Technical Manual

for Machinery Application of

SORBTEX

Preformed Fabric Neoprene or Rubber

Shock Damping — Vibration Isolation Materials

VOSS ENGINEERING, INC.

Manufacturers of Vibration and Shock Controls —

Bridge and Structural Bearing Pads

6965 N. HAMLIN AVE • LINCOLNWOOD, IL 60645 • (847) 673-8900 • FAX (847) 673-1408

Table of Contents

	Page
The Nature of Vibration and Shock	1
Damping	5
SORBTEX Load-Deflection Data	6
Area Effect of SORBTEX	8
Natural Frequency Computations	10
Forced Vibration	12
Secondary Disturbances	14
Supporting Structure	14
Degrees of Freedom	15
Human Evaluation of Vibration	16
How to Use Data on Specific Vibration Problems	18
Shock-Isolation Fundamentals	22
The Shock Absorbing Properties of SORBTEX	22
Impact Forces	23
Drop Forge Hammer Application of SORBTEX	25
Driven Impact Machines	28
Shock Resonance	29
Stability	29
Horizontal Shock	29
Human Evaluation of Shock	29
How to Use Data on Specific Shock Problems	30

Appendix

Unload Characteristics of SORBTEX	A
Maximum Loading on SORBTEX	B
Breakdown Strength of SORBTEX	B
Creep Tests	B
Effect of Water on SORBTEX Shock-Isolation Properties	B
Distribution of Loads by SORBTEX	C
Anchor Bolts	C
Piping and Connections	C
Noise Reduction	D
Glossary of Terms Used in This Manual	E

Index of Charts

		Page
Figure 1 -	Typical load-deflection curves for linear and non-linear materials	2
Figure 2 -	Natural frequency of SORBTEX and linear materials	3
Figure 3 -	Transmissibility curve for a linear isolator	4
Figure 4 -	Vibratory Displacement Curve - Non-Linear Isolator	4
Figure 5 -	Typical damping curve for SORBTEX	5
Figure 6 -	Load-deflection curves for SORBTEX	7
Figure 7 / Fig. 7A	Area Correction Factors for SORBTEX	9
Figure 8 -	Basic Natural Frequency curve for SORBTEX	10
Figure 9 -	Natural Frequency Correction Factor for SORBTEX	11
Figure 10 -	Transmissibility curve for SORBTEX	12
Figure 11 -	Magnification factor curve for SORBTEX	13
Figure 12 -	Human Evaluation of vibration	17
Figure 13 -	Shock Transmission Ratio Curves for Forge Hammers	27
Figure 14 -	Unload factor for SORBTEX	A

The Nature of Vibration and Shock

Vibration and shock produce both force and motion causing stresses in the machine itself and in the machine's supporting structure. Machine produced disturbances are frequently transmitted to remote positions where they cause stresses either by direct deformation, or by sympathetic response to the disturbing frequency.

If the motion resulting from such disturbances is primarily air borne and within the audible range, it is recognized as noise. If the excitation is primarily "felt", it is identified as vibration when continuous, or as shock when sudden and short in duration. When such disturbances reach objectionable proportions -- either in the machine itself, or interfere with adjacent machines, or cause objectionable physical or psychological effect on plant employees, such disturbances should be controlled and minimized. For, not only can excessive vibration and shock cause mechanical and structural failures, but they can also greatly impair production efficiency and employee well being.

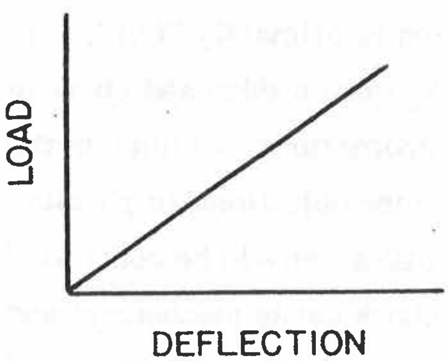
Whether the primary objective be the correction of vibration or shock for structural safety, employee comfort, or interference in production, the requirement is the same -- to reduce vibration. This may be done by reducing the unbalance or intensity of impact, or by the use of vibration and shock-isolation techniques.

This manual is designed to discuss isolation techniques and how they are efficiently applied with SORBTEX preformed, fabric-impregnated materials. The following discussion covers the areas of vibration-isolation and shock absorption to assist the engineer in solving conditions where vibration and shock are, or could be excessive.

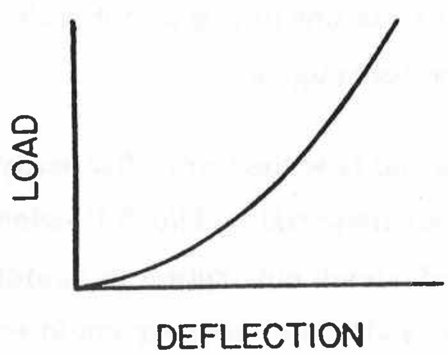
For the purpose of this presentation, vibration is considered as a continuing oscillation (steady-state) such as is caused by an unbalanced machine operating continuously. Shock is considered as the disturbance produced by a suddenly applied force or impact in which the ensuing oscillations die out due to the internal resistance of the system prior to the application of the next impulse.

It is not unusual for shock disturbanoes to be sufficiently close to each other to approach the steady-state vibration condition and must be handled as such.

All vibration and shock isolators require the use of resilient materials. Resilience is the ability of a material to deform (and store energy) when subjected to a load. Such materials are either linear or non-linear. A linear material is one in which the deflection of the material increases proportionately with the load, i.e., doubling the load also doubles the deflection. With a non-linear material, the deflection does not increase proportionately to the load. For example, doubling the load may produce one and one-half times the deflection. This is known as a "hardening" spring. It is possible for a material to deflect at a greater rate than the load (softening spring) but such materials are rarely used in vibration isolation and warrant no further discussion here. Typical load-deflection curves for a linear and non-linear material are shown in Figure 1.



LINEAR MATERIAL



NON LINEAR MATERIAL

FIGURE 1

Vibration principles are generally presented with linear springs because the theory so developed lends itself to simple analysis.

Practically all commercial isolators are non-linear. The application of vibration theory based on "linear" assumptions is satisfactory from a practical engineering viewpoint for small displacements. For large displacements, the non-linear characteristics become more significant and must be considered.

SORBTEX is a non-linear isolator of the "hardening" spring type. It is recommended and preferred over linear and other non-linear isolators because of its durability, high ultimate strength, ease of application and low cost. It is especially desirable for use under heavy applications where replacement and/or maintenance involve considerable lost production time and high cost.

It is usual in any basic dissertation on vibration principles to consider only vertical motion. For purposes of clarity, this approach will also be used here. However, five other types of motion will be discussed later, and it will be shown that consideration of vertical motion alone is not sufficient in many cases.

The natural frequency of a system is the frequency at which the system vibrates naturally when displaced from its rest position. A linear isolator always vibrates freely at the same frequency regardless of how much it is displaced initially, as shown in the upper part of Figure 2. This natural frequency depends on the static deflection of the resilient material due to the dead weight of the object it supports. The natural frequency of SORBTEX increases, as the initial displacement increases. This is represented in the lower part of Figure 2.

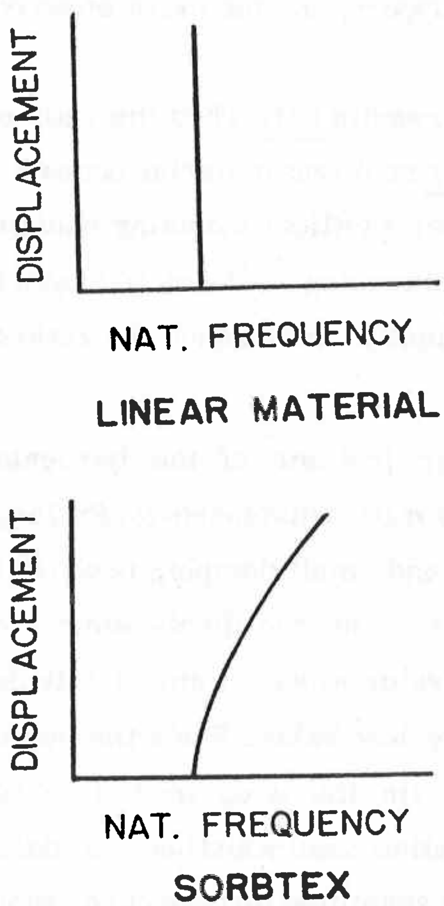
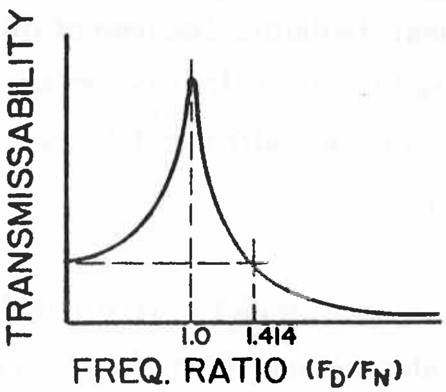


FIGURE 2

When a periodic disturbing force, as is caused by the unbalance of a rotating machine, is imposed on a linear isolator, the force transmitted to the supporting structure depends on the ratio of the disturbing force frequency (F_D) to the natural frequency of the support (F_N). This results in the familiar transmissibility curve shown in Figure 3.



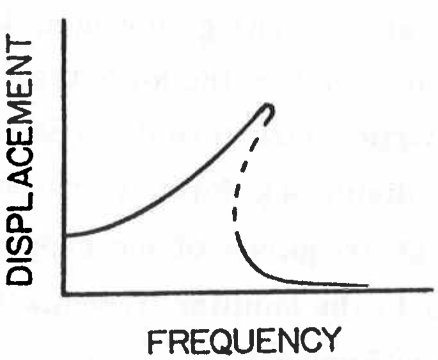
LINEAR ISOLATOR

FIGURE 3

This curve illustrates that if the ratio F_D/F_N is very low, the full force of the unbalance is transmitted to the support. As the ratio increases, so does the transmitted force until at a ratio of 1.0 the supporting structure is subjected to many times the intensity of force produced by the machine. As the ratio increases further, the magnitude of the force is reduced until at a ratio of 1.414, the force transmitted is the same as though the frequency ratio approached zero (isolator is extremely stiff).

At greater ratios than 1.414 the isolator begins to perform the function for which it is provided -- to reduce the force transmitted to the support. The greater the ratio becomes, the less the force transmitted to the support, and the more effective the isolator.

It is important to emphasize that vibration isolation results only when the ratio of F_D/F_N is greater than 1.414. It is not true that any resilient material beneath a vibrating machine will reduce vibration. An improper resilient mounting actually increases vibration. Proper use of a resilient mounting reduces the natural frequency of the machine on its mounting sufficiently to increase the ratio of F_D/F_N as far as practicable above 1.414.



NON LINEAR ISOLATOR

FIGURE 4

With a non-linear isolator of the hardening spring type, the vibration displacement for large disturbing forces and small damping is shown in Figure 4. In this case, the displacement increases to some value when it immediately decreases to a very low value. Since the motion changes abruptly (in the area of the dashed curve) small vibration results and hence a sudden reduction in the transmitted force occurs beyond resonance rather than a gradual reduction as in the case of a linear material.

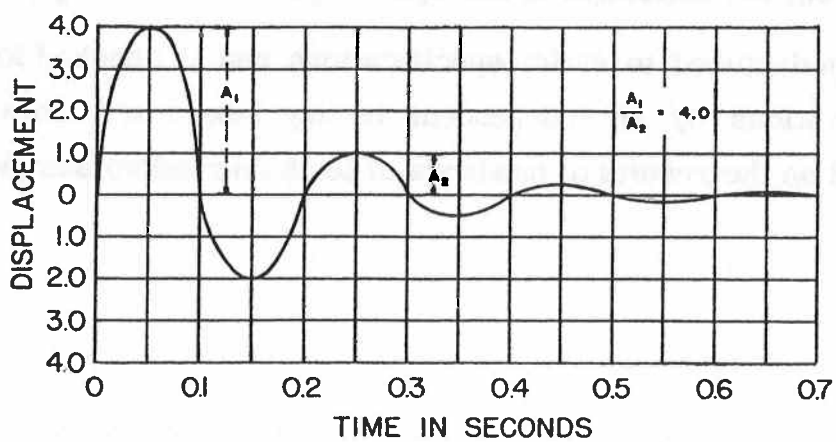
Damping

The physical effect of damping in the resilient material is to cause the object or machine set in motion to come to rest more quickly than without it. All materials have an inherent amount of damping. The amount varies in different materials. In general, laminated materials such as SORBTEX have greater damping values than non-laminated materials.

When a machine on a mounting is suddenly displaced and "just" returns to its original position of equilibrium without oscillating, it is said to be critically damped. When the machine oscillates many times before coming to rest, the mounting is said to have low damping qualities. Damping is measured in terms of the Logarithmic Decrement, or as a proportion of critical damping. For the purpose of comparison, the following tabulation indicates the relative damping properties of some of the materials used in vibration isolation:

Material	Logarithmic Decrement	Ratio of Critical Damping
SORBTEX	1.40	0.22
Rubber	0.51	0.08
Felt	0.69	0.11
Cork (ground and compressed)	0.68	0.11
Natural Cork	0.88	0.14
Steel	0.03	0.005

A typical damped oscillation curve with SORBTEX is shown in Figure 5.



TYPICAL DAMPING CURVE FOR SORBTEX

FIGURE 5

A reasonable amount of damping has a desirable effect in both vibration and shock isolation. In shock, damping permits the oscillation of the impact to die out more rapidly. In vibration isolation, damping reduces the motion of the vibrating machine for all frequencies, and reduces the force transmitted to the support when the machine passes through resonance during run-up and coast-down. The following tabulation represents the order of magnitude of the reduction in transmitted force and motion of the machine (at resonance) due to increased damping:

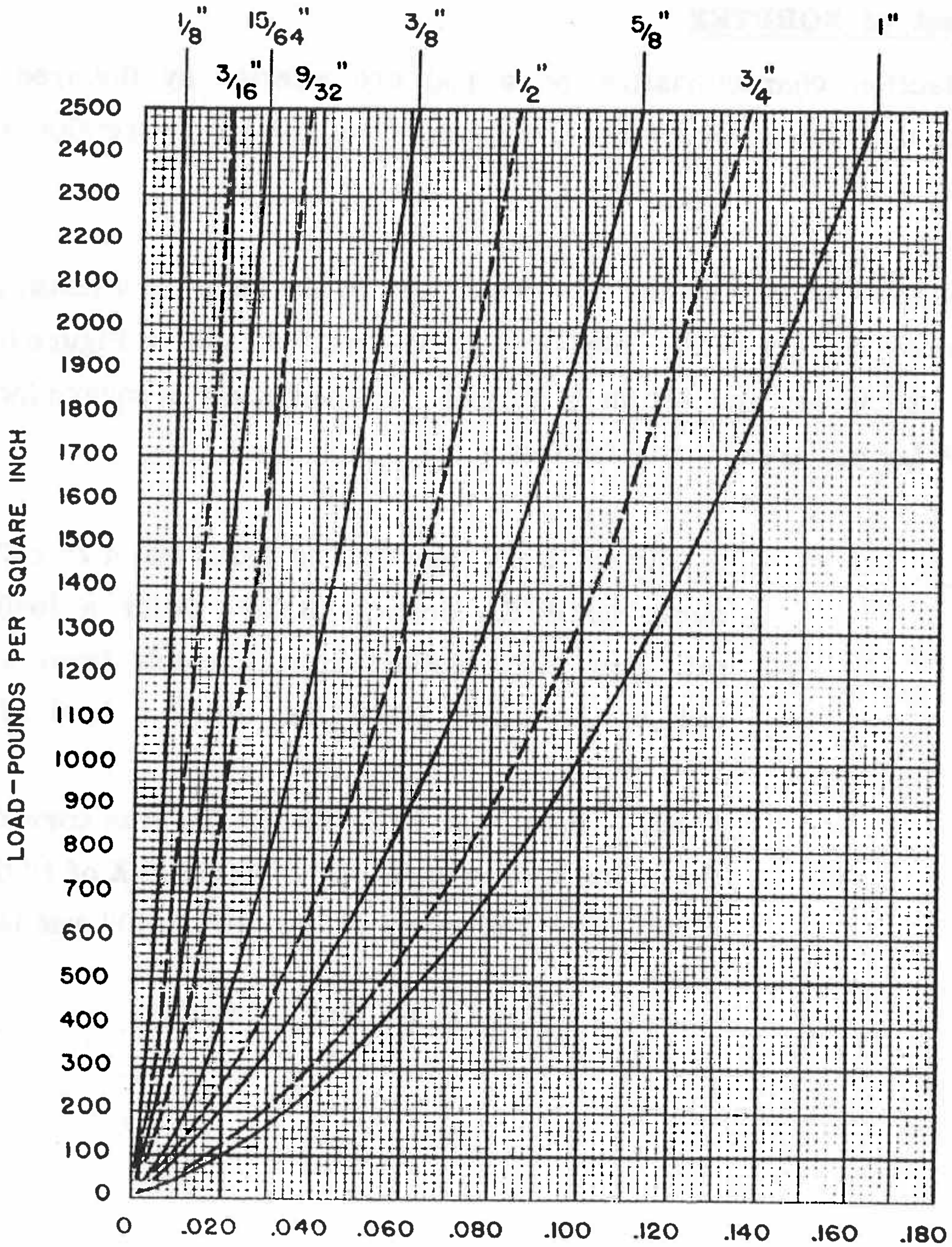
Ratio of Critical Damping	Force Transmitted to Support or Vibratory Motion of Machine
0.05	100%
0.10	50%
0.22 (SORBTEX)	25%

Damping also has the effect of reducing the natural frequency of a mounting, but this effect is very slight and is generally neglected. In the case of SORBTEX, the natural frequency is reduced by approximately 1.5% due to its high damping properties.

SORBTEX Load-Deflection Data

Load-Deflection data for various thicknesses of SORBTEX stock material are shown in Figure 6. As required by specifications, the determination of these characteristics has been made on 2" x 2" specimens. When stacking several pads of a given thickness, the deflection is multiplied by the number of pads.

SORBTEX is manufactured to strict specifications and is checked for conformity to those specifications by an independent testing laboratory. Data presented in Figure 6 is based on the results of hundreds of tests on random samples.



DEFLECTION OF SORBTEX – INCHES
(2" X 2" PAD)
FIGURE 6

Example: The deflection of a 2" x 2" pad of 1" thick SORBTEX under a loading of 1000 psi is 0.100". The deflection of 4 stacked pads is therefore 0.400".

Area Effect of SORBTEX

Load-Deflection characteristics of a pad are affected by the area of the pad. Comprehensive laboratory tests were made to provide correction factors for SORBTEX.

Square samples of increasing size were used in the laboratory tests. Correction factors to be applied to the Load-Deflection data indicated in Figure 6 (using the 2" x 2" specimen) are shown in Figure 7 for pad areas in square inches and in Figure 7A for pad areas in square feet.

Example:

In Figure 6 on page 7 it is found that a 2" x 2" pad of 1" thick SORBTEX deflects 0.100" under a load of 1,000 psi. How much deflection will result from a 10" x 10" pad of 1" thick SORBTEX under a load of 1,000 psi?

From Figure 7, it is found that the area correction factor for a 100 square inch pad of SORBTEX of 1" thickness is 0.715. The deflection of the 10" x 10" pad is therefore:

0.715 x 0.100" = 0.0715"

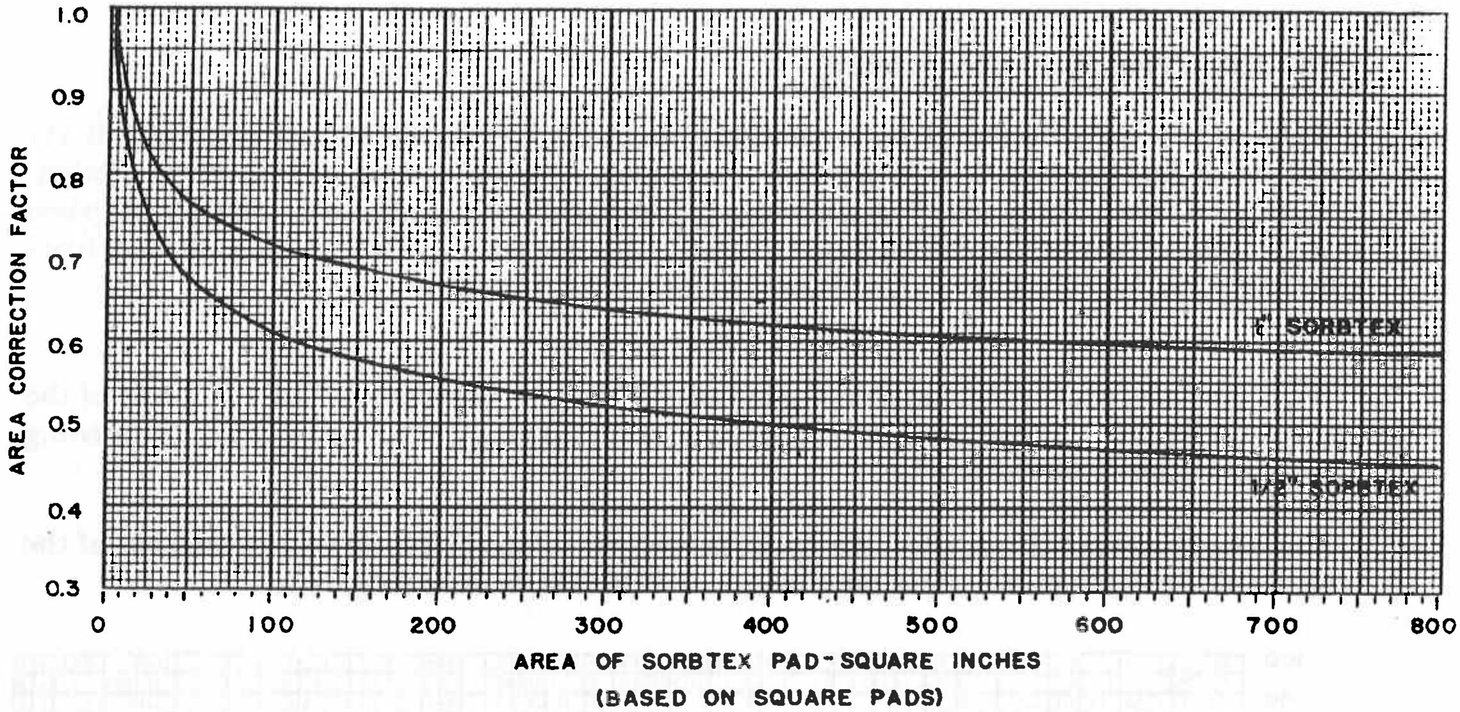


FIGURE 7

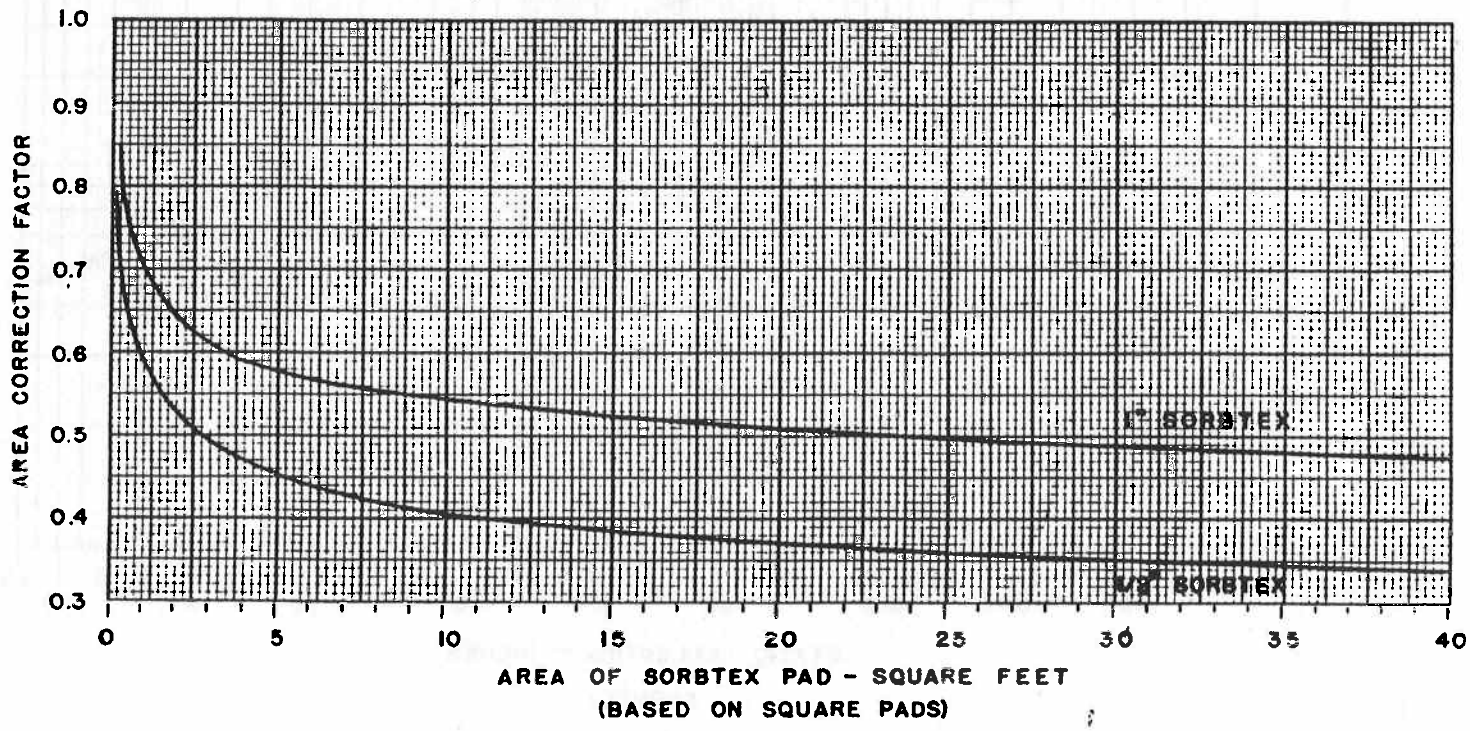


FIGURE 7A

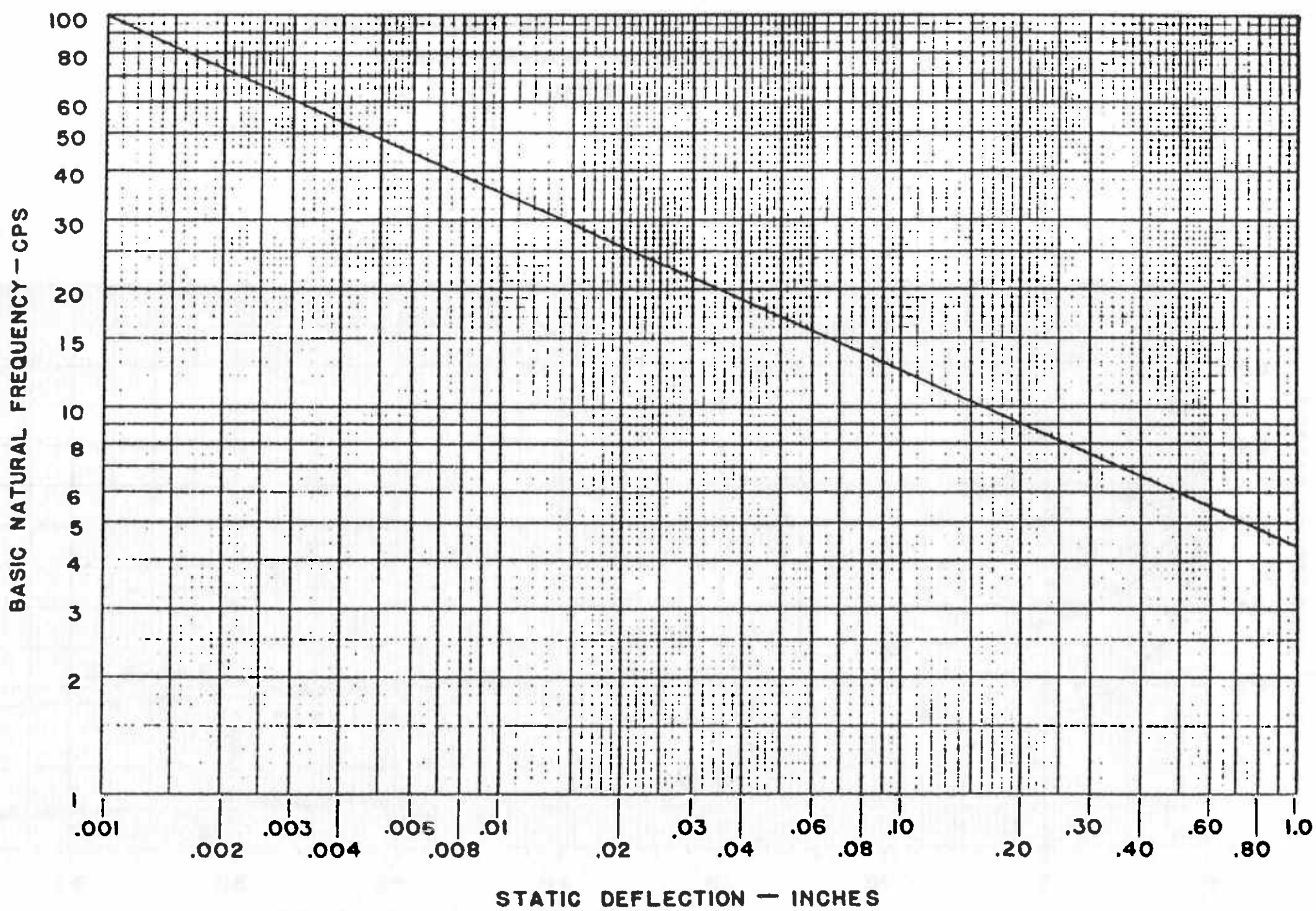
Natural Frequency Computations

When a machine mounted on a resilient mounting is displaced and released, it vibrates at its characteristic natural frequency. For purposes of this presentation, "Basic Natural Frequency" is the natural frequency of a machine on SORBTEX when displaced or vibrated through very small displacements. Such Basic Natural Frequency may be determined from the following relationship:

$$F'_N = 3.13\sqrt{\frac{K}{p}}$$

"F'_N" is the Basic Natural Frequency in cycles per second, "K" is the slope of the Load-Deflection curve at the appropriate unit loading, and "p" is the unit loading in pounds per square inch.

For convenience, Figure 8 has been prepared to simplify the determination of the basic natural frequency of a machine on a SORBTEX mounting:

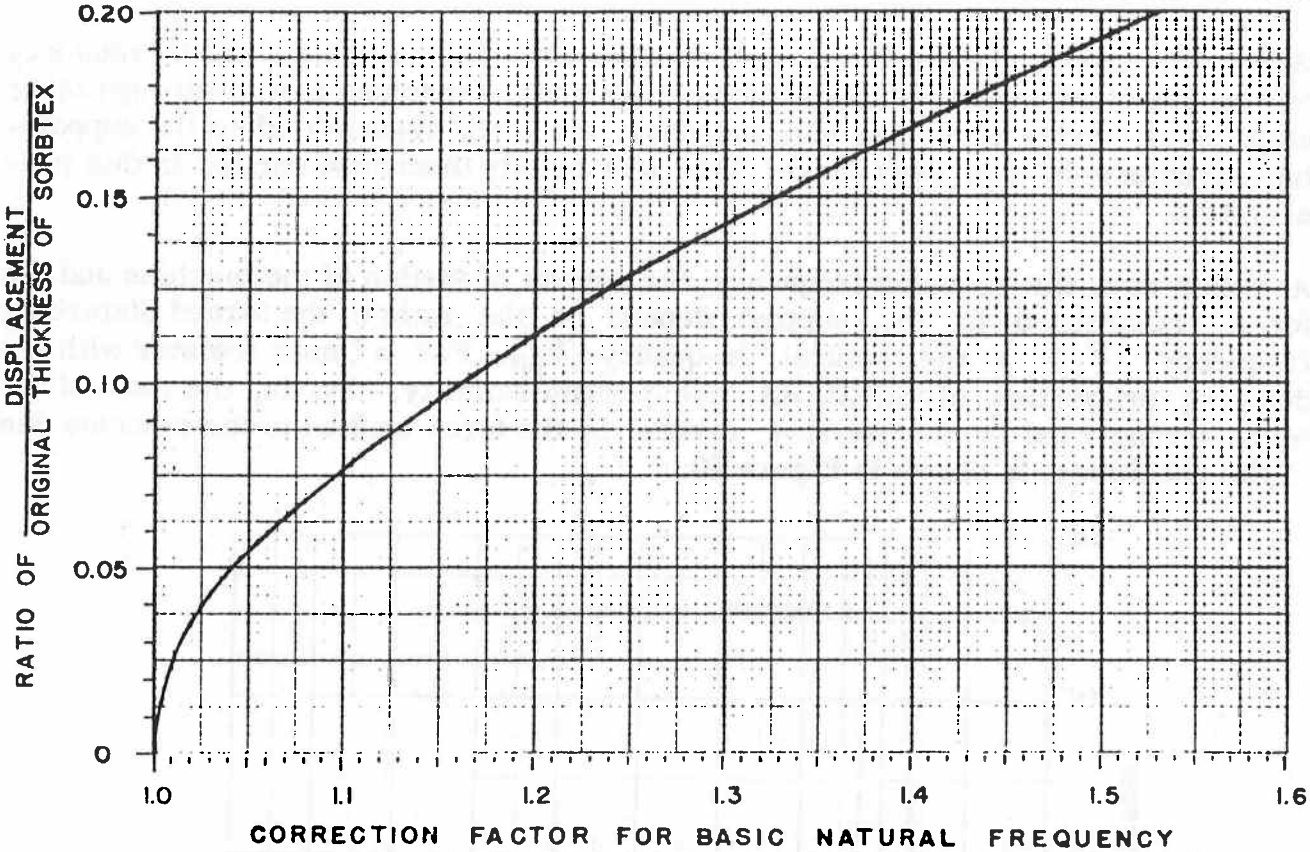


SORBTEX

FIGURE 8

Example: The static deflection of three 1/2 inch thick pads of SORBTEX under a given loading, and corrected for area effect is 0.160". From Figure 8, it is found that the Basic Natural Frequency is 10.0 cycles per second.

When large displacements are produced, a correction factor must be applied to the Basic Natural Frequency indicated by Figure 8. This correction factor is shown in Figure 9 as a function of the ratio of displacement to the original thickness of SORBTEX. The corrected natural frequency is obtained by multiplying the Basic Natural Frequency from Figure 8, by the correction factor for the appropriate Displacement/Original Thickness ratio from Figure 9.



SORBTEX

FIGURE 9

Example: The Basic Natural Frequency of a SORBTEX mounting whose original thickness is 1-1/2 inch, is 10.0 cps. Find the natural frequency when the supported load is subjected to a displacement of 0.195":

$$\text{Ratio of } \frac{\text{Displacement}}{\text{Original Thickness}} = \frac{0.195}{1.5} = .13$$

Correction factor from Figure 9 is 1.255
Natural frequency is 1.255 x 10.0 = 12.55 cps.

It is to be understood that "static deflection" pertains to the change in thickness of the pad under the weight being supported. "Displacement" is the distance the object is moved from its rest position when vibrating. Displacement of a vibrating object may change due to the disturbance, but the deflection (or static deflection) depends only on the weight of the supported object, and is determined from the load deflection characteristics of the resilient material. The static deflection is actually the rest position about which the displacement occurs.

Forced Vibration

An object supported on a resilient mounting can be forced to vibrate at a frequency other than its natural frequency by subjecting the object to uniformly periodic disturbances. Such periodic disturbances are produced, for example, by the unbalance of a rotating machine; the frequency of the disturbance is the same as the RPM of the machine.

When the forced frequency of the machine is the same as its natural frequency on the resilient mounting, resonance occurs and the machine moves through large amplitudes; under such resonant response, the force transmitted to the supporting structure is also very large. This was briefly discussed earlier in this presentation.

At other than the resonant frequency, the amount of motion of the machine and the force transmitted to the support depend on the ratio of the forced disturbing frequency (F_D) to the natural frequency (F_N). For a linear isolator with the damping properties of SORBTEX, the transmissibility, that is, the ratio of the force transmitted by the isolator, divided by the force applied to the machine due to the unbalance, is shown in Figure 10.

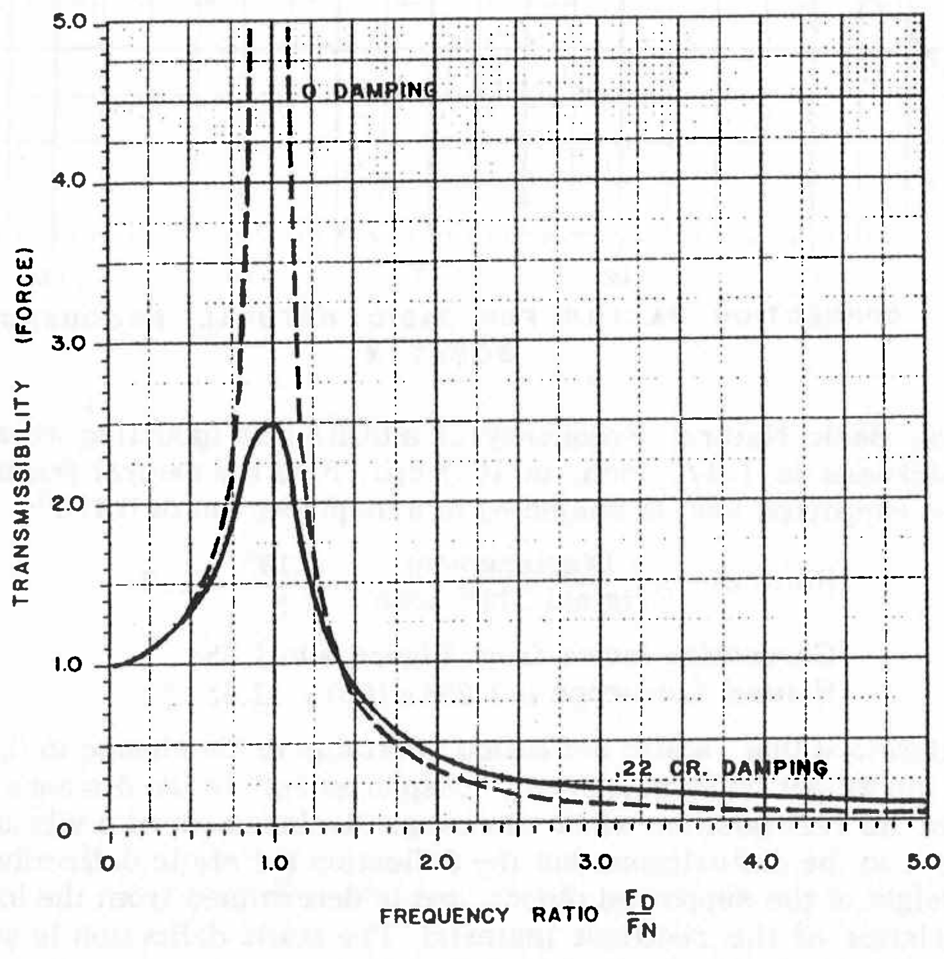


FIGURE 10

The magnification factor, or the ratio of the vibration amplitude (displacement of the machine) to the equivalent static deflection caused by the unbalance force acting independently on the isolator (an imaginary condition) is shown in Figure 11.

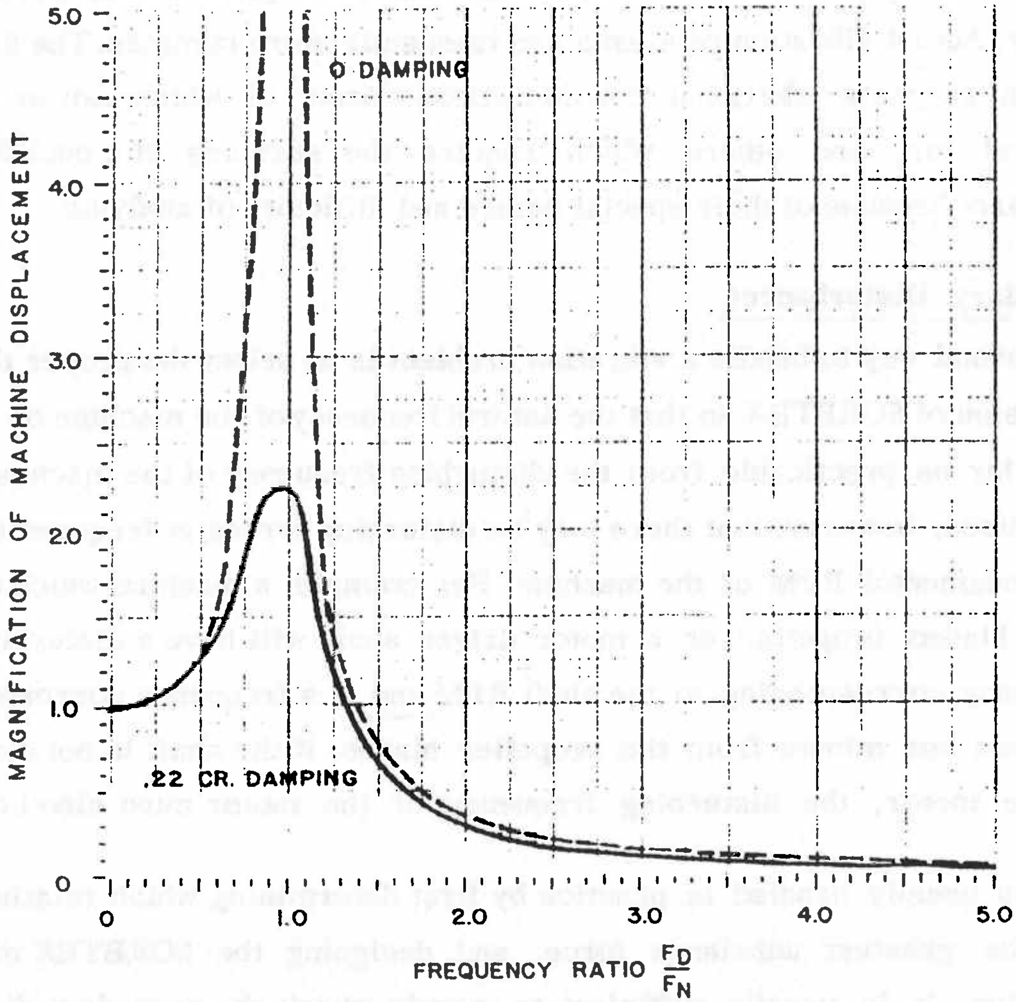


FIGURE 11

The solid curves in Figures 10 and 11 may be used for SORBTEX applications. The effect of the increased natural frequency of SORBTEX under large displacements is provided for since these charts are presented in terms of frequency ratios.

In non-linear systems the magnification curve in the vicinity of resonance is more "pointed" than indicated in Figure 11. The physical effect of this sharper peak indicates that the resonance range is more rapidly passed through by a machine running up to operating speed or coasting down to a stop. Since the linear assumptions used in Figure 11 result in slightly higher magnifications than actually occur with SORBTEX, this deviation is on the safe side and the simplifying assumptions are justified.

Example: For a Frequency Ratio of 3.0, and a damping of .22 critical damping, the Transmissibility Factor (force) is 0.21 from Figure 10, and the Magnification Factor (displacement) is 0.11 from Figure 11.

Other Considerations in Using SORBTEX

The foregoing presentation idealizes the vibration problem for the sake of basic clarity. Actual vibration problems are frequently more complex. The following discussion suggests additional considerations, some of which can be conveniently provided for, and others which require the services of a qualified vibration consultant because of their special nature and difficulty of analysis.

Secondary Disturbances

The normal way to handle a vibration problem is to select the proper thickness and dimension of SORBTEX so that the natural frequency of the machine on its mounting is as far as practicable from the disturbing frequency of the machine. It must be recognized, however, that there may be disturbing forces at frequencies other than the fundamental RPM of the machine. For example, a machine which consists of a three bladed propeller on a motor driven shaft will have a disturbing force at a frequency corresponding to the shaft RPM and at a frequency corresponding to the impulses per minute from the propeller blades. If the shaft is not directly driven by the motor, the disturbing frequency of the motor must also be considered.

This is usually handled in practice by first determining which rotating component has the greatest unbalance force, and designing the SORBTEX mount for this condition. It is usually sufficient to merely check the secondary disturbing frequencies against the natural frequency of the designed mounting to be sure that the secondary frequency is adequately removed from resonance. It may be necessary to sacrifice a small part of the efficiency of the isolator relative to the primary disturbing force to prevent a significant increase in transmission relative to a secondary disturbing force.

Supporting Structure

Our previous development of vibration isolation techniques assumed the supporting structure to be relatively rigid. If such structure has a natural frequency close to one of the disturbing frequencies of the machine, the structure, or a portion of it, will vibrate in resonance with the disturbing frequency. The proper use of SORBTEX will reduce the force transmitted to the supporting structure, but it, or any other isolator, will not alter the structure or prevent it from performing as the resilient mounting which it is, with its own characteristics of weight and springiness.

Problems of this type are very complex and require the services of a consultant. In some cases the structure or component must be made more rigid to alleviate such conditions. In other cases, it may be more practical and economical to alter the structure, or part of it, so that it is more flexible.

Degrees of Freedom

In the foregoing analysis, vibration was considered to be vertical in direction. In some cases this is true, but not true in other cases. A machine may vibrate in a straight line (translation mode) or it may rock (rotation mode). Translation may be horizontal in one of two perpendicular directions, or it may be vertical. It may rock (rotate) about one of the horizontal axes or about a vertical axis.

The rotational modes are usually visualized by comparing the machine to a ship at sea. It may "pitch", that is, the bow moves down while the stern moves up -- or it may "roll" when the left side moves down while the right side moves up; each of these motions is rotation about a horizontal axis. A ship may also "yaw" in which case the bow moves to the left while the stern moves to the right; this is a rotation about a vertical axis. It is not unusual when the axis of rotation lies outside the actual physical dimensions of the machine.

Isolation technique should be directed to the mode which is objectionable. If this is not done, the conditions may not only be unaffected, but may be aggravated. Although it is possible that the objectionable vibration may be a combination of any two or more of the six modes discussed, it is more usual that a single mode is of primary importance. Each of the separate modes has its own characteristic natural frequency. Unless the objectionable mode is obvious, it must be determined by measurements in order to properly direct the vibration isolation effort. The natural frequencies of the rotational modes are usually difficult to compute since mass moments of inertia are important to their solution.

The most effective way to minimize the response of the rotational modes is to support the machine as close as possible to the position of the center of gravity (in both the vertical and horizontal directions). Every effort should be exerted to minimize the eccentricity of the disturbing force with respect to the supports.

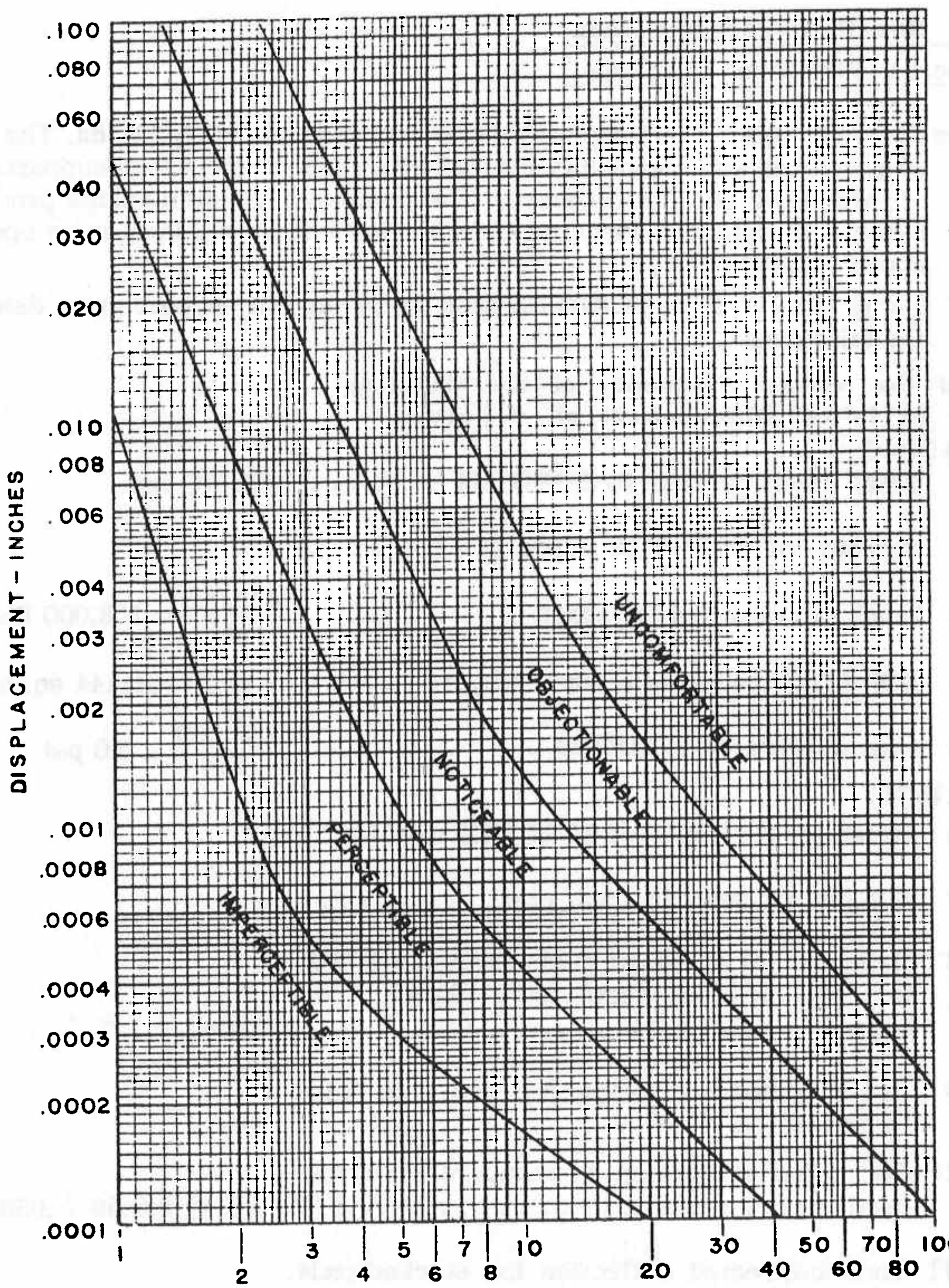
Human Evaluation of Vibration

As previously mentioned, the human response to vibration is frequently an important factor in determining the degree of isolation that will be required under a machine.

The most extensive investigations into the human evaluation of vibration were those of Reiher and Meister (1931 and 1935) in Germany. These investigations consisted of subjecting many persons with different environmental backgrounds and different ages to vibrations of various controlled frequencies and displacements. The vibration was produced in both vertical and horizontal directions and the persons participating were tested in both standing and reclining positions. After being subjected to several minutes of vibration, those tested were each asked to classify various intensities into one of several categories ranging from imperceptible to uncomfortable.

It was found that the sensitivity of the body varies with its position, whether standing or reclining, and with the direction of the vibration, whether vertical or horizontal. In general, the body is more sensitive to higher frequencies than to lower frequencies, more sensitive to vertical vibration when standing, and more sensitive to horizontal vibration when reclining.

Figure 12 has been prepared to summarize the above study. Individuals may differ in their evaluation of the intensity of a specific vibration condition, but in general, the chart is a reliable guide. Subsequent U.S. studies are in agreement.



HUMAN EVALUATION OF VIBRATION

FIGURE 12

Example: At a frequency of 10 cycles per second, a displacement of 0.0001" will be imperceptible to a person, while a displacement of 0.0030" would probably be considered objectionable.

How to Use the Preceding Data On Specific Vibration Problems

Vibration Example No. 1: A large rotating machine weighs 432,000 lbs. The center of gravity is symmetrically located with respect to the four supports, each of which is one foot square. The unbalance in the machine produces a maximum dynamic force of 160,000 lbs. under full load at its operating speed of 1800 RPM.

Using two 1" thick SORBTEX pads under the full support area, determine the following:

A. Find the Natural Frequency of the Mounting For an Initial Displacement of 0.3 Inch.

LOADING

A-1	Total load carried by SORBTEX	432,000 lbs.
A-2	Number of SORBTEX supports	4
A-3	Load carried per support	$\frac{432,000}{4}$ = 108,000 lbs.
A-4	SORBTEX pad area at each support	1 sq. ft. or 144 sq.in.
A-5	Unit loading on SORBTEX	$\frac{108,000}{144}$ = 750 psi

DEFLECTION

A-6	Standard thickness of SORBTEX used	1"
A-7	Number of pads in each stack	2
A-8	Deflection of standard thickness of SORBTEX for unit loading from A-5, Figure 6 on page 7.	0.084"
A-9	Area correction factor for pad size from Figure 7 on page 9	0.69
A-10	Corrected deflection of standard thickness used	0.084" x 0.69 = .058"
A-11	Total corrected deflection for stacked pads. (A-7 x A-10)	2 x .058" = .116"
A-12	Basic Natural Frequency from Figure 8 on page 10, based on A-11	11.5 cycles per second
A-13	Initial displacement (given)	0.3"
A-14	Ratio of initial displacement in terms of original thickness	$\frac{0.3"}{2.0"}$ = .15

Vibration Example No. 1 - Continued

A-15	Basic Natural Frequency correction factor due to initial displacement from Figure 9 on page 11	1.327
A-16	The Natural Frequency of the Mounting For An Initial Displacement of 0.3" (A-12 x A-15)	11.5 x 1.327 = 15.3 cps

B. Find the Total Force Transmitted to the Supporting Structure at Operating Speed

B-1	Disturbing frequency (Machine RPM)	$\frac{1800}{60}$ = 30 cps
B-2	Ratio of disturbing frequency to the Basic Natural Frequency	$\frac{F_D}{F_N} = \frac{30.0}{11.5} = 2.61$
B-3	Transmissibility (force) from Figure 10 on page 12	0.25
B-4	Total maximum dynamic force	160,000 lbs.
B-5	Total Force Transmitted to the Supporting Structure at Operating Speed (B-3 x B-4) . . .	160,000 x 0.25 or 40,000 lbs.

C. Find the Vibratory Motion of the Machine at Operating Speed

C-1	At magnification factor of 1.0, the motion of the machine will produce an additional load on each support of	$\frac{160,000}{4}$ = 40,000 lbs.
C-2	Additional unit loading due to dynamic force acting statically (C-1/A-4)	$\frac{40,000}{144}$ = 278 psi
C-3	Total equivalent static loading (A-5 + C-2)....	750 + 278 = 1028 psi
C-4	Deflection of SORBTEX under equivalent static load (recompute steps A-6 thru A-11 for loading determined in C-3)	0.139"
C-5	Motion (displacement of machine) due to dynamic load alone (at mag. factor of 1.0) C-4 minus A-11	0.139 - .116 = .023"
C-6	Magnification Factor (displacement) from Figure 11 on page 13	0.140
C-7	The Vibratory Motion of the Machine at Operating Speed (C-5 x C-6)	0.023" x 0.140 = .0032"

Vibration Example No. 2: A machine weighing 150,000 lbs. will be attached to a concrete slab weighing 22,500 lbs. The unbalance of the machine produces a maximum dynamic force of 10,000 lbs. under its operating speed of 1800 RPM.

Determine the area and thickness of SORBTEX required beneath the concrete slab to reduce the force transmitted to the foundation at operating speed to a total force of 2,600 lbs. Assume 6 symmetrically placed mountings beneath the slab.

D-1	Total dynamic force at operating speed	10,000 lbs.		
D-2	Permissible force on foundation at operating speed	2,600 lbs.		
D-3	Required transmissibility	$\frac{2,600}{10,000} = 0.26$		
D-4	Required frequency ratio from Figure 10 on page 12	$\frac{F_D}{F_N} = 2.5$		
D-5	Disturbing frequency (machine RPM)	$\frac{1800}{60} = 30$ cps		
D-6	Required Basic Natural Frequency	$F_N = \frac{30.0}{2.5} = 12.0$ cps		
APPROXIMATE DEFLECTIONS REQUIRED				
D-7	Total trial thickness of SORBTEX	2"	3"	4"
D-8	Standard thickness assumed	1"	1"	1"
D-9	Number of pads required	2	3	4
D-10	Total deflection required for Basic Natural Frequency, Figure 8, page 10	0.105"	0.105"	0.105"
D-11	Deflection required per pad (D-10/D-9). . . .	0.053"	0.035"	0.026"

Vibration Example No. 2 - Continued

D-12	Unit loading required for approximate deflection D-11, from Figure 6 on page 7	370 psi	210 psi	140 psi
D-13	Total load to be carried by all supports (machine plus slab)	150,000 + 22,500 = 172,500 lbs.		
D-14	Total load to be carried per support.	$\frac{172,500}{6} = 28,750$ lbs.		
D-15	Approximate area of SORBTEX required (D-14/D-12) in square inches.	77.5	136.5	205.0

CORRECTED AREAS REQUIRED		2"	3"	4"
D-16	Area correction factors from Figure 7 on page 9	0.73	0.69	0.67
D-17	Corrected deflections required (D-11/D-16)..	0.073"	0.051"	0.039"
D-18	Corrected unit loading required on SORBTEX from Figure 6 on page 7.	600 psi	350 psi	240 psi
D-19	Corrected areas required (D-14/D-18) in square inches	48.0	81.0	120.0

Conclusion: Since the loadings are all within the allowable loading for SORBTEX, any of the above solutions are equally satisfactory. Due to considerations other than vibration, the three inch thickness is preferred, hence 81 square inches is required per support. Thus at each of the six supports, 3 SORBTEX pads 1" thick and 9" x 9" in dimension would be specified.

It should be recognized that any limitations such as support area, pad thickness, or loading limits reduces the computation to a more direct solution.

Shock-Isolation Fundamentals

Shock is the disturbance produced by a suddenly applied force or impact in which the ensuing oscillations die out due to the internal resistance of the system. The purpose of shock-isolation is to minimize the disturbance produced by a sudden force or impact.

When it is desired to break an object by shock, such as dropping it from a height, we drop the object on a hard unyielding surface rather than a soft resilient surface. The impact force is many times greater on the hard surface than on the soft resilient surface. The physical relationship which defines this condition is expressed as

$$Ft = mv$$

"F" is the force, "t" is the time interval of its action, "m" is the mass of the object, and "v" is the velocity of the object. It is also recognized that "mv" is the momentum of the object.

Since the momentum is independent of the impact surface, it is apparent that the product of "Ft" must be the same whether the impact surface is hard or soft, and the smaller the "t" (time interval), the greater must be "F" (force). Therefore, when an object is stopped in a very short time, such as when it strikes a hard surface, the force developed is very large.

It is this principle that applies when using SORBTEX to reduce the transmitted force to the foundation or support of a machine and hence to the surrounding area. Such reduction in force also results in lower stress levels in the components of the machine.

The Shock Absorbing Properties of SORBTEX

SORBTEX is exceptionally well suited for use as a shock absorbing material because of its durability, ease of installation, and high damping properties.

Damping is particularly desirable in shock mountings to dissipate the oscillations produced by impact before the next impact occurs. This prevents shock resonance. For, if the oscillations continue until the next impact occurs, it is possible that the impact may occur in phase with the oscillation and produce even greater disturbance than without the shock mounting. In view of the high damping properties of SORBTEX (see page 5), the probability of shock resonance is minimized, and it may be used in installations where the impact is much more frequent than other materials would permit.

The "hardening spring" Load-Deflection characteristics of SORBTEX (see page 7) are also highly desirable in shock applications since SORBTEX becomes stiffer as displacement increases, thus producing an advantageously variable restoring force.

Impact Forces

The accurate determination of the actual forces produced by impact machines is extremely difficult to calculate, and the procedures are not within the scope of this presentation. For those impact machines in which the impact is produced by a direct-connected driving mechanism (driven impact), it is sufficient for most applications to consider that the momentum of the moving components upon impact transfer their momentum to the body of the machine subjected to the impact. This momentum is then transferred to the support of the machine.

Since the force produced and the time interval through which it acts must be equal to the momentum, as shown on the previous page, it is apparent that the force is reduced by increasing the time interval. A machine on a resilient mounting oscillates at its natural frequency when suddenly displaced. Its motion is momentarily stopped in one quarter of a cycle. Thus, the time interval "t" through which the impact force "F" acts is a direct function of the natural frequency of the machine on its mounting.

A machine set on a rigid mounting will be subjected to very large forces upon impact, while a machine mounted on a resilient mounting will permit the force to act for a longer time interval, and thus the force is of less intensity.

It may be considered therefore, that the force transmitted to the support via a resilient mounting varies as the natural frequency of the mounting. That is, if a mounting is modified so its natural frequency is reduced by a factor of two, the force transmitted to the support will be one half as much. The order of magnitude of the force transmitted through a resilient mounting to a rigid support during impact may be computed by the following relationship:

$$F = .01035\ wvf_n$$

"F" is the force in pounds, "w" is the weight of the moving component in pounds, "v" is the velocity of the moving component on impact in inches per second, and "f_n" is the natural frequency of the machine on its mounting in cycles per second. To determine the natural frequency of a machine on SORBTEX, see pages 10 and 11 in the vibration section of this presentation.

In most applications, the support of a machine is not rigid. For practical purposes, it may be considered that the support is sufficiently rigid if the natural frequency of the support is at least 1.5 times the natural frequency of the machine on its SORBTEX mounting. In such cases, the reduction in shock transmission through a SORBTEX mounting may be determined from the following relationship.

$$S.T.R. = \frac{f_n}{f_o}$$

"S.T.R." is the Shock Transmission Ratio, or the ratio of the shock force with SORBTEX to the shock force without SORBTEX; "f_n" is the natural frequency of the machine on SORBTEX and "f_o" is the natural frequency of the machine on its support without SORBTEX.

In vibration (steady-state) considerations, the performance of the mounting must be known in the vicinity of resonance because a machine must pass through such conditions while "running up" to operating speed or "coasting down" to a stop. In shock, such considerations do not apply, and SORBTEX, or any other isolator, should be used only when the support has a natural frequency at least 1.5 times that of the contemplated resilient mounting. When these conditions are not fulfilled, a special analysis is required not within the scope of this presentation.

Drop Forge Hammer Application of SORBTEX

Since SORBTEX is ideally suited for use beneath drop forge hammers, this section is devoted to such applications. The "driven impact" type of machines previously described are forced through an impact cycle by a direct-connected driving mechanism, while the working part of the forge hammer operates free from restraint in the direction of impact.

The "gravity drop" forge hammer is one in which the hammer, including the die, is released from a pre-determined height and falls freely until it strikes the work being forged. It is then raised either mechanically, pneumatically or hydraulically to the pre-determined height and again released. The velocity of the hammer on impact may be computed from the following relationship:

$$v = 27.8 \sqrt{h}$$

"v" is the impact velocity in inches per second and "h" is the height of free fall in inches.

"Steam drop" forge hammers are those in which the hammer and die are subjected to an additional force while being dropped from a pre-determined height. The additional force is usually provided by steam pressure on a piston, although in some cases air pressure is used. For purposes of this presentation, the term "steam drop" is used regardless of whether steam or air is employed. For "steam drop" forge hammers, the following relationship may be used to compute the velocity of the hammer on impact:

$$v = 27.8\sqrt{S + \frac{PAS}{W}}$$

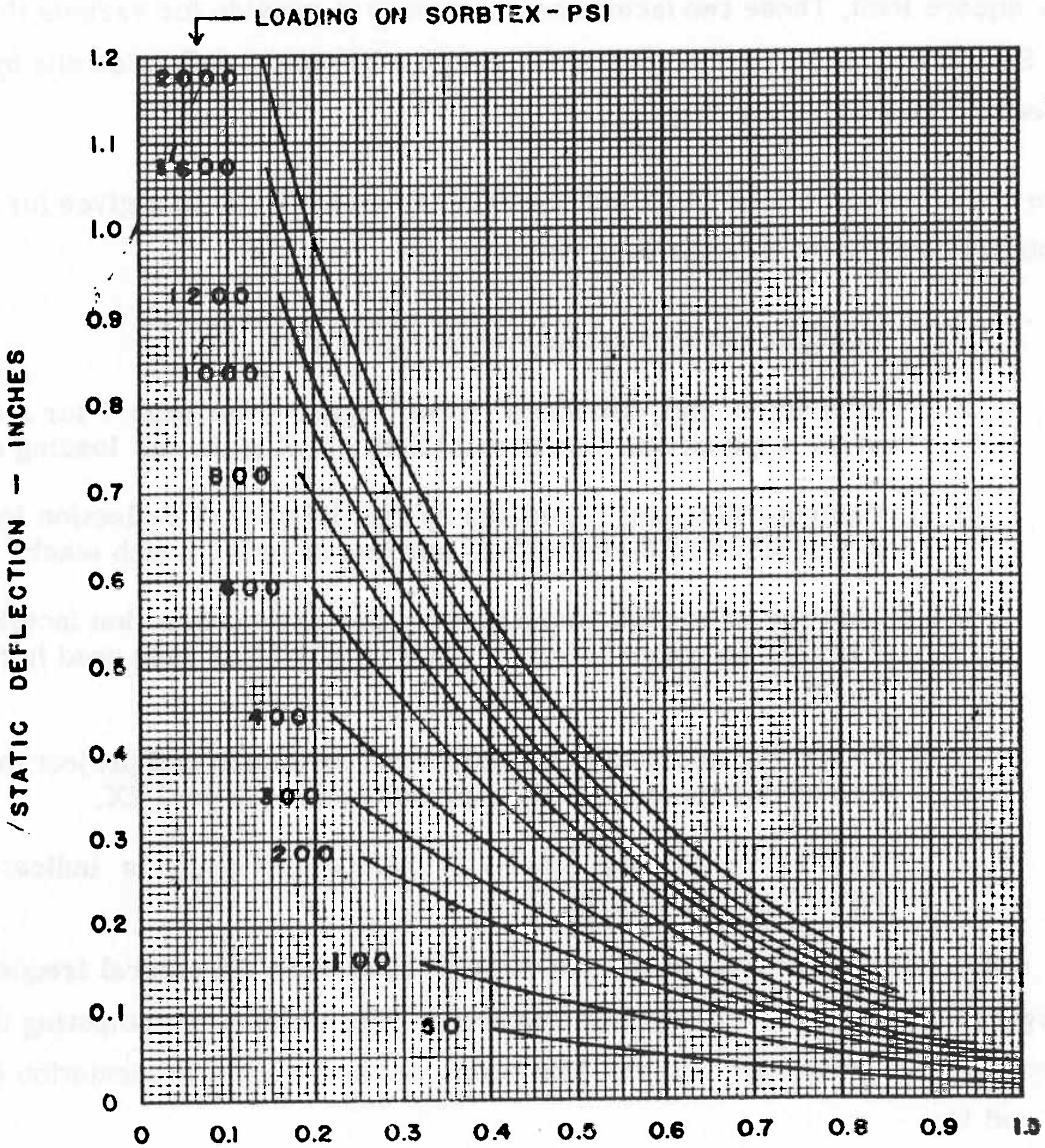
"v" is the impact velocity in inches per second, "S" is the stroke of the hammer, "P" is the mean effective pressure in pounds per square inch, "A" is the area of the cylinder in square inches, and "W" is the total weight of the hammer and die.

The amount of force transmitted to the anvil of a forge hammer, and hence to the foundation, varies within wide limits due to the nature of the work being forged, its temperature, and the "free bounce" of the hammer. A discussion of these factors is not within the scope of this presentation. In view of these recognized variables, many of which are indeterminate, it was considered that the determination of shock transmission characteristics of SORBTEX, based on theoretical considerations, would be unreliable. Experimental techniques were therefore used to determine the shock absorbing properties of SORBTEX beneath forge hammers.

In general, a drop forge hammer has an anvil weight 20 to 25 times the weight of the hammer. The weight of the concrete foundation supporting the unit is generally three times the weight of the hammer and anvil combined. These proportions were maintained for the purposes of the experimental determinations.

Since the most severe blows in a forging operation are those that consist of die-to-die contact, all tests employed such impact conditions for purposes of severity and uniformity. Impact velocities up to 200 inches per second were used. The concrete foundation was placed on a relatively rigid support in order to evaluate SORBTEX under the most severe conditions. Intensity of forces transmitted to the foundation by the anvil during impact were measured under conditions of solid contact -- that is, no resilient material was placed between the anvil and foundation, and then various thicknesses of SORBTEX were placed between the anvil and the foundation. The unit loading (psi) on the SORBTEX was also varied during these tests.

The results of this investigation are presented in convenient and usable form in Figure 13. Shock Transmission Ratio is defined as the ratio of the force transmitted to the foundation with SORBTEX, to the force transmitted to the foundation without SORBTEX (solid contact). Thus a Shock Transmission Ratio of 0.25 means that the SORBTEX mounting has reduced the force transmitted to the foundation to one quarter of the force which would be transmitted without SORBTEX (75% reduction).



DROP FORGE HAMMER ISOLATION
WITH SORBTEX
FIGURE 13

For convenience, Figure 13 expresses the Shock Transmission Ratio in terms of the deflection under static loading and the unit loading on the SORBTEX in pounds per square inch. These two factors are necessary to provide for various thicknesses of SORBTEX, and to incorporate the effect of reduced deflection due to the area effect of SORBTEX (see page 9).

The chart is used to determine the Shock Transmission Ratio of a given (or assumed) installation of Sorbtex in the following manner:

1. Compute the unit loading on the SORBTEX
2. Determine the deflection from Figure 6 on page 7 for a single pad of the appropriate thickness of SORBTEX at the unit loading computed.
3. Compute the total deflection by multiplying the deflection for a single pad of SORBTEX by the total number of pads in each stack.
4. Multiply this total deflection by the area correction factor (Figures 7 or 7A on page 9) for the area of individual pads used in the installation.
5. Enter Figure 13 with the corrected deflection and project this deflection to the appropriate loading (psi) on the SORBTEX.
6. The corresponding Shock Transmission Ratio is indicated on the lower scale of Figure 13.

In some cases, it may be of interest to determine the natural frequency of the forge hammer on its SORBTEX mounting. The method of computing the natural frequency is discussed in the vibration section of this presentation (see pages 10 and 11).

Other Shock Considerations

Other considerations in shock absorption are indicated on the following page. Some of these can be conveniently provided for, while others require the services of a qualified vibration consultant.

Driven Impact Machines

This type of machine usually has a motor driven bull gear, pump or other allied equipment. The design of the shock mounting should be reviewed to insure that the steady-state disturbing frequency does not approach resonance with the natural frequency of the mounting.

Shock Resonance

Although shock analysis is normally based on a single impact, the repetition of the impact must not approach the natural frequency of the mounting. Otherwise, a resonance build-up may occur which will result in excessive oscillation of the machine and increased transmitted force.

Stability

It is conceivable that in order to obtain a sufficient reduction in shock transmission, unusually large static deflections may be required. This may result in undesirable lateral stability of the machine on its mounting. In such cases, it may also be necessary to use SORBTEX as lateral guides to improve stability.

Horizontal Shock

The foregoing presentation assumed that the impact occurred in a vertical direction. For large horizontal or unusually inclined impacts, SORBTEX can be used to best advantage by placing the pads so that the impact force is approximately perpendicular to the face of the pads.

Human Evaluation of Shock

The human evaluation of vibration (steady-state) has previously been discussed on page 16. As far as is known, no specific investigation has been made in the human evaluation of shock. Such research would be extremely difficult since the evaluation would depend on the duration of the impact disturbance, its decay characteristics, and the frequency of occurrence of the disturbances. In general, it may be considered that the displacements shown in Figure 12 on page 17 may be doubled for repetitious impacts in rapid succession (but not overlapping), and increased by a factor of 4 for infrequent impacts.

How to Use the Preceding Data On Specific Shock Problems

Shock Example No. 1: A punch press weighs 50,000 lbs. It has 4 supports symmetrically located about the horizontal position of the center of gravity. It is presently rigidly attached to a concrete slab which has a natural frequency of 40 cycles per second. The press delivers 20 blows per minute; the flywheel rotates at the rate of 240 RPM. The ram weighs 2,500 lbs., and the velocity of the ram on impact is 125 inches per second.

What will be the reduction in shock transmitted to the concrete slab when 5 one-half inch thick pads of SORBTEX (8" x 8") are stacked beneath each support?

D-1	Total load carried by SORBTEX.	50,000 lbs.
D-2	Number of SORBTEX supports	4
D-3	Load carried per support (D-1/D-2)	12,500 lbs.
D-4	Area of SORBTEX pad used at each support..	8" x 8" = 64 sq. in.
D-5	Unit loading on SORBTEX.	$\frac{12,500}{64} = 195$ psi
D-6	Stock thickness of SORBTEX used	1/2"
D-7	Number of pads in each stack	5
D-8	Deflection of stock thickness of SORBTEX for unit loading D-5 from Figure 6 on page 7..	0.0165"
D-9	Area correction factor for pad size, D-4 from Figure 7 on page 9	0.65
D-10	Corrected deflection of stock thickness used..	0.0165" x 0.65 = .0107"
D-11	Total corrected deflection for stacked pads (D-7 x D-10)	0.0107" x 5 = .0535"

NATURAL FREQUENCY

D-12	Basic Natural Frequency from Figure 8 on page 10 based on D-11	16.3 cps

Shock Example No. 1 - Continued

D-13	Total force transmitted through SORBTEX $F = .01035\ wvf_n$ (see page 24)	$.01035 \times 2500 \times 125 \times 16.3 = 52{,}700$ lbs.
D-14	Force transmitted per support (D-13/D-2) .	$\frac{52{,}700}{4} = 13{,}175$ lbs.
D-15	Additional unit loading on SORBTEX due to impact force (D-14/D-4)	$\frac{13{,}175}{64} = 206$ psi
D-16	Total equivalent static loading (D-5 + D-15)..	195 + 206 = 401
D-17	Deflection of SORBTEX under equivalent static load (recompute D-6 through D-11 for loading determined in D-16)	0.0910"
D-18	Initial displacement of machine due to impact load alone (D-17 minus D-11)	0.0910" - 0.0535" = 0.0375"
D-19	Ratio of initial displacement in terms of original thickness	$\frac{0.0375''}{2.5''} = 0.015$
D-20	Basic Natural Frequency correction factor due to initial displacement, from Figure 9 on page 11	1.005
D-21	Corrected natural frequency (D-12 x D-20)....	16.3 x 1.005 = 16.4 cps
D-22	The Shock Transmission Ratio is equal to $\frac{f_n}{f_o}$ (see page 24)	S.T.R. = $\frac{16.4}{40.0} = 0.410$
D-23	Reduction in Shock Transmission (1 minus D-22)	1 - 0.410 = 0.590 or 59.0%

NOTE: Since the Basic Natural Frequency of the shock mounting is 16.3 cps and the RPM of the flywheel is 4.0 cps (240 RPM) further investigation of steady-state vibration is not necessary.

Shock Example No. 2: A conventional drop forge hammer weighing 800,000 lbs. is set on 8 one inch thick stacked pads of SORBTEX. The base area is such that 4 stacks are used. Pad size is two feet by three feet. The foundation rests on well compacted sand.

Find the reduction in shock transmission to the foundation due to the SORBTEX.

E-1	Total load carried by SORBTEX.	800,000 lbs.
E-2	Number of SORBTEX stacks	4
E-3	Load carried by each stack (E-1/E-2)	$\frac{800,000}{4}$ = 200,000 lbs.
E-4	Area of SORBTEX pads used in each stack. . .	2' x 3' = 6 sq. ft. or 864 sq. in.
E-5	Unit loading on SORBTEX	$\frac{200,000}{864}$ = 232 psi

DEFLECTION

E-6	Stock thickness of SORBTEX used	1"
E-7	Number of pads in each stack	8
E-8	Deflection of stock thickness of SORBTEX for unit loading E-5 from Figure 6 on page 7..	0.0375"
E-9	Area correction factor for pad size E-4 from Figure 7A on page 9	0.57
E-10	Corrected deflection of stock thickness used..	0.0375" x .57 = 0.0214"
E-11	Total corrected deflection for stacked pads (E-7 x E-10)	0.0214" x 8 = 0.1712"
E-12	Shock Transmission Ratio from Figure 13 on page 27	0.49
<u>E-13</u>	<u>Reduction in Shock Transmission (1 minus E-12)</u>	1 - 0.49 = <u>.51 or 51.0%</u>

Appendix and Glossary of Terms Used

Appendix

The unload characteristics of SORBTEX may be of interest to engineers for special applications.

Figure 14 permits the determination of deflection during the unload cycle by multiplying the deflection obtained from Figure 6 (on Page 7) for a specific loading (and pad thickness) by the corresponding Unload Factor shown in Figure 14.

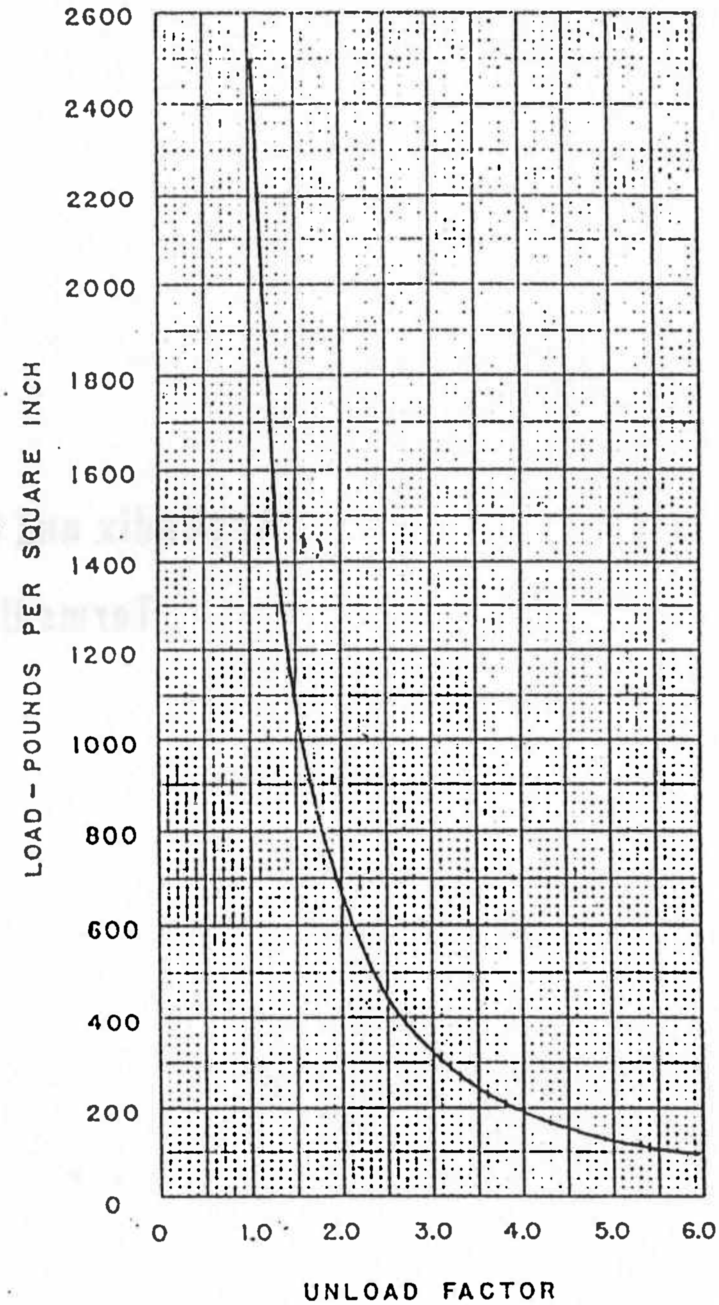


FIGURE 14

Example: What is the remaining deflection of a 2" x 2" pad of 1" thick SORBTEX after the pad has been loaded to 2500 psi and then unloaded to 1000 psi.

From Figure 6 (page 7) it is found that the deflection for this pad at 1000 psi is 0.100". From Figure 14, the corresponding unload factor is 1.55. The deflection at 1000 psi during the unload cycle is therefore:

1.55 x 0.100 = 0.155"

The following information on SORBTEX and its application provides additional useful data of interest to users of this material.

Maximum Loading on SORBTEX

Load-Deflection data has been provided up to loads of 2500 psi to provide complete information for all applications. It is recommended, however, that for use in vibration and shock isolation, the unit loading on the SORBTEX due to the dead weight of the machine do not exceed 2000 psi.

Breakdown Strength of SORBTEX

Destruction tests under compression loads reveal that a one-half inch thick pad of SORBTEX is capable of withstanding unit loads in excess of 17,500 psi before rupture occurs.

Creep Tests

Creep is defined as the additional deformation that occurs with time in a material under constant loading. Long period creep studies on SORBTEX are currently in progress. Preliminary data is shown below for the several loading conditions being investigated. Creep is expressed as the ratio of additional deformation (after initial deflection) in terms of the original thickness of the SORBTEX.

	UNIT LOADING		
Days	500 psi	1,000 psi	2,000 psi
1	0.007	0.011	0.015
10	0.011	0.016	0.021
100	0.014	0.019	0.025

Effect of Water on SORBTEX Shock-Isolation Properties

As part of the investigation of the shock-isolation properties of SORBTEX, shock transmission characteristics were measured for various thicknesses of normally dry SORBTEX under different loading conditions. These tests were repeated on the same pieces of SORBTEX after they had been completely submerged in water for a period of 30 days. The shock transmission ratios were identical in both cases. It is apparent, therefore, that the performance of SORBTEX as a shock isolator is unaffected by prolonged exposure to water.

Distribution of Loads by SORBTEX

SORBTEX has a long-recognized application as a bearing pad between irregular surfaces to provide uniform load distribution and to prevent local "high stress" conditions. The resilient properties of SORBTEX make it more desirable for this purpose than lead or mortar, especially under dynamic loading, because of its ability to recover and adjust to changing conditions.

It is possible for a machine or structural member to vibrate because of poor contact with its support. This is most likely to occur when the components in contact are very stiff and can not distort sufficiently to improve the "poor" contact condition. SORBTEX has the resiliency to provide good contact between such bearing areas and eliminate this source of possible trouble.

Anchor Bolts

Usually, it is not necessary to use anchor bolts on a machine that is properly mounted on SORBTEX unless: (a) the vertical dynamic forces produce loadings on the SORBTEX as great or greater than those produced by the dead weight of the machine, or (b) the horizontal dynamic forces exceed the frictional forces that can be developed between the contact surfaces of the mounting.

When it is necessary or desirable to use anchor bolts, appropriate washers of SORBTEX must be used beneath the heads or nuts of the bolts or studs to prevent direct transmission between the machine and its support via the anchors. Sufficient clearance must also be provided between the bolt and its hole to prevent direct metal-to-metal contact. Where necessary, SORBTEX bushings can be used in the bolt holes.

Piping and Connections

Whenever piping or other relatively rigid connections join the supporting structure to the machine mounted on SORBTEX, appropriate flexible connections should be provided to prevent: (a) direct transmission of the vibration, (b) restraint of the machine, and (c) local high stress conditions in the connection.

Noise Reduction

SORBTEX is effective in interrupting the direct transmission of noise through the structure. Approximately 90% of the noise transmitted by steel-to-steel contact can be eliminated by the use of SORBTEX.

It is to be recognized, however, that except in special cases, noise problems are usually associated with the transmission of noise energy through the air rather than through the structure. SORBTEX, or any other isolator, has negligible effect on such airborne transmission of noise.

Glossary of Terms Used in This Manual

Acceleration: The rate of change of velocity of a vibrating object (inches per second per second).

Area Correction Factor: A coefficient which corrects for the reduction in deflection resulting from pad areas greater than 2" x 2". Specifications require that Load-Deflection data be based on the 2" x 2" specimen.

Damping: The internal friction in a material which resists the motion of vibration.

Critical Damping: When a system free-to-vibrate has sufficient damping to just come to rest after being displaced, the system is said to be critically damped.

Ratio of Critical Damping: The ratio of the actual damping in a system to the critical damping.

Deflection or Static Deflection: The distance that a load compresses a resilient material or spring. For purposes of this manual, the dead weight of the supported body is the load.

Degrees of Freedom: The ways in which a rigid body may vibrate.

Displacement: The distance that a body moves from its position of rest during vibration (in inches).

Dynamic Forces: Fluctuating forces in a machine. These are the forces that cause vibration when the machine is operating.

Frequency: The number of times a vibratory motion repeats itself in an interval of time (RPM, revolutions per minute - CPS, cycles per second).

Forced Frequency: The number of times a disturbance repeats itself in an interval of time.

Natural Frequency: The number of complete cycles per interval of time through which a body will oscillate when displaced from its rest position.

Basic Natural Frequency: The natural frequency of a body on a non-linear isolator when subjected to infinitely small displacements.

Isolation: The reduction of a force transmitted through a resilient mounting, or the reduction in the motion of a body under dynamic forces.

Linear Spring: An elastic material whose load-deflection characteristic is a straight line.

Logarithmic Decrement: A term which defines the amount of damping. It is equal to the natural logarithm of the ratio of the maximum displacement in one cycle to the maximum displacement in the next successive cycle under conditions of free vibrations.

Magnification Factor: A ratio of displacement of a vibrating machine on a resilient mounting to the displacement that would result if the dynamic force acted statically on the mounting (an imaginary condition).

Momentum: A term used to describe the potential impact intensity of a moving body. It is equal to the product of the mass of the body and the velocity of the body (pound seconds).

Non-Linear Springs: An elastic material whose load-deflection characteristic is a curved line.

Resiliency: The ability of a material to recover from deformation of any kind.

Shock: The disturbance produced by a suddenly applied force or impact.

Shock Transmission Ratio: The ratio of the force transmitted to the support through a resilient mounting, to the force transmitted without the resilient mounting (solid contact).

Transmissibility: The ratio of the vibratory force transmitted to the support through a resilient mounting to the dynamic force produced by the machine.

Unit Loading: The load on each square inch of the resilient material. This is equal to the supported load divided by the area of mounting supporting the load (pounds per square inch).

Velocity: The rate of change of displacement of a vibrating body, or the speed of a driven or free falling body in inches per second.

Vibration: A continuous oscillation (steady-state) such as is caused by the operation of an unbalanced machine.