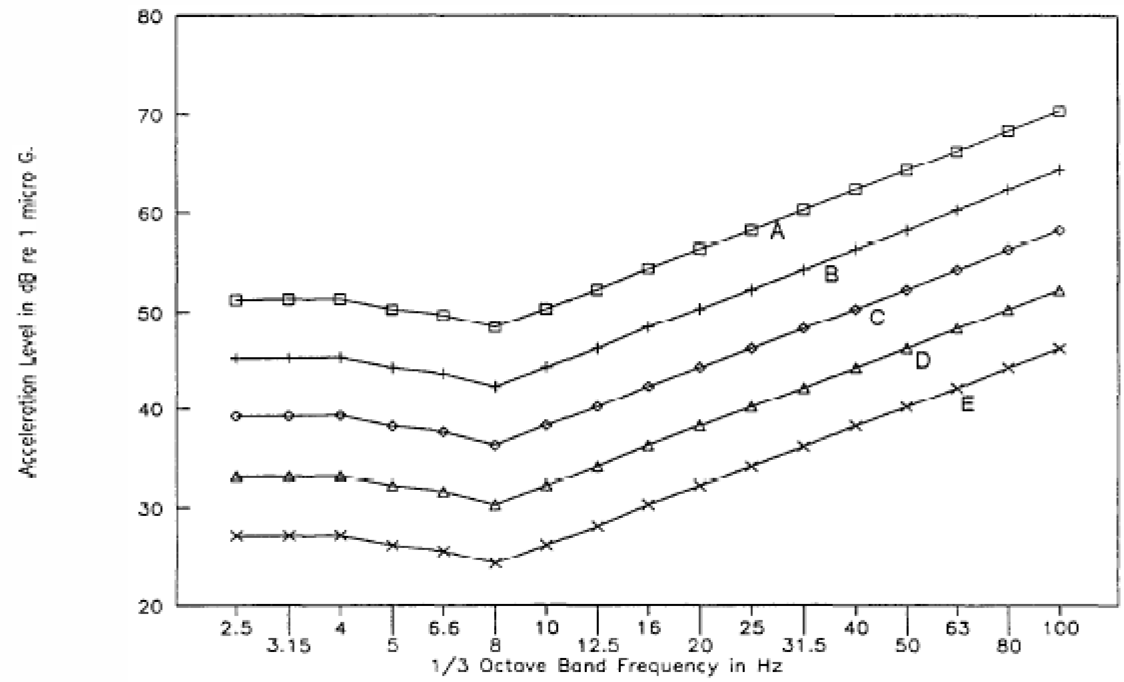


Figure 2

Vibration Criteria for Damage Risk to Buildings.



Note - A - 100 X Microscopes.
B - 500 X Microscopes.
C - 1,000 X Microscopes.
D - Electron Beam Mircoscopes to 0.3 micrometer geometries.
E - Anticipated Adequate for future low submicron geometries.

Figure 3

Vibration Criteria for Sensitive Equipment in Buildings

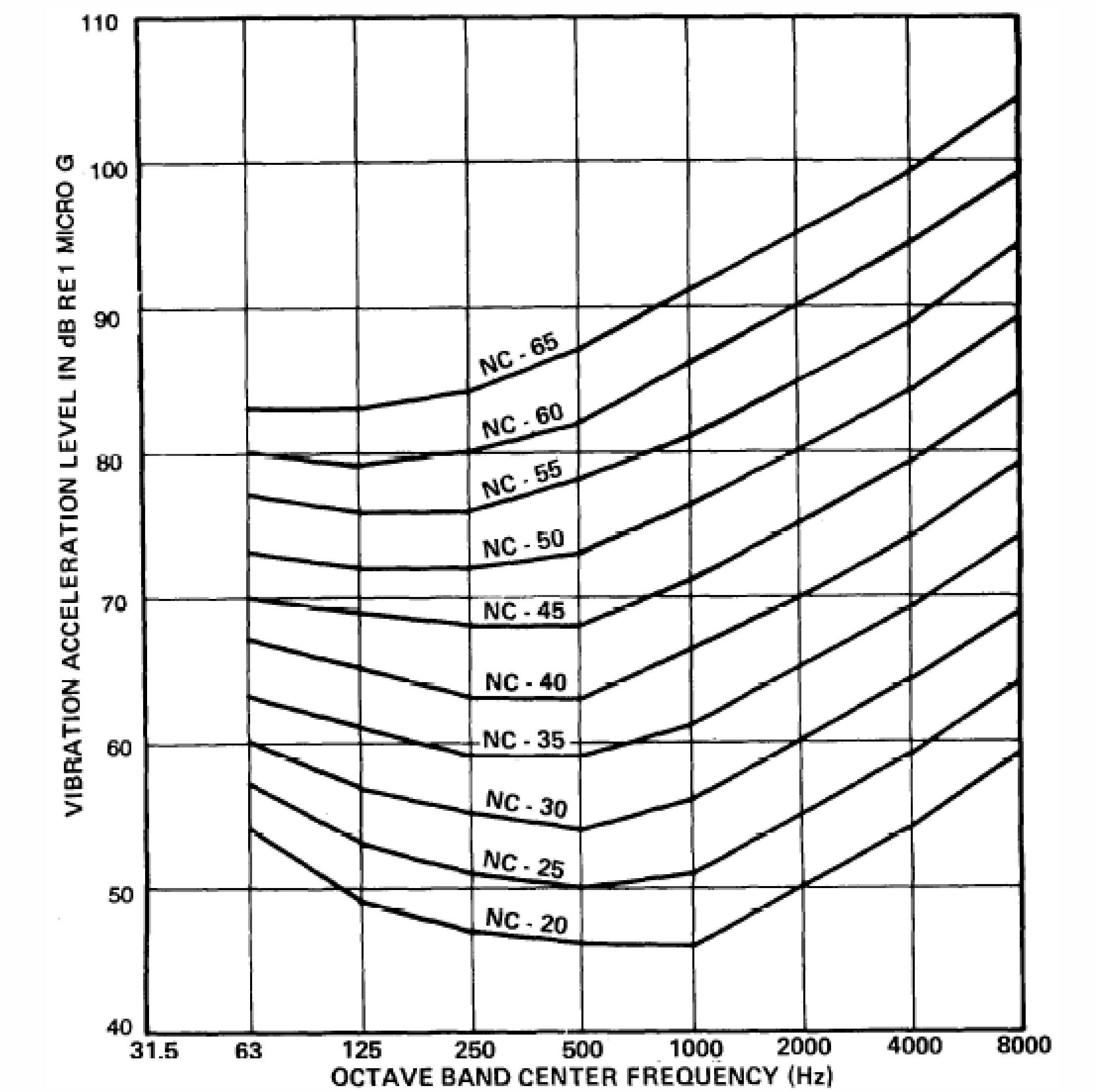


Figure 4

Vibration Acceleration Levels of a Large Vibrating Surface that Will Produce Radiated Sound Levels into a Room Approximating the Sound Levels of the NC Curves

2. VIBRATION ISOLATION ELEMENTS. Table 5 lists the principal types of vibration isolators and their general range of applications. This table may be used as a general guide for comparing isolators and their range of static deflections and natural frequencies as applied to two equipment categories (rotary and reciprocating) and two equipment locations (noncritical and critical). Additional details are required for actual selections of mounts. Vibration isolator types are discussed in this paragraph, and equipment installations are discussed in the remaining paragraphs of this discussion.

2.1 STEEL SPRING ISOLATORS. Steel springs are used to support heavy equipment and to provide isolation for the typical low-frequency range of about 3 to 60 Hz (180- to 3600-rpm shaft speed). Steel springs have natural frequencies that fall in the range of about 1 Hz (for approximately 1-inch static deflection) to about 6 Hz (for approximately 1/4-inch static deflection). Springs transmit high frequency structure borne noise, so they should be supplemented with a high-frequency pad-type isolator when used to support equipment directly over critical locations in a building. Unhoused "stable" steel springs are preferred over housed unstable or stable springs. Unstable springs tend to tilt over when they are loaded and to become short-circuited when they bind against the inside walls of the spring housing. Stable steel springs have a diameter that is about 0.8 to 1.2 times their compressed height. They have a horizontal stiffness that is approximately equal to their vertical stiffness; therefore, they do not have a tendency to tilt sideways when a vertical load is applied. The free-standing unhoused spring can easily be inspected to determine if the spring is compressed correctly, is not overloaded to the point that adjacent coils are solid against one another, and is not binding against its mounting bracket, and to ensure that all springs of a total installation are uniformly compressed and that the equipment is not tilting on its base. For reasons of safety, steel springs are always used in compression, not in tension.

2.2 NEOPRENEIN-SHEAR ISOLATORS. Neoprene is a long-lasting material which, when properly shaped, can provide good vibration isolation for the conditions shown in Table 1. Typically, neoprene-in-shear mounts have the appearance of a truncated cone of neoprene bonded to the bottom and top metal plates for bolting to the floor and to the supported equipment. The mount usually has an interior hollow space that is conically shaped. The total effect of the shaping is that for almost any direction of applied load, there is a shearing action on the cross section of neoprene. In this shearing configuration, neoprene serves as a vibration isolator; hence, the term “neoprene-in-shear.” A solid block of neoprene in compression is not as effective as an isolator. Manufacturers’ catalogs will show the upper limit of load-handling capability of large neoprene-in-shear mounts. Two neoprene-in-shear mounts are sometimes constructed in series in the same supporting bracket to provide additional static deflection. This gives the double deflection mount referred to in Table 1.

2.3 COMPRESSED GLASS FIBER. Blocks of compressed glass fiber serve as vibration isolators when properly loaded. The manufacturers have several different densities available for a range of loading conditions. Typically, a block is about 2-inches thick and has an area of about 10 to 20 in^2, but other dimensions are available. These blocks are frequently used in series with steel springs to remove high-frequency structure-borne noise, and they are often used alone, at various spacings, to support floating concrete floor slabs. The manufacturer’s data should be used to determine the density and area of a block required to achieve the desired static deflection. Unless otherwise indicated, a static deflection of about 5 to 10 percent of the uncompressed height is normal. With longtime use, the material might compress an additional 5 to 10 percent of its height. This gradual change in height must be kept in mind during the designing of floating floors to meet floor lines of structural slabs.

3. VIBRATION CONTROL

3.1 INTRODUCTION. This discussion provides the details of vibration isolation mountings so that the desired vibration conditions discussed above can be met for most electrical and mechanical equipment. In addition typical forms of vibration isolators are given, five general types of mounting systems are described, and summary tables offer suggested applications of five mounting systems for the mechanical equipment commonly found in buildings.

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Isolator Type	Typical Range of Static Deflection (in.)	Corresponding Approximate Range of Natural Frequency (Hz)	Vibration Isolation Applications -- Non-specific			
			Noncritical Locations[c]		Critical Locations[c]	
			Rotary Equipment	Reciprocating Equipment	Rotary Equipment	Reciprocating Equipment
Steel spring[a]	.25 to 10	6 to 1	Yes	Yes	Yes	Special[d]
Neoprene-in-shear, double deflection	.25 to .5	6 to 4	Yes	Yes	Yes	No[e]
Neoprene-in-shear, single deflection	.1 to .25	10 to 6	Yes	Yes	Yes	No[e]
Compressed block of glass fiber, 2-in. thick[b]	.02 to .15	20 to 8	Yes	No	Yes	No
Neoprene pad, ribbed or waffle-pattern, 1 to 4 layers[b]	.02 to .25	20 to 6	Yes	No	Yes	No
Felt or cork pads or strips	.01 to .1	30 to 10	See text for applications and limitations			
Air Spring	---	10 to 1	See text for applications and limitations			

[a]Always use pad-type isolator in series with spring to control high-frequency structureborne noise in critical locations.

[b]May be used alone for relatively high-speed rotary equipment or in series with steel springs in critical locations for reduction of high-frequency structureborne noise. Not normally used alone for vibration isolation of reciprocating equipment.

[c]Refer to paragraph 4-2d for definition of noncritical and critical locations.

[d]Special design required for reciprocating equipment at critical locations, especially for low speeds.

[e]Not normally recommended for this application, but can be adapted as special design.

Table 1

General Types and Applications of Vibration Isolators

3.2.4 RIBBED NEOPRENE PADS. Neoprene pads with ribbed or waffle-pattern surfaces are effective as high frequency isolators in series with steel springs. In stacks of 2 to 4 thicknesses, they are also used for vibration isolation of flow power rotary equipment. The pads are usually about ¼ to 3/8 inches thick, and they compress by about 20 percent of their height when loaded at about 30 to 50 lb/in^2. Higher durometer pads may be loaded up to about 100 lb/in^2. The pads are effective as isolators because the ribs provide some shearing action, and the spaces between the ribs allow lateral expansion as an axial load is applied. The manufacturer's literature should be used for proper selection of the material (load-deflection curves, durometer, surface area, height, etc.).

3.2.5 FELT PADS. Felt strips or pads are effective for reducing structureborne sound transmission in the mounting of piping and vibrating conduit. One or more layers of 1/8 or 1/4 inch thick strips should be wrapped around the pipe under the pipe clamps that attach the piping to building structures. Felt pads will compress under long time and high load application and should not be used alone to isolate vibration of heavy equipment.

3.2.6 CORK PADS. Cork pads, strips, or blocks may be used to isolate high frequency structureborne noise, but they are not recommended for high load bearing applications because cork gradually compresses under load and loses its resilience. High density construction cork is sometimes used to support one wall of a double wall. In this application, the cork will compress slightly with time, and it will continue to serve as a high frequency isolator (say, for structureborne noise above about 100 to 200 Hz), but it will not provide good low frequency isolation at equipment driving frequencies of about 10 to 60 Hz. Years ago, before other resilient materials came into widespread use, cork was often misused under heavy vibrating equipment mounts; full area cork pads were frequently loaded at rates of 1 to 5 lb/in^2. This is such a low loading rate that the cork appears stiff and does not provide the desired resilience. If cork is to be used for vibration isolation, a load deflection curve should be obtained from the supplier, and the cork should be used in the central linear region of the curve (possibly loaded at about

10 to 20 lb/in^2). With this loading, the compressed material will have an initial deflection of about 5% and will continue to compress gradually with age.

3.2.7 AIR SPRINGS. Air springs are the only practical vibration isolators for very low frequencies, down to about 1 Hz or even lower for special problems. An air mount consists of pressurized air enclosed in a resilient reinforced neoprene chamber. The air is pumped up to the necessary pressure to carry its load. Since the chamber is subject to very slow leakage, a system of air mounts usually includes a pressure sensing monitor and an air supply (either a pump or a pressurized air tank). A group of air mounts can be arranged to maintain very precise leveling of a base by automatic adjustment of the pressure in the various mounts. If air mounts are used in a design, an active air supply is required. Operational data should be obtained from the manufacturer.

Category	Area (and Acoustic Requirements)	Noise Criterion[a]
1	Bedrooms, sleeping quarters, hospitals, residences, apartments, hotels, motels, etc. (for sleeping, resting, relaxing).	NC-20 to NC-30
2	Auditoriums, theaters, large meeting rooms, large conference rooms, radio studios, churches, chapels, etc. (for very good listening conditions).	NC-15 to NC-30
3	Private offices, small conference rooms, classrooms, libraries, etc. (for good listening conditions).	NC-30 to NC-35
4	Large offices, reception areas, retail shops and stores, cafeterias, restaurants, etc. (for fair listening conditions).	NC-35 to NC-40
5	Lobbies, drafting and engineering rooms, laboratory work spaces, maintenance shops such as for electrical equipment,etc. (for moderately fair listening conditions).	NC-40 to NC-50
6	Kitchens, laundries, shops, garages, machinery spaces, power plant control rooms, etc. (for minimum acceptable speech communication, no risk of hearing damage).	NC-45 to NC-65

Table 2

3. MOUNTING ASSEMBLY TYPES. In this section, five basic mounting systems are described for the vibration isolation of equipment. These mounting systems are applied to specific types of equipment. Certain general conditions relating to all the systems are first mentioned.

3.1 GENERAL CONDITIONS.

3.1.1 BUILDING USES. Isolation recommendations are given for three general equipment locations: on grade slabs, on upper floors above noncritical areas, and on upper floors above critical areas. It is assumed that the building under consideration is an occupied building involving many spaces that would require or deserve the low noise and vibration environments of such buildings as hotels, hospitals, office buildings, and the like, as characterized by categories 1 through 4 in Table 2. Hence, the recommendations are aimed at providing low vibration levels throughout the building. If a building is intended to serve entirely such uses as those of categories 5 and 6 of Table 2, the recommendations given here are too severe and can be simplified at the user's discretion. An on-grade slab usually represents a more rigid base than is provided by a framed upper floor, so the vibration isolation recommendations can be relaxed for on-grade installations. Of course, vibration isolation treatments must be the very best when a high-quality occupied area is located immediately under the MER, as compared with the case where a "buffer zone" or noncritical area is located between the MER and the critical area.

3.1.2 STRUCTURAL TIES, RIGID CONNECTIONS. Each piece of isolated equipment must be free of any structural ties or rigid connections that can shortcircuit the isolation joint.

3.1.2.1 ELECTRICAL CONDUIT should be long and "floppy" so that it does not offer any resistance or constraint to the free movement of the equipment. Piping should be resiliently supported. Limit stops, shipping bolts, and leveling bolts on spring isolators should be set and inspected to ensure that they are not inadvertently short-circuiting the spring mounts.

3.1.2.2 ALL BUILDING TRASH should be removed from under the isolated base of the equipment. Loose pieces of grout, 2x4s, nuts, bolts, soft drink bottles, beer cans, welding rods, pipes, and pipe couplings left under an equipment base can shortcircuit the isolation mounts. It is recommended that a 2-inch to 4-inch clearances be provided under all isolated equipment in order to facilitate inspection and removal of trash from under the base.

3.1.2.3 FOR MANY EQUIPMENT INSTALLATIONS, there is no need to bolt down the isolation mounts to the floor because the smooth operation of the machine and the weight of the complete assembly keep the system from moving. For some systems, however, it may be necessary to restrain the equipment from “creeping” across the floor. In these situations, it is imperative that the hold-down bolts not short circuit the pads. A suggested restraining arrangement is illustrated in Figure 5. Simpler versions can be devised.

3.1.2.4 FOR BUILDINGS LOCATED IN EARTHQUAKE prone areas, the isolation mounts should contain snubbers or motion-limiting devices that restrain the equipment against unusual amounts of movement. These snubbers should be set to provide adequate free movement for normal equipment operation. These devices are available from most suppliers of isolator equipment.

3.2 TYPE I MOUNTING ASSEMBLY. The specified equipment should be mounted rigidly on a large integral concrete inertia block. (Unless specified otherwise, all concrete referred to in this discussion should have a density of at least 140 to 150 lb/ft.^{3}.)

(1) The length and the width of the inertia block should be at least 30 percent greater than the length and width of the supported equipment.

(2) Mounting brackets for stable steel springs should be located off the sides of the inertia block at or near the height of the vertical center-of-gravity of the combined completely assembled equipment and concrete block. If necessary, curbs or pedestals should be used under the base of the steel springs in order to bring the top of the loaded springs up to the center-of-gravity position. As an alternative, the lower portion of the concrete inertia block can be lowered into a pit or cavity in the floor so that the steel springs will not have to be mounted on curbs or pedestals. In any event, the clearance between the floor (or all the surfaces of the pit) and the concrete inertia block shall be at least 4 inches, and provision should be allowed to check this clearance at all points under the block.

(3) Floor slab thickness. It is assumed that MER upper floor slabs will be constructed of dense concrete of 140-150 $lb/ft.^3$ density, or, if lighter concrete is used, the thickness will be increased to provide the equivalent total mass of the specified floor. For large MERs containing arrays of large and heavy equipment, it is assumed that the floor slab thickness will be in the range of 8 to 12 inches, with the greater thicknesses required by the greater floor loads. For smaller MERs containing smaller collections of lighter weight but typical equipment, floor slab thicknesses of 6 to 10 inches are assumed. For occasional locations of one or a very few pieces of small high-speed equipment (say 1800 rpm or higher) having no reciprocating action, floor slabs of 4 to 6 inches may be used with reasonable expectation of satisfactory results. However, for reciprocating-action machines operating at the lower speeds (say, under 1200 rpm), any floor slab thicknesses reduced from those listed above begin to invite problems. There is no clear crossover from “acceptable” to “unacceptable” in terms of floor slab thickness, but each reduction in thickness increases the probability of later difficulties due to vibration. The thicknesses mentioned here are based on experience with the “acoustics” of equipment installations. These statements on thicknesses are in no way intended to represent structural specifications for a building. “Housekeeping pads” under the equipment are assumed, but the height of these pads is not to be used in calculating the thickness of the floor slab.

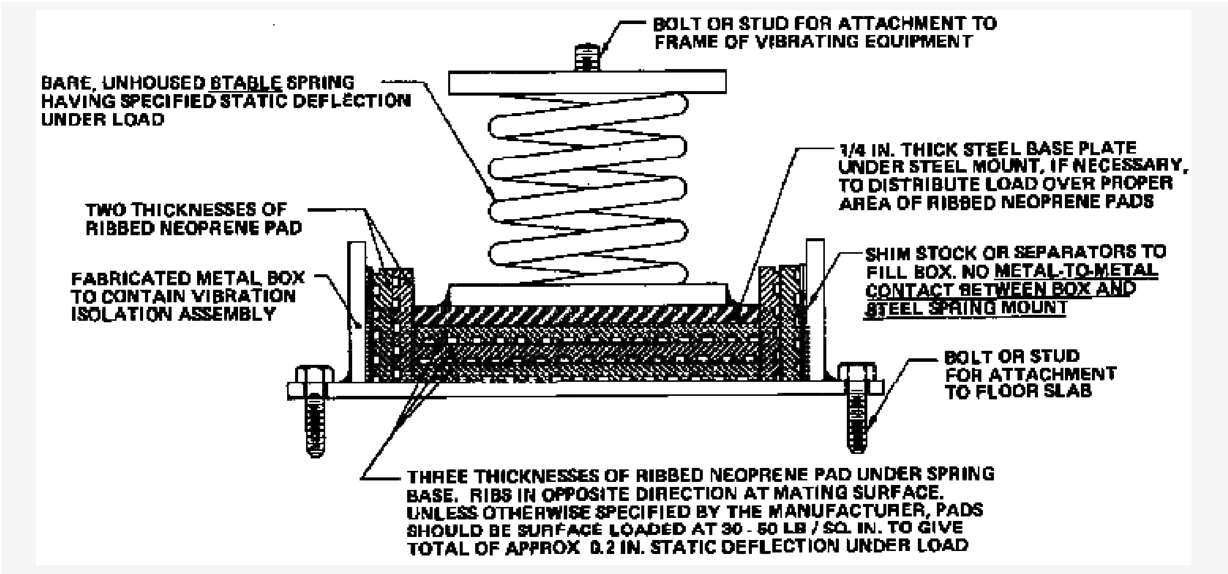

Figure 5

Suggested Arrangement of Ribbed Neoprene Pads for Providing Resilient Lateral Restraint to a Spring Mount

(4) The ratio of the weight of the concrete block to the total weight of all the supported equipment (including the weight of any attached filled piping up to the point of the first pipe hanger) shall be in accordance with the recommendations given in the paragraph and table for the particular equipment requiring this mounting assembly. The inertia block adds stability to the system and reduces motion of the system in the vicinity of the driving frequency. For reciprocating machines or for units involving large starting torques, the inertia block provides much-needed stability.

(5) The static deflection of the free-standing stable steel springs shall be in accordance with the recommendations given in the paragraph and table for the particular equipment. There shall be adequate clearance all around the springs to assure no contact between any spring and any part of the mounted assembly for any possible alignment or position of the installed inertia block.

3.3 . TYPE II MOUNTING ASSEMBLY. This mount is the same as the Type I mount in all respects except that the mounting brackets and the top of the steel springs shall be located as high as practical on the concrete inertia block but not necessarily as high as the vertical center-of-gravity position of the assembly, and the clearance between the floor and the concrete block shall be at least 2 inches.

(1) If necessary, the steel springs can be recessed into pockets in the concrete block, but clearances around the springs should be large enough to assure no contact between any spring and any part of the mounted assembly for any possible alignment or position of the installed inertia block. Provision must be made to allow positive visual inspection of the spring clearance in its recessed mounting.

(2) When this type of mounting is used for a pump, the concrete inertia block can be given a T-shape plan, and the pipes to and from the pump can be supported rigidly with the pump onto the wings of the T. In this way, the pipe elbows will not be placed under undue stress.

(3) The weight of the inertia block and the static deflection of the mounts shall be in accordance with the recommendations given in the table for the particular equipment.

3.4 TYPE III MOUNTING ASSEMBLY. The equipment or the assembly of equipment should be mounted on a steel frame that is stiff enough to allow the entire assembly to be supported on flexible point supports without fear of distortion of the frame or misalignment of the equipment. The frame should then be mounted on resilient mounts-steel springs or neoprene-in-shear mounts or isolation pads, as the static deflection would require. If the equipment frame itself already has adequate stiffness, no additional framing is required, and the isolation mounts may be applied directly to the base of the equipment.

(1) The vibration-isolation assembly should have enough clearance under and all around the equipment to prohibit contact with any structural part of the building during operation.

(2) If the equipment has large starting and stopping torques and the isolation mounts have large static deflections, consideration should be given to providing limit stops on the mounts. Limit stops might also be desired for large deflection isolators if the filled and unfilled weights of the equipment are very different.

3.5 TYPE IV MOUNTING ASSEMBLY. The equipment should be mounted on an array of "pad mounts". The pads may be of compressed glass fiber or of multiple layers of ribbed neoprene or waffle pattern neoprene of sufficient height and of proper stiffness to support the load while meeting the static deflection recommended in the applicable accompanying tables. Cork, cork-neoprene, or felt pad materials may be used if their stiffness characteristics are known and if they can be replaced periodically whenever they have become so compacted that they no longer provide adequate isolation.

(1) The floor should be grouted or shimmed to assure a level base for the equipment and therefore a predictable uniform loading on the isolation pads.

(2) The pads should be loaded in accordance with the loading rates recommended by the pad manufacturer for the particular densities or durometers involved. In general, most of these pads are intended for load rates of 30 to 60 psi, and if they are underloaded (for example, at less than about 10 psi), they will not be performing at their maximum effectiveness.

3.6 TYPE V MOUNTING ASSEMBLY (FOR PROPELLER-TYPE COOLING TOWERS). Large, low-speed propeller-type cooling towers located on roof decks of large buildings may produce serious vibration in their buildings if adequate vibration isolation is not provided. In extreme cases, the vibration may be evident two or three floors below the cooling towers.

(1) It is recommended that the motor, drive shaft, gear reducer, and propeller be mounted as rigidly as possible on a "unitized" structural support and that this entire assembly be isolated from the remainder of the tower with stable steel springs in

accordance with Table 9. Adequate clearance between the propeller tips and the cooling tower shroud should be provided to allow for starting and stopping vibrations of the propeller assembly. Several of the cooling tower manufacturers provide isolated assemblies as described here. This type of mounting arrangement is shown schematically in Figure 6.

(2) In addition, where the cooling tower is located on a roof deck directly over an acoustically critical area, the structureborne waterfall noise may be objectionable. It can be reduced by locating three layers of ribbed or waffle-pattern neoprene between the base of the cooling tower and the supporting structure of the building. This treatment is usually not necessary if there is a noncritical area immediately under the cooling tower.

(3) A single-treatment alternate to the combined two treatments of (1) and (2) above is the isolation of the entire cooling tower assembly on stable steel springs, also in accordance with Table 10. The springs should be in series with at least two layers of ribbed or waffle-pattern neoprene if there is an acoustically critical area immediately below the cooling tower (or within about 25 feet horizontally on the floor immediately under the tower). It is necessary to provide limit stops on these springs to limit movement of the tower when it is emptied and to provide limited movement under wind load.

(4) Pad materials, when used, should not be short-circuited by bolts or rigid connections. A schematic of an acceptable clamping arrangement for pad mounts is shown in Figure 7. Cooling tower piping should be vibration-isolated in accordance with suggestions given for piping.

4. TABLES OF RECOMMENDED VIBRATION ISOLATION DETAILS

4.1 TABLE FORMAT. A common format is used for all the tables that summarize the recommended vibration isolation details for the various types of equipment. A brief description of the format is given here.

4.1.1 EQUIPMENT CONDITIONS. The three columns on the left of the table (location, rating, and speed of the equipment) define the equipment conditions covered by the recommendations. The rating is given by a power range for some equipment, cooling capacity for some, and heating capacity for some. The rating and speed ranges generally cover the range of equipment that might be encountered in a typical building. Subdivisions in rating and speed are made to accommodate variations in the isolation. If vibrating equipment is supported or hung from an overhead floor slab, immediately beneath an acoustically critical area, the same degree of vibration isolation should be provided as is recommended for the location designated as "on upper floor above critical area". Similarly, if the vibrating equipment is hung from an overhead floor slab beneath a noncritical area, the same vibration isolation should be provided as is recommended for the location designated as "on upper floor above noncritical area".

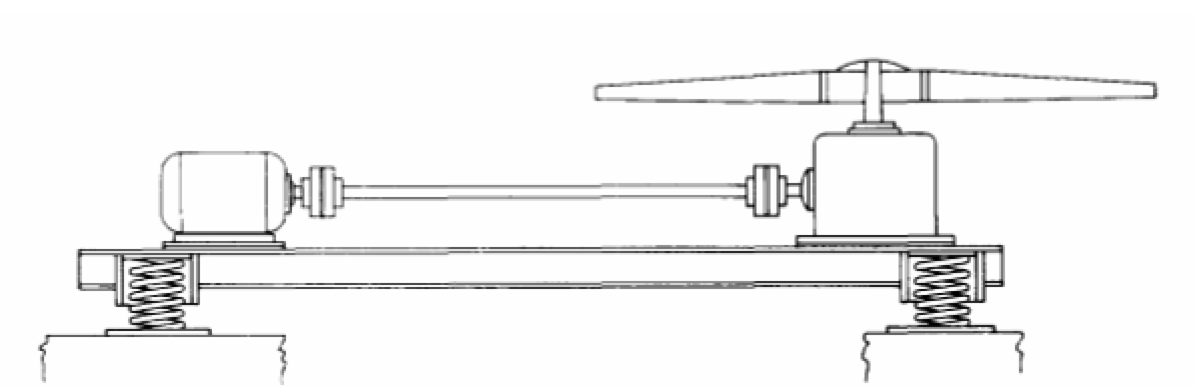

Figure 6

Schematic of Vibration Isolation Mounting for Fan and

Drive-Assembly of Propeller-Type Cooling Tower

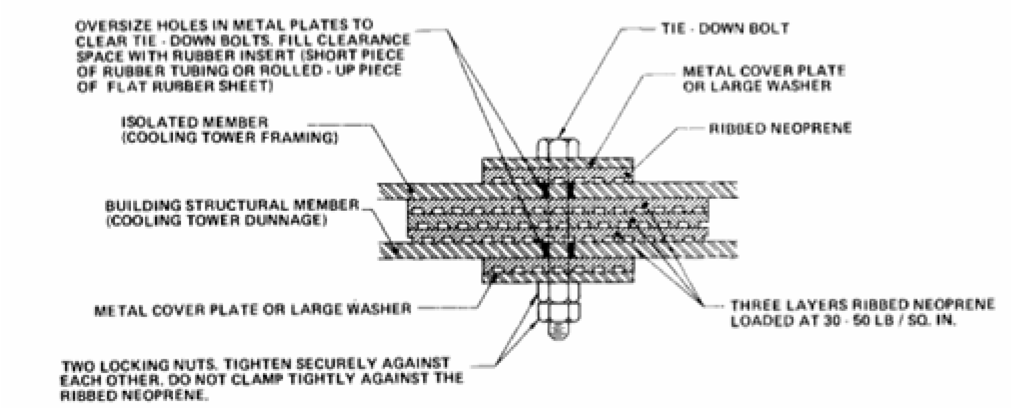

Figure 7

Schematic of a Resilient Clamping Arrangement with Ribbed Neoprene Pads

4.1.2 MOUNTING RECOMMENDATIONS. The three columns on the right of the table summarize three basic groups of recommendations: Column 1, the type of mounting; Column 2, the suggested minimum ratio of the weight of the inertia block (when required) to the total weight of all the equipment mounted on the inertia block; and Column 3, the suggested minimum static deflection of the isolator to be used.

(a) When the weight of the inertia block is being considered, the larger weight of the range given should be applied where the nearby critical area is very critical, or where the speed of the equipment is near the lower limit of the speed range given, or the rating of the equipment is near the upper limit of the rating range. Conversely, the lower end of the weight range may be applied where the nearby critical area is less critical, or where the speed is near the upper limit of the speed range, or the rating is near the lower limit of the rating range.

(b) When the static deflection of the isolators is being considered, these minimum values are keyed to the approximate span of the floor beams; that is, as the floor span increases, the floor deflection increases, and therefore the isolator deflection must increase. The specific minimum deflection in effect specifies the type of isolator that can be used. Refer to Table 1 for the normal range of static deflection for most isolators. Specific selections should be made from manufacturers' catalog data.

(c) The recommendations given here assume that a moderate amount of large equipment (say, more than five or six pieces) totaling more than this equipment are given in Table 4. These recommendations apply also to the drive unit used for a single piece of equipment remote from other equipment. The recommendations can be relaxed, either by decreasing the static deflection of the mount or by decreasing the weight of the inertia block, or even by eliminating the inertia block where a critical area is not involved.

(d) Resilient support of all piping connected to vibrating equipment should be in accordance with the recommendations herein. This recommendation applies to the mounting of each piece of vibrating equipment, even though it is not repeated below for each piece of equipment.

4.2 CENTRIFUGAL AND AXIAL-FLOW FANS. The recommended vibration isolation mounting for fans are given in Table 3. Ducts should contain flexible connections at both the inlet and discharge of the fans, and all connections to the fan assembly should be clearly flexible. The entire assembly should bounce with little restraint when one jumps up and down on the unit. Where supply fan assemblies are located over critical areas, it is desirable to install the entire inlet casing and all auxiliary equipment (coil decks and filter sections) on floated concrete slabs. The floated slab may also serve to reduce airborne noise from the fan inlet area into the floor area below. Large ducts (cross-section area over 15 sq feet) that are located within about 30 feet of the inlet or discharge of a large fan (over 20 hp) should be supported from the floor or ceiling with resilient mounts having a static deflection of at least 1/4 inch.

4.3 RECIPROCATING-COMPRESSOR REFRIGERATION EQUIPMENT. The recommended vibration isolation for this equipment are given in Table 4. These recommendations apply also to the drive unit used with the reciprocating compressor.

Pipe connections from this assembly to other equipment should contain flexible connections.

Equipment Conditions			Mounting Recommendations				
Equipment Location	Power Range (hp)	Speed Range (rpm)	Column 1	Column 2	Column 3 30 ft.	40 ft.	50 ft.
On Grade Slab	UNDER 3	UNDER 600	NO ISOLATION REQUIRED				
		600-1200					
		OVER 1200					
	3-25	UNDER 600	III	—	1 in.		
		600-1200			½		
		OVER 1200			½		
	26-200	UNDER 600	III	—	1½ in.		
		600-1200			1		
		OVER 1200			½		
On Upper Floor Above Non-Critical Area	UNDER 3	UNDER 600	III	—	1 in.	1½ in.	2 in.
		600-1200	III	—	½	3/4	1
		OVER 1200	III	—	½	½	3/4
	3-25	UNDER 600	II	2	1	1½	2
		600-1200	III	—	1½	2	3
		OVER 1200	III	—	1	1½	2
	26-200	UNDER 600	II	2	2	3	4
		600-1200	II	2	1½	2	3
		OVER 1200	II	2	1	1½	2
On Upper Floor Above Critical Area	UNDER 3	UNDER 600	II	2	1½	2	3
		600-1200	III	—	1½	2	3
		OVER 1200	III	—	1	1½	2
	3-25	UNDER 600	II	3	2	3	4
		600-1200	II	2	1½	2	3
		OVER 1200	II	2	1	1½	2
	26-200	UNDER 600	II	3	3	4	5
		600-1200	II	2	2	2½	3
		OVER 1200	II	2	1	1½	2

Col. 1: Mounting type (see text).
Col. 2: Minimum ratio of weight of inertia block to total weight of supported load.
Col. 3: Minimum static deflection of stable steel springs in inches for indicated floor span in feet.

Table 3

Vibration Isolation Mounting for Centrifugal and Axial-Flow Fans

Equipment Conditions			Mounting Recommendations				
Equipment Location	Cooling Capacity (Tons)	Speed Range (rpm)	Column 1	Column 2	Column 3 30 ft.	Column 3 40 ft.	Column 3 50 ft.
On Grade Slab	10-50	600-900	III		2 in.		
		901-1200	III		1½		
		1201-2400	III		1		
	51-175	600-900	II	2-3	2		
		901-1200	III		2		
		1201-2400	III		1½		
On Upper Floor Above Non-Critical Area	10-50	600-900	II	2-3	2 in.	3 in.	4 in.
		901-1200	II	2-3	1½	2	3
		1201-2400	II	2-3	1½	1½	2
	51-175	600-900	II	3-4	3	4	5
		901-1200	II	3-4	2	3	4
		1201-2400	II	2-3	2	2	3
On Upper Floor Above Critical Area	10-50	600-900	II	3-4	3	4	5
		901-1200	II	3-4	2	3	4
		1201-2400	II	2-3	2	2	3
	51-175	600-900	I	4-6	3	4	5
		901-1200	II	3-5	2	3	4
		1201-2400	II	3-4	2	2	3

Col. 1: Mounting type (see text).
Col. 2: Minimum ratio of weight of inertia block to total weight of supported load.
Col. 3: Minimum static deflection of stable steel springs in inches for indicated floor span in feet.

Table 4

Vibration Isolation Mounting for Centrifugal and Axial-Flow Fans

4.4 ROTARY-SCREW-COMPRESSOR REFRIGERATION EQUIPMENT. The recommended vibration isolation for this equipment are given in Table 5.

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4.5 CENTRIFUGAL-COMPRESSOR REFRIGERATION EQUIPMENT. The recommended vibration isolation for this equipment, including the drive unit and the condenser and chiller tanks, are given in Table 6.

4.6 ABSORPTION-TYPE REFRIGERATION EQUIPMENT. The recommended vibration isolation for this equipment are given in Table 7.

4.7 BOILERS. The recommended vibration isolation for boilers are given in Table 8. These apply for boilers with integrally attached blowers. Table 3 should be followed for the support of blowers that are not directly mounted on the boiler. A flexible connection or a thermal expansion joint should be installed in the exhaust breaching between the boiler and the exhaust stack.

4.8 STEAM VALVES. Steam valves are usually supported entirely on their pipes; recommendations herein should be applied to the resilient support of steam piping, including steam valves.

4.9 COOLING TOWERS. The recommended vibration isolation for propeller-type cooling towers are given in Table 9. Additional recommendations for the installation are given herein which describes the Type V mounting assembly. The recommended vibration isolation for centrifugal-fan cooling towers are given in Table 10.

4.10 MOTOR-PUMP ASSEMBLIES. Recommended vibration isolation for motor-pump units are given in Table 11. Electrical connections to the motors should be made with long “floppy” lengths of flexible armored cable, and piping should be resiliently supported. For most situations, a good isolation mounting of the piping will overcome the need for flexible connections in the pipe. An important function of the concrete inertia block (Type II mounting) is its stabilizing effect against undue bouncing of the pump assembly at the instant of starting. This gives better long-time protection to the associated piping. These same recommendations may be applied to other motordriven rotary devices such as centrifugal-type air compressors and motor-generator sets in the power range up to a few hundred horsepower.

4.11 STEAM TURBINES. Table 12 provides a set of general isolation recommendations for steam turbine driven rotary equipment, such as gears, generators, or centrifugal-type gas compressors. The material given in Table 6 applies when a steam turbine is used to drive centrifugal compressor refrigeration equipment. The recommendations given in Table 4 apply when a steam turbine is used to drive reciprocating-compressor refrigeration equipment or reciprocating-type gas compressors.

4.12 GEARS. When a gear is involved in a drive system, vibration isolation should be provided in accordance with recommendations given for either the main power drive unit or the driven unit, whichever imposes the more stringent isolation conditions.

4.13 TRANSFORMERS. Recommended vibration isolation for indoor transformers are given in Table 13. In addition, power leads to and from the transformers should be as flexible as possible. In outdoor locations, earthborne vibration to nearby neighbors is usually not a problem, so no vibration isolation is suggested. If vibration should become a problem, the transformer could be installed on neoprene or compressed glass fiber pads having 1/4-inch static deflection.

4.14 AIR COMPRESSORS. Recommended mounting for centrifugal type air compressors of less than 10 hp are the same as those given for motor-pump units in Table 11. The same recommendations would apply for small (under 10 hp) reciprocating type air compressors. For reciprocating type air compressors (with more than two cylinders) in the 10 to 50 hp range, the recommendations given in Table 4 apply for the particular conditions. For 10 to 100 hp, one or two cylinder, reciprocating type air compressors, the recommendations of Table 14 apply. This equipment is a potentially serious source of low frequency vibration in a building if it is not isolated. In fact, the compressor should not be located in certain parts of the building, even if it is vibration isolated. The forbidden locations are indicated in Table 14. When these compressors are used, all piping should contain flexible connections and the electrical connections should be made with flexible armored cable.

5. VIBRATION ISOLATION-MISCELLANEOUS.

5.1 RESILIENT PIPE SUPPORTS. All piping in the MER that is connected to vibrating equipment should be supported from resilient ceiling hangers or from floor-mounted resilient supports.

(1) As a general rule, the first three pipe supports nearest the vibrating equipment should have a static deflection of at least one-half the static deflection of the mounting system used with that equipment. Beyond the third pipe support, the static deflection can be reduced to 1/4 inch or ½ inch for the remainder of the pipe run in the MER.

(2) When a pipe passes through the MER wall, a minimum 1-inch clearance should be provided between the pipe and the hole in the wall. The pipe should be supported on either side of the hole, so that the pipe does not rest on the wall. The clearance space should then be stuffed with fibrous filler material and sealed with a nonhardening caulking compound at both wall surfaces.

(3) Vertical pipe chases through a building should not be located beside acoustically critical areas. If they are located beside critical areas, pipes should be resiliently mounted from the walls of the pipe chase for a distance of at least 10 feet beyond each such area, using both low-frequency and high-frequency isolation materials.

(4) Pipes to and from the cooling tower should be resiliently supported for their full length between the cooling tower and the associated MER. Steam pipes should be resiliently supported for their entire length of run inside the building. Resilient mounts should have a static deflection of at least 1/2 inch.

(5) In highly critical areas, domestic water pipes and waste lines can be isolated with the use of 1/4-inch- to 1/2-inch-thick wrappings of felt pads under the pipe strap or pipe clamp.

(6) Whenever a steel spring isolator is used, it should be in series with a neoprene isolator. For ceiling hangers, a neoprene washer or grommet should always be included; and if the pipe hangers are near very critical areas, the hanger should be a combination hanger that contains both a steel spring and a neoprene-in-shear mount.

(7) During inspection, the hanger rods should be checked to ensure they are not touching the sides of the isolator housing and thereby shorting out the spring.

5.2 FLEXIBLE PIPE CONNECTIONS. To be effective, a flexible pipe connection should have a length that is approximately 6 to 10 times its diameter. Tie rods should not be used to bolt the two end flanges of a flexible connection together. Flexible connections are either of the bellows type or are made up fitted with an exterior braided jacket to confine the neoprene. These connections are useful when the equipment is subject to fairly high-amplitude vibration, such as for reciprocating-type compressors. Flexible connections generally are not necessary when the piping and its equipment are given thorough and compatible vibration isolation. For serious pipe vibration problems, two flexible connections should be used, mounted 90 degrees to each other. Inertial masses may be attached to the piping to add stability and help maintain pipe alignment.

5.3 NONVIBRATING EQUIPMENT. When an MER is located directly over or near a critical area, it is usually desirable to isolate most of the nonvibrating equipment with a simple mount made up of one or two pads of neoprene or a 1 inch or 2 inch layer of compressed glass fiber. Heat exchangers, hot water heaters, water storage tanks, large ducts, and some large pipe stands may not themselves be noise sources, yet their pipes or their connections to vibrating sources transmit small amounts of vibrational energy that they then may transmit into the floor. A simple minimum isolation pad will usually prevent this noise transfer.

5.3 SUMMARY. In this publication, fairly complete vibration isolation mountings are laid out for most of the equipment included in an MER. Most of these have been developed and proven over many years of use. Although all the entries of the accompanying tables have not been tested in actual equipment installations, the schedules are fairly self consistent in terms of various locations and degrees of required isolation. Hence, the mountings are considered realistic and reliable. They are not extravagant when considered in light of the extremely low vibration levels required to achieve near inaudibility. The noise and vibration control methods given here are designed to be simple to follow and to put into use. If these methods and recommendations are carried out, with appropriate attention to detail, most equipment installations will be tailored to the specific needs of the building and will give very satisfactory results acoustically.

Equipment Conditions			Mounting Recommendations				
Equipment Location	Cooling Capacity (Tons)	Speed Range (rpm)	Column 1	Column 2	Column 3		
					30 ft.	40 ft.	50 ft.
On Grade Slab	100-500	2400-4800	III		1 in.		
On Upper Floor Above Non-Critical Area	100-500	2400-4800	III		1 in.	1½ in.	2 in.
On Upper Floor Above Critical Area	100-500	2400-4800	II	2-3	1 in.	1½ in.	2 in.

Col. 1: Mounting type (see text).
Col. 2: Minimum ratio of weight of inertia block to total weight of supported load.
Col. 3: Minimum static deflection of stable steel springs in inches for indicated floor span in feet.

Table 5

Vibration Isolation Mounting for Rotary Screw Compressor Refrigeration Equipment Assembly

Equipment Conditions			Mounting Recommendations				
Equipment Location	Cooling Capacity (Tons)	Speed Range (rpm)	Column 1	Column 2	Column 3		
					30 ft.	40 ft.	50 ft.
On Grade Slab	100-500	OVER 3000	III		3/4 in.		
	501-4000	OVER 3000	III		1 in.		
On Upper Floor Above Non-Critical Area	100-500	OVER 3000	III		1 in.	1½ in.	2 in.
	501-4000	OVER 3000	III		1½	2	3
On Upper Floor Above Critical Area	100-500	OVER 3000	II	2-3	1½	2	3
	501-4000	OVER 3000	II	3-5	1½	2	3

Col. 1: Mounting type (see text).
Col. 2: Minimum ratio of weight of inertia block to total weight of supported load.
Col. 3: Minimum static deflection of stable steel springs in inches for indicated floor span in feet.

Table 6

Vibration Isolation Mounting for Centrifugal Compressor Refrigeration Equipment Assembly

Equipment Conditions			Mounting Recommendations				
Equipment Location	Cooling Capacity (Tons)	Speed Range (rpm)	Column 1	Column 2	Column 3 30 ft.	Column 3 40 ft.	Column 3 50 ft.
On Grade Slab	ALL SIZES		IV		¼ in.		
On Upper Floor Above Non-Critical Area	ALL SIZES		III		½ in.	3/4 in.	1 in.
On Upper Floor Above Critical Area	ALL SIZES		III		1 in.	1½ in.	2 in.

Col. 1: Mounting type (see text).
Col. 2: Minimum ratio of weight of inertia block to total weight of supported load.
Col. 3: Minimum static deflection of isolators in inches for indicated floor span in feet.

Table 7

Vibration Isolation Mounting for Absorption-Type Refrigeration Equipment Assembly.

Equipment Conditions			Mounting Recommendations				
Equipment Location	Heating Capacity (bhp)	Speed Range (rpm)	Column 1	Column 2	Column 3 30 ft.	40 ft.	50 ft.
On Grade Slab	UNDER 200		—		NOT REQUIRED		
	200-1000				NOT REQUIRED		
	OVER 1000				NOT REQUIRED		
On Upper Floor Above Non-Critical Area	UNDER 200		III		1/8 in.	¼ in.	½ in.
	200-1000		III		¼	½	1
	OVER 1000		III		¼	½	1
On Upper Floor Above Critical Area	UNDER 200		III		½	1	1½
	200-1000		III		1	1½	2
	OVER 1000		III		1	1½	2

Col. 1: Mounting type (see text).
Col. 2: Minimum ratio of weight of inertia block to total weight of supported load.
Col. 3: Minimum static deflection of isolators in inches for indicated floor span in feet.

Table 8

Vibration Isolation Mounting for Boilers

Equipment Conditions			Mounting Recommendations			
Equipment Location	Power Range (hp)	Speed Range (rpm)	Column 1	Column 2	Column 3	
On Grade Slab	VIBRATION ISOLATION USUALLY NOT REQUIRED					
On Upper Floor Above Non-Critical Area	UNDER 25	150–300 301–600 OVER 600	V	INSTALL ON	5 in. 3 3	SPRINGS MAY BE LOCATED
	25-150	150–300 301–600 OVER 600	V	DUNNAGE ATTACHED TO	6 4 3	UNDER DRIVE ASSEMBLY
	OVER 150	150–300 301–600 OVER 600	V	BUILDING COLUMNS ONLY	6 5 4	OR UNDER TOWER BASE
On Upper Floor Above Critical Area	SAME AS FOR LOCATION ABOVE NONCRITICAL AREA, EXCEPT INSTALL RIBBED OR WAFFLE-PATTERN NEOPRENE BETWEEN TOWER AND BUILDING.					

Col. 1: Mounting type (see text).
Col. 2: Minimum ratio of weight of inertia block to total weight of supported load (not applicable here).
Col. 3: Minimum static deflection of stable steel springs in inches.

Table 9

Vibration Isolation Mounting for Propeller-Type Cooling Towers

Equipment Conditions			Mounting Recommendations				
Equipment Location	Power Range (hp)	Speed Range (rpm)	Column 1	Column 2	Column 3 30 ft.	 40 ft.	 50 ft.
On Grade Slab	VIBRATION ISOLATION USUALLY NOT REQUIRED						
On Upper Floor Above Non-Critical Area	UNDER 25	450-900 901-1800 OVER 1800	III		1 in. 3/4 3/4	1½ in. 1 1	2 in. 1½ 1½
	25-150	450-900 901-1800 OVER 1800	III		1½ 1 3/4	2 1½ 1	3 2 1½
	OVER 150	450-900 901-1800 OVER 1800	III		2 1½ 1	3 2 1½	4 3 2
On Upper Floor Above Critical Area	UNDER 25	450-900 901-1800 OVER 1800	III	INCLUDE RIBBED OR WAFFLE-PATTERN NEOPRENE BETWEEN TOWER AND BUILDING	1½ 1 3/4	2 1½ 1	3 2 1½
	25-150 -	450-900 901-1800 OVER 1800	III		2 1½ 1	3 2 1½	4 3 2
	OVER 150	450-900 901-1800 OVER 1800	III		3 1½ 1	4 2 1½	6 3 2

Col. 1: Mounting type (see text).
Col. 2: Minimum ratio of weight of inertia block to total weight of supported load.
Col. 3: Minimum static deflection of stable steel springs in inches for indicated floor span in feet.

Table 10

Vibration Isolation Mounting for Centrifugal-Type Cooling Towers

Equipment Conditions			Mounting Recommendations				
Equipment Location	Power Range (hp)	Speed Range (rpm)	Column 1	Column 2	Column 3		
					30 ft.	40 ft.	50 ft.
On Grade Slab	UNDER 20	450-900	VIBRATION ISOLATION USUALLY NOT REQUIRED FOR ACOUSTIC PURPOSES				
		901-1800					
		1801-3600					
	20-100	450-900	II	2-3	1½		
		901-1800	II	1½-2½	1		
		1801-3600	II	1½-2½	3/4		
	OVER 100	450-900	II	2-3	2		
		901-1800	II	2-3	1½		
		1801-3600	II	1½-2½	1		
On Upper Floor Above Non-Critical Area	UNDER 20	450-900	II	2-3	1½ in.	2 in.	3 in.
		901-1800	II	1½-2½	1	1½	2
		1801-3600	II	1½-2½	3/4	1	1½
	20-100	450-900	II	2-3	1½	2	3
		901-1800	II	2-3	1	1½	2
		1801-3600	II	1½-2½	1	1½	2
	OVER 100	450-900	II	3-4	2	3	4
		901-1800	II	2-3	1½	2	3
		1801-3600	II	2-3	1	1½	2
On Upper Floor Above Critical Area	UNDER 20	450-900	II	3-4	1½	2	3
		901-1800	II	2-3	1	1½	2
		1801-3600	II	2-3	3/4	1	1½
	20-100	450-900	II	3-4	2	3	4
		901-1800	II	2-3	1½	2	3
		1801-3600	II	2-3	1	1½	2
	OVER 100	450-900	II	3-4	3	4	5
		901-1800	II	2-3	2	3	4
		1801-3600	II	2-3	1½	2	3

Col. 1: Mounting type (see text).
Col. 2: Minimum ratio of weight of inertia block to total weight of supported load.
Col. 3: Minimum static deflection of stable steel springs in inches for indicated floor span in feet.

Table 11

Vibration Isolation Mounting for Motor-Pump Assemblies

Equipment Conditions			Mounting Recommendations				
Equipment Location	Power Range (hp)	Speed Range (rpm)	Column 1	Column 2	Column 3		
					30 ft.	40 ft.	50 ft.
On Grade Slab	500-1500	OVER 3000	III		½ in.		
	1501-5000	OVER 3000	III		3/4		
	5001-15000	OVER 3000	III		1		
On Upper Floor Above Non-Critical Area	500-1500	OVER 3000	III		1 in.	1½ in.	2 in.
	1501-5000	OVER 3000	III		1½	2	3
	5001-15000	OVER 3000	III		2	3	4
On Upper Floor Above Critical Area	500-1500	OVER 3000	II	2-3	1	1½	2
	1501-5000	OVER 3000	II	2-3	1½	2	3
	5001-15000	OVER 3000	II	2-3	2	3	4

Col. 1: Mounting type (see text).
Col. 2: Minimum ratio of weight of inertia block to total weight of supported load.
Col. 3: Minimum static deflection of stable steel springs in inches for indicated floor span in feet.

Table 12

Vibration Isolation Mounting for Steam-Turbine Driven Rotary Equipment

Equipment Conditions			Mounting Recommendations				
Equipment Location	Power Range (kva)	Speed Range (rpm)	Column 1	Column 2	Column 3		
					30 ft	40 ft	50 ft
On Grade Slab	UNDER 10		IV		1/8 in.		
	10-100		IV		1/8		
	OVER 100		IV		¼		
On Upper Floor Above Non-Critical Area	UNDER 10		IV		1/8 in.	¼ in.	¼ in.
	10-100		III		¼	½	½
	OVER 100		III		¼	½	1
On Upper Floor Above Critical Area	UNDER 10		III		¼	½	3/4
	10-100		III		½	3/4	1
	OVER 100		III		½	1	1½

Col. 1: Mounting type (see text).
Col. 2: Minimum ratio of weight of inertia block to total weight of supported load.
Col. 3: Minimum static deflection of isolators in inches for indicated floor span in feet.

Table 13

Vibration Isolation Mounting for Transformers

Equipment Conditions			Mounting Recommendations				
Equipment Location	Power Range (hp)	Speed Range (rpm)	Column 1	Column 2	Column 3		
					30 ft.	40 ft.	50 ft.
On Grade Slab	UNDER 20	300-600	I	4-8	4 in.		
		601-1200	I	2-4	2		
		1201-2400	I	1-2	1		
	20-100	300-600	I	6-10	5		
		601-1200	I	3-6	3		
		1201-2400	I	2-3	1½		
On Upper Floor Above Non-Critical Area	UNDER 20	300-600	NOT RECOMMENDED				
		601-1200	I	3-6	4 in.	NO[a]	NO[a]
		1201-2400	I	2-3	2	4	NO[a]
	20-100	300-600	NOT RECOMMENDED				
		601-1200	NOT RECOMMENDED				
		1201-2400	I	3-6	3	6	NO[a]
On Upper Floor Above Critical Area	UNDER 20	300-600	NOT RECOMMENDED				
		601-1200	NOT RECOMMENDED				
		1201-2400	I	3-6	4	NO[a]	NO[a]
	20-100	300-2400	NOT RECOMMENDED				

Col. 1: Mounting type (see text).
Col. 2: Minimum ratio of weight of inertia block to total weight of supported load.
Col. 3: Minimum static deflection of stable steel springs in inches for indicated floor span in feet.

[a] "NO" indicates "NOT RECOMMENDED" for this combination of conditions.

Table 14

Vibration Isolation Mounting for One or Two-Cylinder Reciprocating-Type Air Compressors in the 10-to l00-hp Size Range.