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AD 668 838

CONTAINER EFFECTS IN CUSHIONED PACKAGES: URETHANE FOAM CUSHIONING APPLIED AS SIDE PADS

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April 1968

U.S. FOREST SERVICE
RESEARCH PAPER
FPL 91
APRIL 1968

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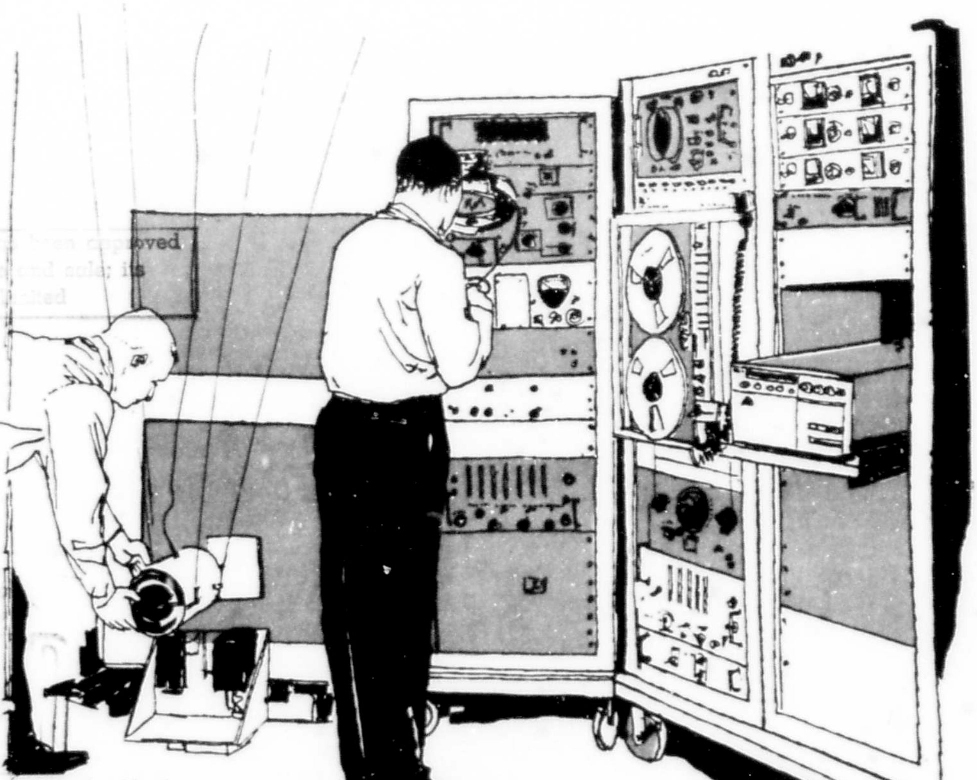

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ABSTRACT

Data on the response of package cushioning material to mechanical shock are generally available to the package designer. When cushioning is used in a package, however, its response is modified, primarily by the container. Two methods of depicting the container effect were used here, the peak acceleration-static stress curve and the undamped shock spectra.

The container effect was important in the performance of cushioned packages using the side-pad method of cushion application. If such cushioned packages were satisfactory on the basis of their flat-drop performance, they seem likely to provide adequate protection against edgewise and diagonally cornerwise impacts as well.

Cleated plywood boxes offered a definite advantage, under certain loading conditions, as shipping containers for cushioned packages.

Container Effects in Cushioned Packages:

Urethane Foam Cushioning Applied as Side Pads[1]

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INTRODUCTION

The primary purpose of package cushioning is to prevent damage to a packaged article during handling and shipment. Considerable information on the response of the cushioning material to mechanical shock is available to the package designer. But, when the cushioning is used in a package, the container may have an effect on the transmitted shock--a point that is generally overlooked or assumed to be favorable.

Most available data on package cushioning material were obtained from tests where the cushioning material was compressed between a falling mass and a rigid backstop.[4] Interposing a container between the cushion and the solid backstop may modify the shock experienced by the falling mass, which represents the contents of the package.

Because of lack of specific information on any container effect, designers often have assumed that the container will simply provide protection in addition to that given by the cushioning material. To see if there was a "container effect" and, if so, what it might be, this study was set up at the U.S. Forest Products Laboratory.

This report covers only the first part of the broad study of container effects in cushioned packages. To get an idea of what this effect might be, the work was started using the two types of shipping containers most widely used by the Air Force--corrugated fiberboard and wood-cleated plywood boxes. The cushioning material used was urethane foam (2 pounds per cubic foot density) chosen to meet the requirement for a material that gives consistent response under repeated loading. The urethane foam was used as side pads because this is a common cushioning method. Results from these evaluations form the basis for further work.

All the emphasis in this study was on preventing shock damage to the package contents. Some packages are cushioned to prevent vibration damage, but this aspect was not investigated here.

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[1] A study conducted in cooperation with the Air Force Packaging Evaluation Agency, Brookley Air Force Base, Alabama, under Contract No. FO 1601-67-M-0047, Item 4. (AFPEA is now located at Air Force Logistics Command, Wright-Patterson Air Force Base, Ohio.)

[2] The assistance of other members of the Packaging Staff of the Forest Products Laboratory in the performance of this research study is gratefully acknowledged. Particular appreciation is extended to John Wiese, engineering technician, and John Waldvogel, electronic development technician (instrumentation), who performed the tests and handled the instrumentation; also to Fred Rattner of the Laboratory's computing section, who assisted in developing and checking the computer program for calculating shock spectra.

[3] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[4] American Society for Testing and Materials. Shock Absorbing Characteristics of Package Cushioning Materials. ASTM D 1596-64.

METHOD

Cushioned packages involving both regular slotted corrugated fiberboard (fig. 1) and wood-cleated plywood (fig. 2) boxes, 13 by 13 by 13 inches inside, were dropped 24 inches in flatwise, diagonally edgewise, and diagonally cornerwise orientations. The rigid 7-inch-cube dummy load (fig. 3 or 4) in each package was cushioned with urethane foam side pads 5 inches square[5] by 3 inches thick. Piezo-resistive accelerometers, in tri-axial array (fig. 5) at the approximate center of gravity of the dummy load, monitored the shock motion (acceleration-time response) of the simulated packaged article. The acceleration-time records were put on magnetic tape and later recorded on paper using a light-beam oscillograph. Discrete weights of the dummy load were chosen to encompass the useful cushion-loading range and extend into the regions of underload and overload.

After each drop, the test packages were opened and the dummy load and cushions restored to their original condition before making the next drop. Thus, no attempt was made to evaluate cumulative degradation of the package protection caused by repeated package impacts, as would be experienced in service. Neither was there any attempt to evaluate creep effects that might alter the cushion response after extended storage periods during which the cushion supports the dead weight of the contents.

In addition to, but preceding package drop tests, the primary[6] cushions used in the packages were evaluated in dynamic compression using equipment shown in figure 6, essentially in accordance with ASTM Method D-1596-64.[4]

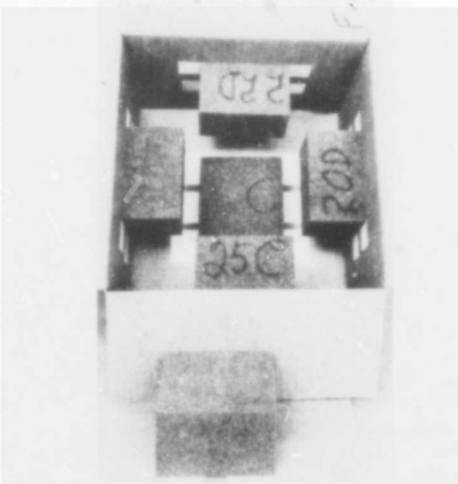


Figure 1.--Fiberboard box used in the package drop tests. The five cushion pads inside the box were positioned before inserting the dummy load. The top pad, attached to a separate sheet of fiberboard, was positioned after the load was in place. Closure was with pressure-sensitive tape applied over the center seam and overlapping onto the ends of the box. (M 132 675)

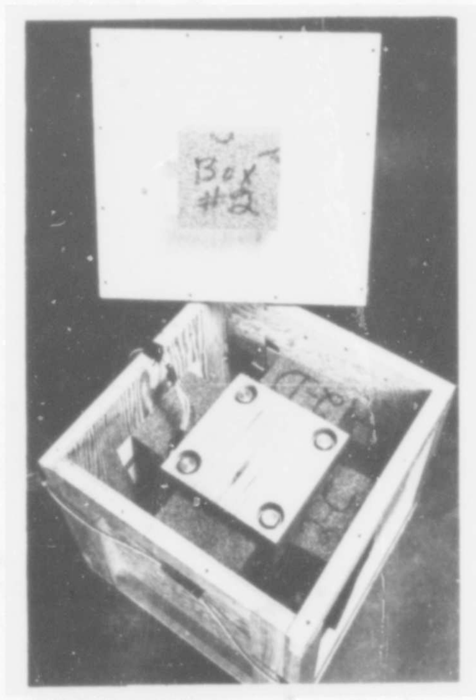


Figure 2.--Cleated plywood box and dummy load with top panel removed. (M 130 163)

[5]To achieve a desired low cushion stress for one set of tests, 7-inch-square cushions were used as bottom pads with the lightest available simulated load.

[6]Primary cushion pads in a cushioned package are those pads on the under side of the load at impact, such as the bottom pad in a box that is dropped flatwise onto its bottom.

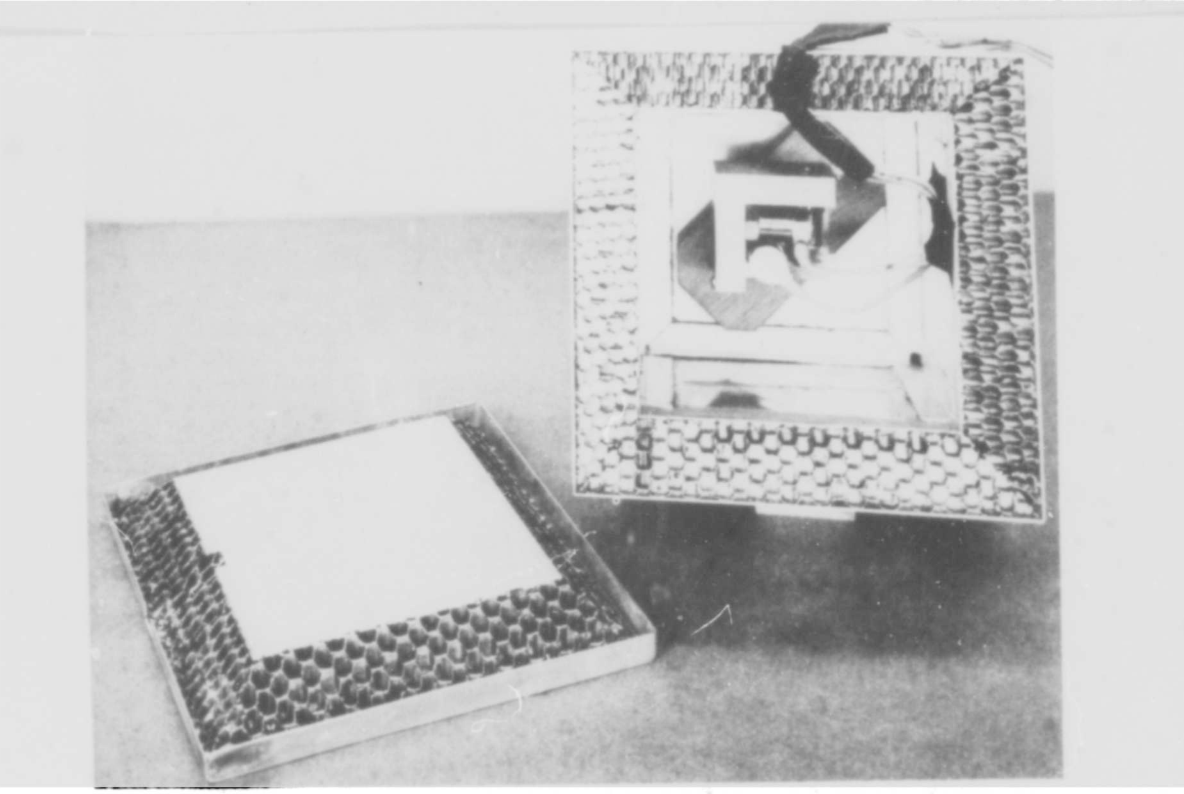


Figure 3.--The lighrweight dummy load, with cover removed, showing 3-way accelerometer arrangement mounted for flatwise drops onto bottom of cushioned package. The cover was taped in place when the unit was assembled for test. (M 132 676)

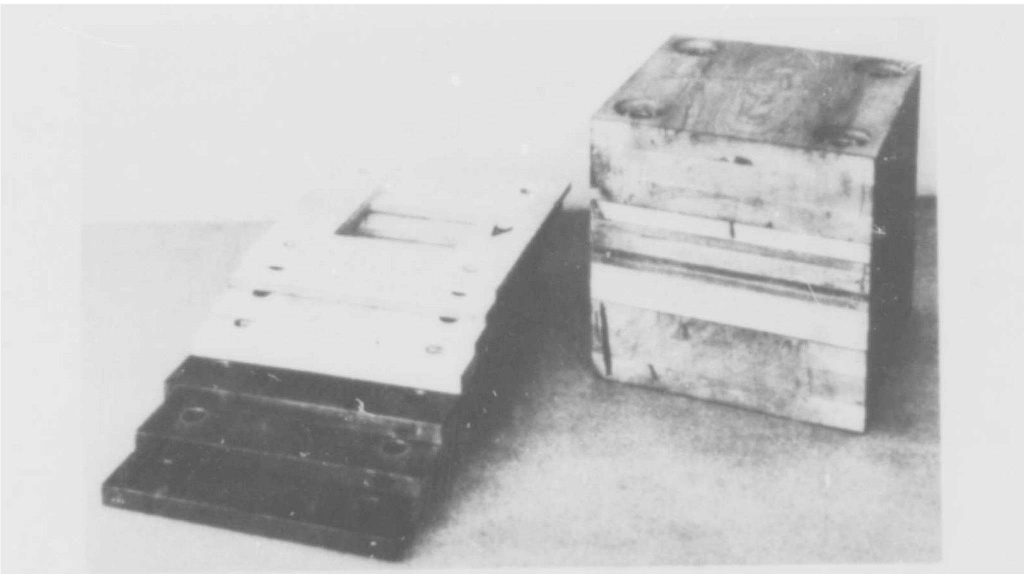


Figure 4.--The heavy dummy load, shown with extra wood and steel laminates. These laminates were interchanged to attain desired weights of the assembled dummy load. (M 132 674)

Figure 5.--The three accelerometers mounted in mutually perpendicular array, as used inside the dummy loads. (M 132 677)

SELECTION OF CUSHIONS FOR TEST PACKAGES

The urethane foam cushioning material was received in four large, 3-inch-thick sheets. It was cut into 5- by 5- by 3-inch pads, each pad being given an identifying code number consisting of a letter (A, B, C, or D for the sheet from which it came) plus a serial number. The pads from the B sheet had noticeably different response to dynamic compression than those from the other three sheets and were eliminated. There was enough difference in the responses of the A, C, and D pads that it was desirable to exercise consistent control over their positions in the test packages. Therefore, in the first four series of package drop tests (table 1), the cushion on the bottom in flatwise drop tests was always an A pad; the two pads under the load in the edgewise tests were A and C pads; and the three pads under the load in the cornerwise tests

Figure 6.--Equipment used in the dynamic compression tests of cushion pads:

A, Pendulum head; B, test specimen. (The test specimen shown is one used in a different study); C, photo cell-light beam setup for measuring impact velocity; D, digital counter for impact velocity measurement; E, numerical display unit for counter; F, oscilloscope; G, magnetic tape recorder; and H, light-beam oscillograph used to record acceleration-time pulses stored on magnetic tape. (M 128 365)

Table 1.--Summary of package tests and results

Series No.	Kind of container	Weight of dummy load	Container orientation	Sequence number of drop	Static stress	Average peak acceleration of load	Number of replicate test drops	Standard deviation	Peak of shock spectrum (undamped)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
		Lb.			P.s.i.	g.		g.	g.
1	Cleated plywood	19.94	Flat	1	0.80	28.1	5	4.57	38.1
		19.94	...do....	5	.80	35.1	3	1.56	....
		19.94	Edge	1	.80	17.9	4	.65	25.0
		19.94	...do....	5	.80	17.7	5	.63	27.7
		19.94	Corner	1	.80	12.9	4	1.79	20.2
		19.94	...do....	4	.80	14.4	4	1.54	19.8
2	Cleated plywood	27.45	Flat	1	1.10	48.7	5	6.62	....
		27.45	...do....	5	1.10	72.3	3	19.95	....
		27.45	Edge	1	1.10	44.2	[1]4	6.73	....
		27.45	...do....	2	1.10	30.6	[1]1	....	....
		27.45	Corner	1	1.10	16.4	5	1.13	....
		27.45	...do....	2	1.10	12.3	[1]1	....	....
3	Fiber-board	4.00	Flat	1	.16	16.9	5	.77	30.0
		4.00	...do....	2	.16	17.6	5	.79	30.8
		4.00	Edge	1	.16	17.8	5	.63	33.4
		4.00	...do....	2	.16	16.7	5	.48	31.8
		4.00	Corner	1	.16	19.5	5	.77	35.0
		4.00	...do....	2	.16	18.5	5	.17	33.9
4	Fiber-board	19.94	Flat	1	.80	43.9	5	1.93	59.5
		19.94	...do....	2	.80	49.7	5	2.77	69.3
		19.94	Edge	1	.80	20.5	[2]2	2.45	....
		19.94	...do....	2	.80	23.5	[2]1	....	....
		19.94	Corner	1	.80	10.3	[2]1	....	14.3
5	Fiber-board	4.00	Flat	1	.16	21.3	3	1.59	35.0
		4.00	Edge	1	.16	18.9	3	1.50	35.3
		4.00	Corner	1	.16	19.7	3	.22	33.0
		10.50	Flat	1	.42	22.7	3	.66	33.8
		10.50	Edge	1	.42	10.7	3	1.02	18.8
		10.50	Corner	1	.42	9.9	3	.10	18.2
		17.35	Flat	1	.69	32.5	3	1.47	45.7
		17.35	Edge	1	.69	8.2	3	1.43	14.0
		17.35	Corner	1	.69	7.7	3	.24	13.7
		22.20	Flat	....	.89	42.9	3	2.81	63.1
		22.20	Edge	...(1)...	.89	......(1)......	...(1)...	....	....
		22.20	Corner	...(1)...	.89	......(1)......	...(1)...	....	....
		[3]4.00	Flat	1	[3].082	34.5	3	.71	51.5
		[3]4.00	...do....	2	[3].082	34.0	3	.82	51.5
6	Cleated plywood	3.90	Flat	1	.156	21.8	3	.35	36.8
		10.53	...do....	1	.42	16.7	3	.88	27.0
		17.38	...do....	1	.69	18.7	3	.51	27.3
		19.85	...do....	1	.80	24.0	2	.50	34.0
		22.20	...do....	1	.89	24.9	3	1.94	36.2
		[3]4.00	...do....	1	[3].082	33.2	3	3.29	51.5
		[3]4.00	...do....	2	[3].082	35.8	3	2.11	51.5

[1] Hard bottoming of the load occurred in all drop tests in this category.

[2] Hard bottoming of the load occurred in the remainder of the five drop tests in this category.

[3] Bottom pad in these containers was 7 inches square.

were A, C, and D. In series 5 and 6, however, all primary pads were C pads. For this reason, the results in the latter two series may not agree closely with those in earlier series.

SHOCK SPECTRA

The undamped shock spectrum (see Appendix 1) was calculated for each of the experimental shocks applied in the package drop tests and in the pendulum tests of the individual cushions. They were generated by a digital computer utilizing a program developed at Forest Products Laboratory from equation (23.33) for relative displacement response given in Volume 2 of the Shock and Vibration Handbook.[7] The program was checked out by using digitized half-sine and terminal-peak sawtooth input functions and comparing the outputs with published shock spectra for these functions.

PRESENTATION AND DISCUSSION OF RESULTS

The results of the drop tests of cushioned packages conducted in this study are summarized in table 1. The first four columns of table 1 are self-explanatory. The fifth column gives the sequence number of the drop for which averaged data are given in certain subsequent columns.[8] Column 6 gives the static stress, defined as the weight of the dummy load divided by the load-bearing area of one of the cushion pads. Note that this same definition applies to edgewise and cornerwise orientations, even though the use of the term here becomes somewhat unrealistic in these instances where two or more cushions support the load.

In the seventh column are listed peak acceleration values of acceleration-time records generated in the corresponding package drop tests. Each value in this column was obtained by averaging the peak values of the individual acceleration-time records, one of which was obtained for each test drop.

The eighth column gives the number of replicate test drops, each with a different package, that are represented by the average peak acceleration value in column 7.

The variability of the observations of peak acceleration (col. 7) is indicated by the corresponding values of standard deviation (calculated from $\sigma = \sqrt{\frac{(x-\bar{x})^2}{n}}$) given in column 9. Considering the nature of the package drop test, the results appear quite uniform.

Column 10 lists the peak value of the shock spectrum obtained from the average of the corresponding acceleration-time pulses generated in the individual drop tests.

It may be seen from series 3 (table 1) and from the results obtained with the 4-pound load in series 5, that at this loading in fiberboard boxes there is little difference in the peak acceleration of the load for flat, edge, and corner drops. However, series 5 shows that increasing the weight of the dummy load causes the peak acceleration experienced by the load to become greater for flat drops, but less for edge and corner drops. In flat drops there was no appreciable flatwise crushing of the fiberboard in bottom flaps, at least with dummy loads as heavy as 17.35 pounds. Therefore, practically all of the energy had to be absorbed by the bottom cushion.

In the edge and corner drops with the heavier loads, energy was absorbed in crushing the edge or corner of the box; some more energy was absorbed by deflection of the box panels backing up the active cushions. Also, in the edge and corner drops there were two or three "bottom" cushions, instead of one, and these were loaded obliquely (a combination of shear and compression) rather than solely in compression as was the bottom pad in the flat drops. The net effect was that the edge and corner drops were generally less severe to package contents than the flat drops. However, in the tests in which the packages obviously involved overloading, as in

[7] Harris, C. M., and Crede, C. E. Shock and Vibration Handbook, Vol. 2, Sec. 23, p. 14. McGraw-Hill Book Co., N.Y. 1961.

[8] For example, the first figure (28.1) in column 7 is the average of the peak acceleration values observed during the first drops of five replicate packages, and the next figure (35.1) is the average of the peak acceleration values observed during the fifth drops of three of these same five replicates.

series 2 and 4 and the packages with the 22.2-pound load in series 5 (table 1), the edge and corner drops exhibited evidence of hard bottoming, while the flat drops did not.

Hard bottoming occurred in edge and corner drops of fiberboard boxes with a load of 19.94 pounds (series 4), but it did not occur with a load of 17.35 pounds (series 5). Hard bottoming occurred in edge and corner drops of cleated plywood boxes with a load of 27.45 pounds (series 2) but did not happen when the load was 19.94 pounds. This difference in the edge and corner drop performance of the fiberboard and cleated plywood boxes with heavy contents involves the relative strength of the two kinds of boxes.

There are two obvious ways in which this operates. The stronger panels of the cleated plywood boxes gave better support to the lower cushions in the edge and corner drops than did the panels backing up the same cushions in the fiberboard boxes. Obviously, if these supporting panels give way, the cushions cannot be very effective in stopping the load. Any appreciable crushing of the striking edge or corner of a fiberboard box reduces the clearance, or available stopping distance for the downward-moving load and increases the likelihood of bottoming. With the heavier loads in the fiberboard boxes, this crushing was a definite factor. No such reduction of available stopping distance was evident in the cleated plywood boxes.

Comparisons of corresponding values of peak acceleration of load, column 7 of table 1, and peak of shock spectrum, column 10, emphasize the inadequacy of the peak acceleration value of the applied shock pulse, alone, as a criterion of the damage potential of the shock. In table 1, the peak of the undamped shock spectrum varies from about 35 percent more to as much as 90 percent more than the peak value of the applied shock pulse.

It has been customary, in reporting the dynamic compression characteristics of package cushioning materials, to present the data in the form of peak acceleration-static stress curves. Such

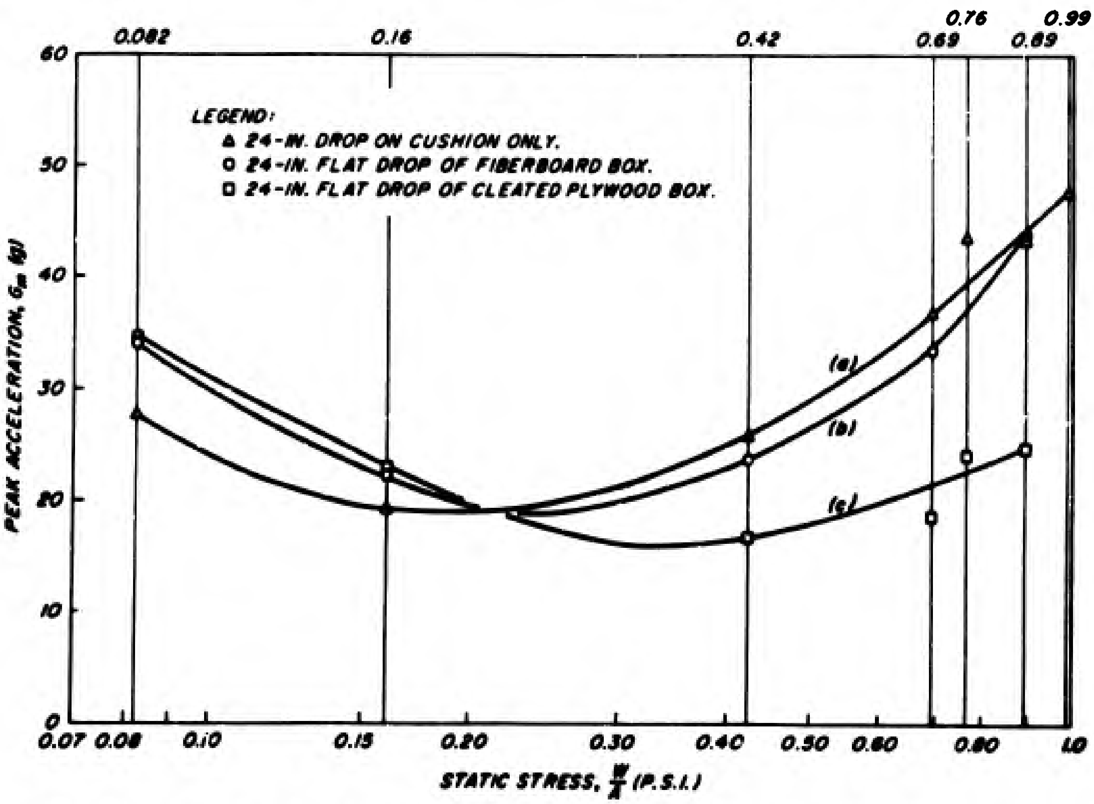


Figure 7.--Peak acceleration-static stress (G_m-W/A) curves for:

(a) Urethane foam pads only; (b) cushioned package in a fiberboard box; and (c) cushioned package in a cleated plywood box. (M 133 144) a curve is a plot of the peak values of acceleration versus the ratio, W/A, (where W is weight of the loading head, in pounds, and the A is the loaded area of the cushion in square inches) for a sufficient number and range of weights of the loading head.

Shown in figure 7 are peak acceleration-static stress (G_m-W/A) curves for: (a) the 5- by 5- by 3-inch[9] urethane foam pads used in the package drop tests, (b) flat drops of cushioned packages using these pads in fiberboard boxes, and (c) flat drops of cushioned packages using these pads in cleated plywood boxes. In the static stress range below about 0.20 p.s.i. (pounds per square inch), the peak acceleration of the dummy load in either kind of container was greater, for equivalent static stress, than that of the loading head in the test of the cushion only. In this same range, the kind of container (fiberboard or cleated plywood box) made little difference in the peak acceleration of the load.

The higher peak acceleration of the load in a container as compared to that predicted from the cushion-only test, for lightweight loads and flat drops, has been observed previously.[10] However, the reason for this appears to be other than package rebound, to which the phenomenon was tentatively attributed.

The oscillograph records of the package impacts involving the 4-pound dummy load, particularly in fiberboard boxes, show that rebound did not occur until well after the acceleration of the load had passed its peak. Therefore, container rebound could not have been responsible for the phenomenon in those instances.

A more probable explanation attributes the present phenomenon to the effect of the four side pads bearing against the vertical sides of the dummy load in these flat drops. The side pads aid the bottom pad in resisting downward movement of the contents. (A simple test was made by removing the bottom pad from several containers of each kind and noting the force required to begin to slide the 4-pound dummy load downward against the resistance of only the four side pads. This force varied from about 5 to 9 pounds.) As the weight of the contents is reduced, the resistance provided by the side pads becomes an increasingly important part of the total force required to stop the downward motion of the contents.

Conversely, the side pad resistance becomes a decreasingly important part of the total force to stop contents motion as the weight of contents is increased. In fact, in the static stress range above about 0.20 p.s.i., the effect of the side pads is obscured by other container effects.

As the weight of contents is progressively increased, a point is reached where the force necessary to stop the contents motion becomes great enough to cause some crushing or distortion of the bottom of the box. This is plainly evident for packages involving cleated plywood boxes. In these containers, the bottom plywood panel, supported by cleats along its outer edges, is free to act as a centrally loaded diaphragm. Thus, it deflects under the heavier impact loads, absorbs a substantial part of the kinetic energy of the contents, and thereby reduces the peak acceleration of the contents during the impact.

To a much lesser extent, flattening and possibly some elastic compression of the two thicknesses (flaps) of fiberboard comprising the bottom of the fiberboard boxes is believed to have absorbed some of the kinetic energy of the contents. This lowered the peak acceleration in the upper range of static stress for these boxes to a value below that for the bare cushion.

As mentioned, a flatwise drop (impact) of a side-pad-cushioned package generally imposes a greater peak stress on the contents than either an edgewise or cornerwise drop. Considering this, the curves in figure 7 point out a particular advantage of cleated plywood boxes for fairly heavy contents in packages cushioned with side pads. The possibility for exploiting this advantage further, by varying the lateral stiffness of the panel material in these boxes in relation to the weight of the contents and size of the box, also exists. Of course, the advantage would be defeated

[9] The data points at static stress = 0.082 p.s.i. were obtained with 7- by 7- by 3-inch pads. Because the lightest dummy load available weighed 4 pounds, giving a static stress of 0.16 p.s.i. with the 5- by 5-inch pads, it was necessary to increase the dimensions of the bottom cushions in the package tests at this static stress.

[10] U.S. Department of Defense. Military Standardization Handbook, Package Cushioning Design. Military Handbook 304, par. 3.2.1.2.5.1. U.S. Naval Supply Depot, Philadelphia, Pa. Nov. 1964.

by intermediate cleats that interfere with the ability of the bottom panel to deflect during flatwise drops.

The inadequacy of the peak value of applied shock (peak acceleration) as a criterion of shock severity is made more evident in figures 8 through 19. Here the upper portions of the figures show shocks measured in 24-inch drops of cushioned packages in A, cleated plywood boxes, and B, fiberboard boxes, compared with C, cushion alone. Corresponding shock spectra A', B', and C' are also shown, together with the peak value of the curve for the cushion alone.

Specifically, the upper set of curves represent the measured acceleration-time pulses as digitized for computer operation, and the lower set are the corresponding zero-damping shock spectra plotted as peak response acceleration versus the natural frequency of the responding systems.

These 12 figures present the acceleration-time data obtained in test series 5 and 6 of table 1, plus the corresponding acceleration-time data for "C" cushion pads obtained in the pendulum-impact test using a drop height equivalent to a 24-inch free fall. (All of the primary pads in these two series were "C" pads.)

If every article to be packaged were a rigid, unyielding structure throughout, such as the dummy loads used in the test packages, there would be no need for the shock spectra. The peak acceleration of all parts of such an article would be the same as the peak acceleration of the applied shock.

Many articles that must be cushioned for shipment, however, are assemblies consisting of a fairly rigid main structure to which are attached individual parts or subassemblies that often are the most damage-prone elements of the entire article. Due to their own inertia and the resilience of their attachment to the main structure, the motion of these elements during an externally applied shock will differ from the motion of the main structure. Each will respond at its own natural frequency (see Appendix 1), and the maximum acceleration it will experience, disregarding damping, will be shown by the value of the appropriate shock spectrum at that natural frequency.

Consider, for instance, the conditions represented by figure 8. Suppose that instead of being a solid, concentrated mass, the 4-pound load contained a small, fragile, mechanical element capable of vibrating at its own natural frequency of 45 c.p.s. (cycles per second). The peak acceleration indicated by the cushion-only test is about 28 g's. However, as indicated by the package-drop shock spectra, the small, fragile, mechanical element in either of the test packages would have experienced a peak acceleration, not of 28 g's, but of 51 g's. Even if the design had been based on drop tests of cushioned packages, comparable to those in this study, the indicated peak acceleration would have been about 35 g's in the cleated plywood box and about 33 g's in the fiberboard box.

This emphasizes the possible danger of basing the design of cushioned packages solely on conventional peak acceleration-static stress curves for the cushioning material used, or even on peak acceleration measurements taken on the dummy load in drop tests of a rigid mockup of the proposed design.

In general, the shock spectra for the experimentally generated shocks (cushion test and package drop impacts) exhibit a rapid rise in peak response acceleration in the frequency range from 0 to 20 c.p.s. Generally, they indicate a maximum response somewhere between 20 and 60 cycles, then taper off in an oscillatory fashion, tending to become asymtotic at high natural frequencies to the peak value of the input function.

The maximum value of the undamped response, as indicated by the shock spectrum, is always greater than the peak value of the shock itself. In some instances, the shock-spectrum (undamped) peak is as much as 90 percent greater than the peak value of the acceleration-time pulse from which the shock spectrum was derived (table 1).

CONCLUSIONS

1. The container effect is an important factor in the performance of cushioned packages utilizing the side pad method of cushion application.

2. Flatwise impacts of cushioned packages, such as those used in this study, generally subject the contents to more severe treatment than do edgewise or cornerwise impacts.

3. Cleated plywood boxes exhibited a definite advantage, under the observed loading conditions,

that could be exploited when they are used as shipping containers for cushioned packages.

4. The value of peak acceleration of the load in a cushioned package does not, by itself, provide sufficient information on the damage potential of a given applied shock.

5. The use of the shock spectrum is an improvement over the use of peak acceleration, by itself, as a criterion of damage potential in impacts applied to contents of cushioned packages.

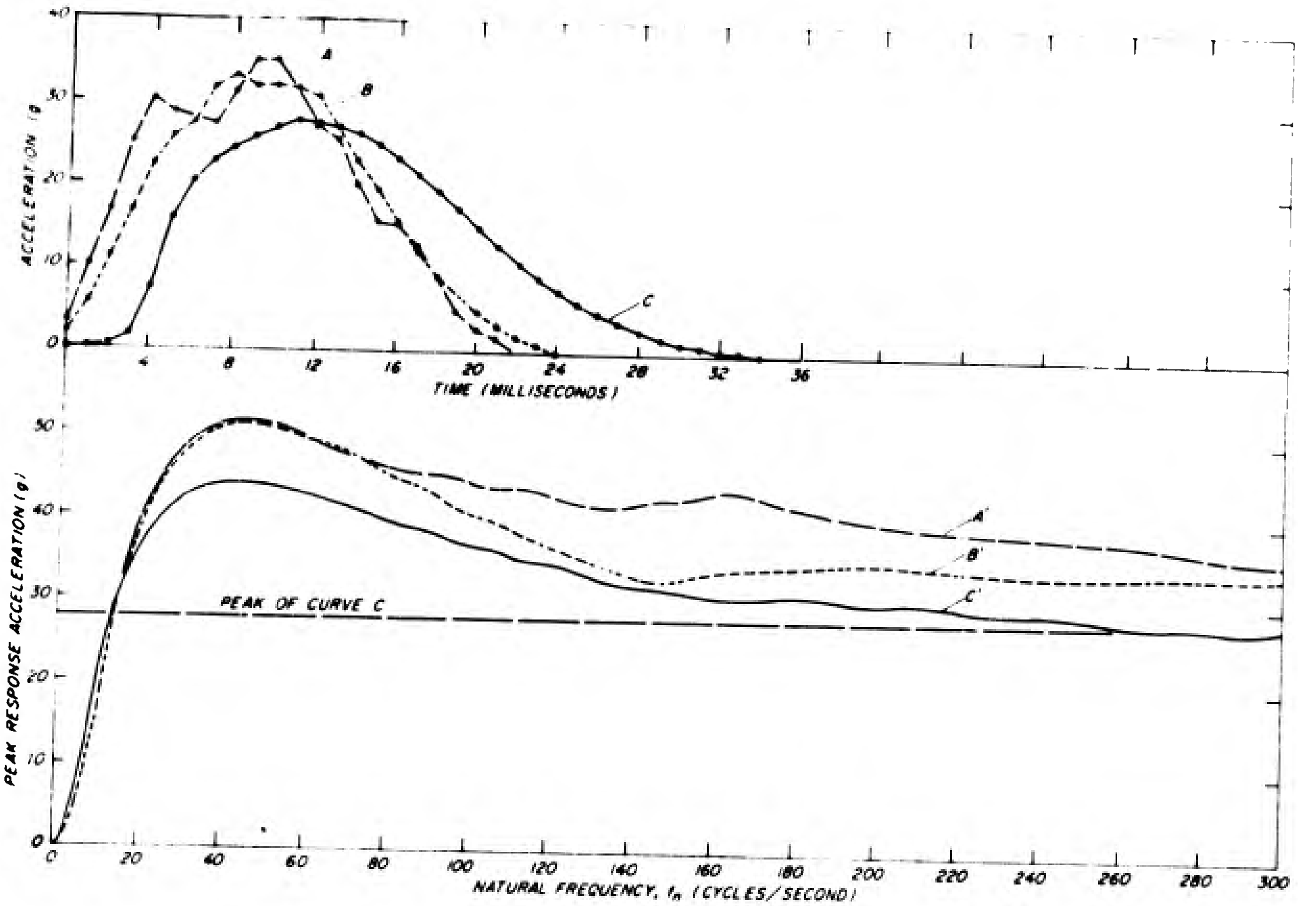


Figure 8.--Shock in flatwise (bottom) drop of cleated plywood box A and fiberboard box B compared to shock of cushion alone C. The static stress was 0.082 p.s.i. (4-pound load, 7-inch-square cushions) in all instances. A', B', and C' are corresponding shock spectra.

(M 133 150)

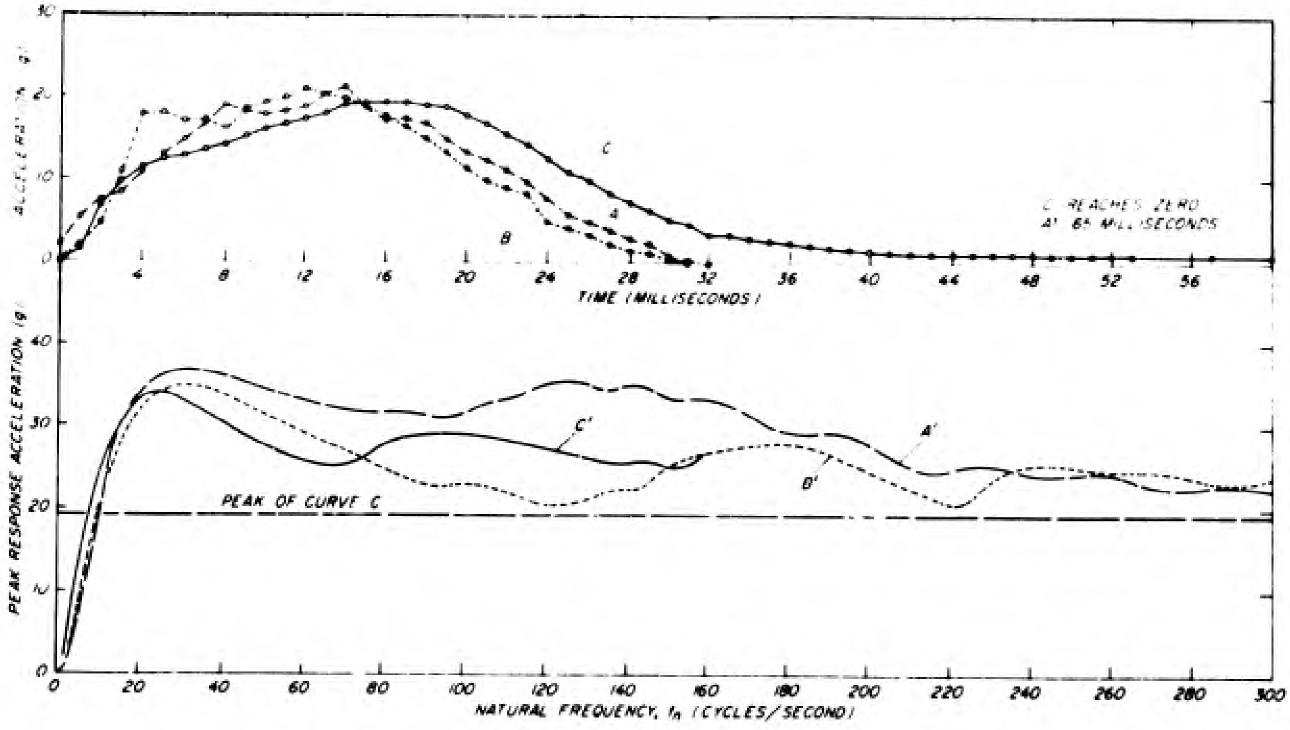


Figure 9.--Shock in flatwise (bottom) drop of cleated plywood box A and fiberboard box B compared to shock of cushion alone C. The static stress was 0.16 p.s.i. (4-pound load and 5-inch-square cushions) in all instances. A', B', and C' are corresponding shock spectra. (M 133 155)

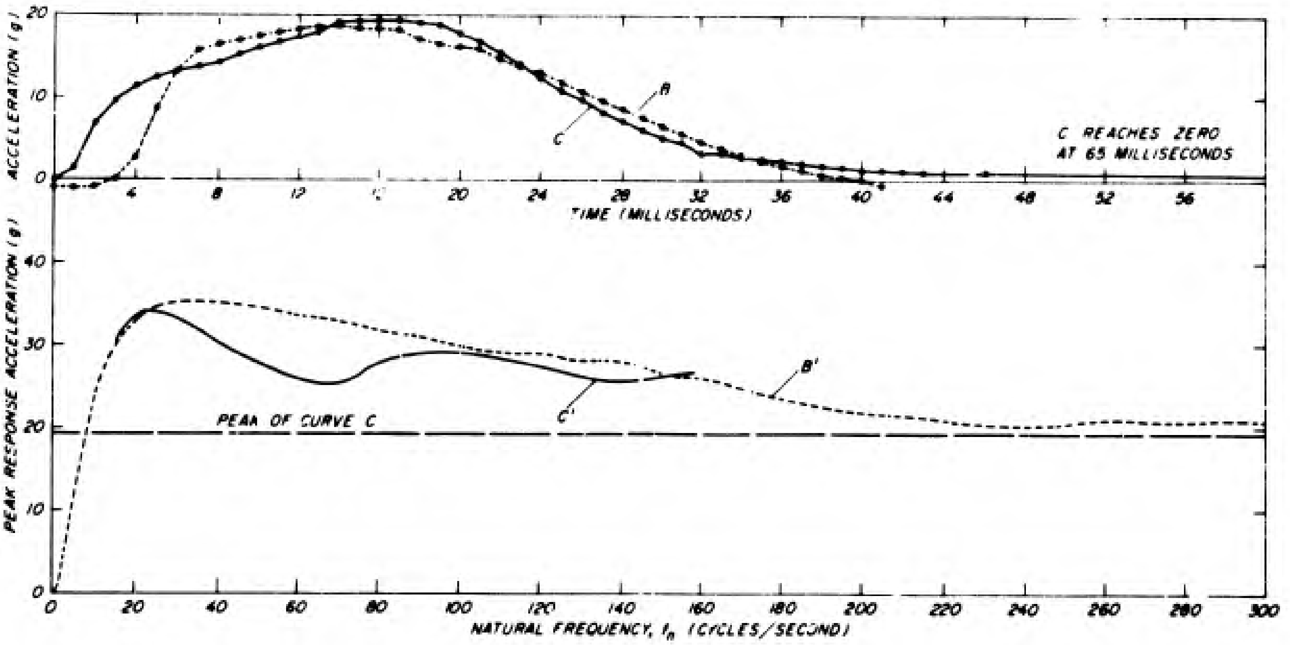


Figure 10.--Shock in edgewise drop (bottom edge) of fiberboard box B compared to shock of cushion alone C. Static stress was 0.16 p.s.i. (load of 4 pounds and 5-inch-square cushions). B' and C' are corresponding shock spectra. (M 133 154)

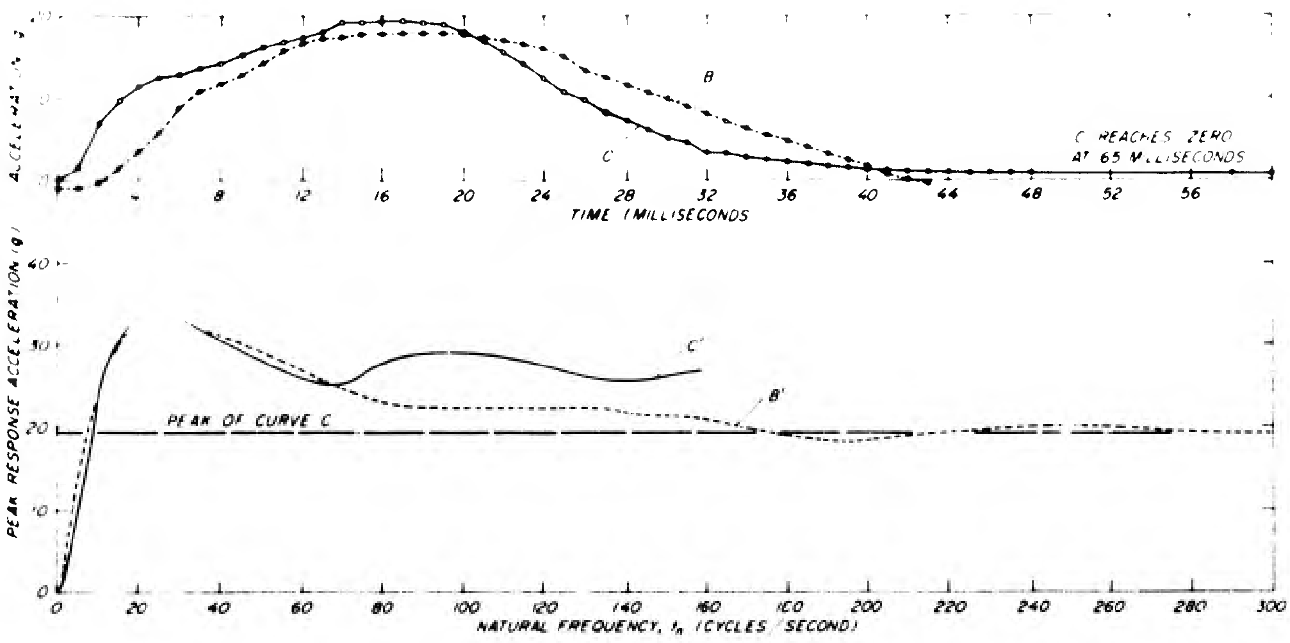


Figure 11.--Shock in diagonally cornerwise (bottom corner) drop of fiberboard box B compared to shock of cushion alone C. Static stress was 0.16 p.s.i. (load of 4 pounds and 5-inch-square cushions). B' and C' are corresponding shock spectra.

(M 133 153)

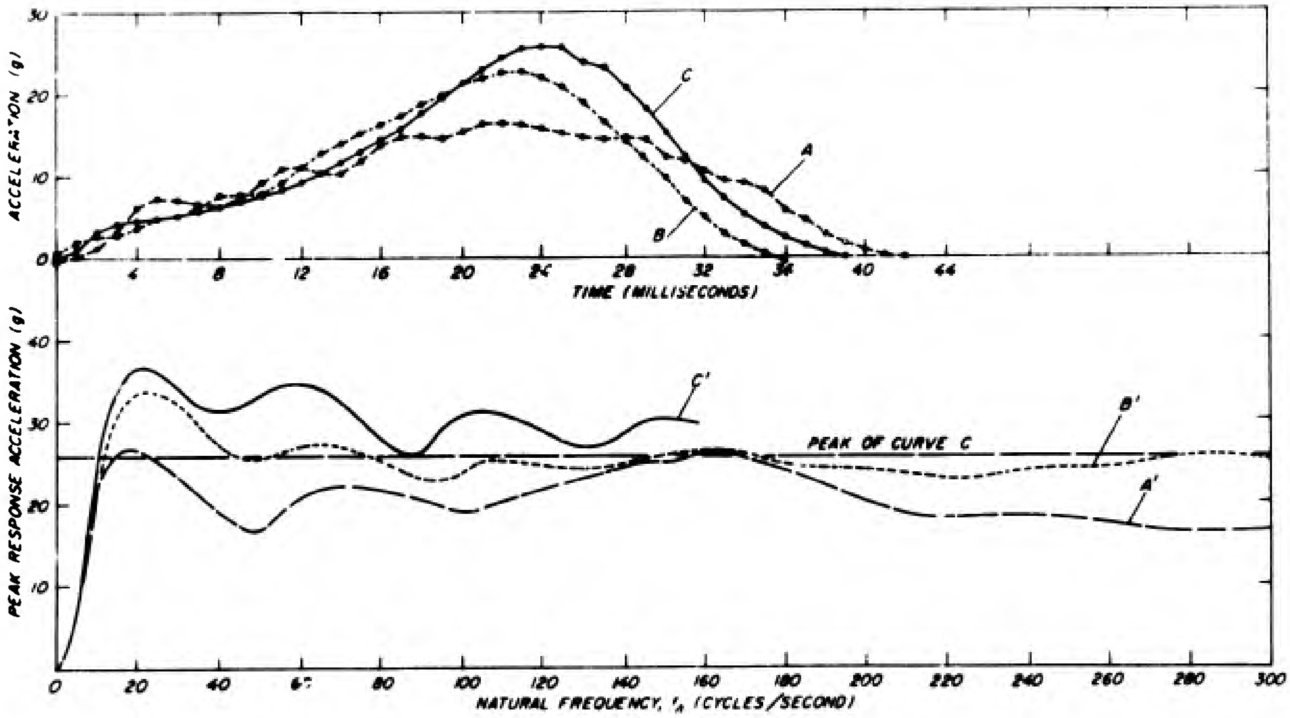


Figure 12.--Shock in flatwise (bottom) drop of cleated plywood box A and fiberboard box B compared to shock of cushion alone C. The static stress was 0.42 p.s.i. (10.5-pound load and 5-inch-square cushions). The corresponding shock spectra are A', B', and C'.

(M 133 152)

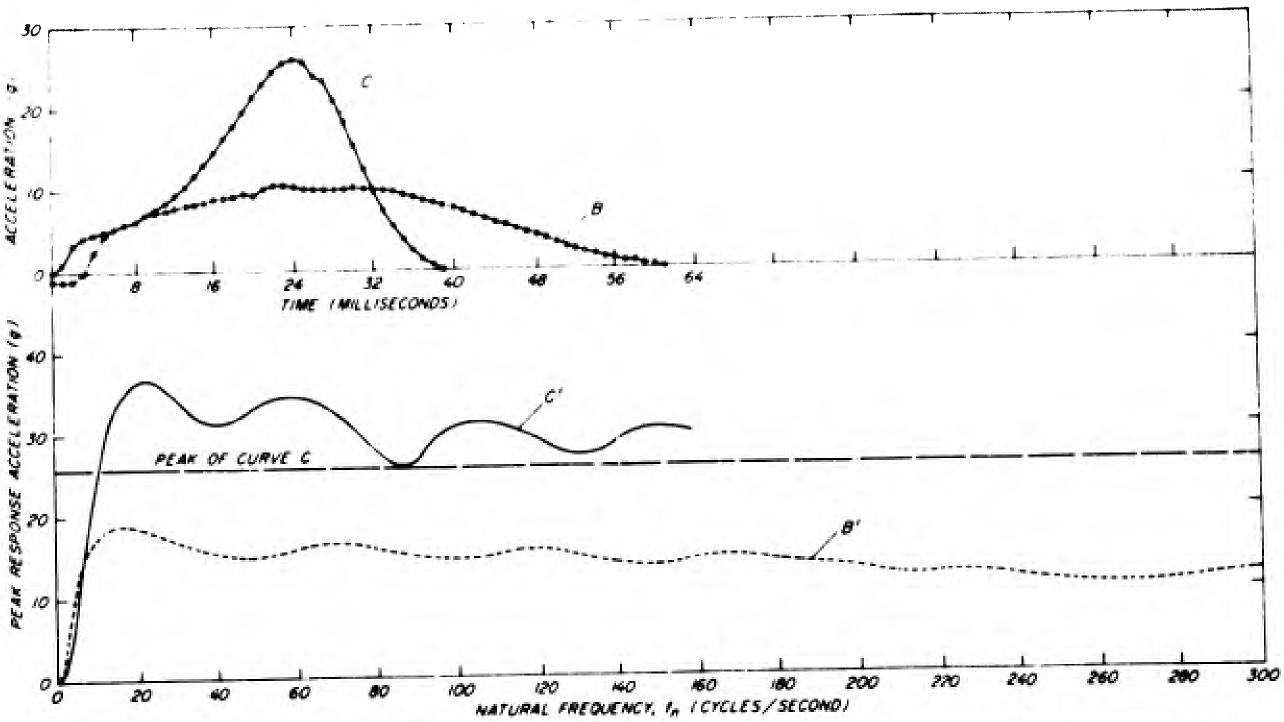


Figure 13.--Shock in edgewise (bottom edge) drop of fiberboard box B compared to shock of cushion alone C. Static stress was 0.42 p.s.i. (load of 10.5 pounds and 5-inch-square cushions). The corresponding shock spectra B' and C' are also shown. (M 133 145)

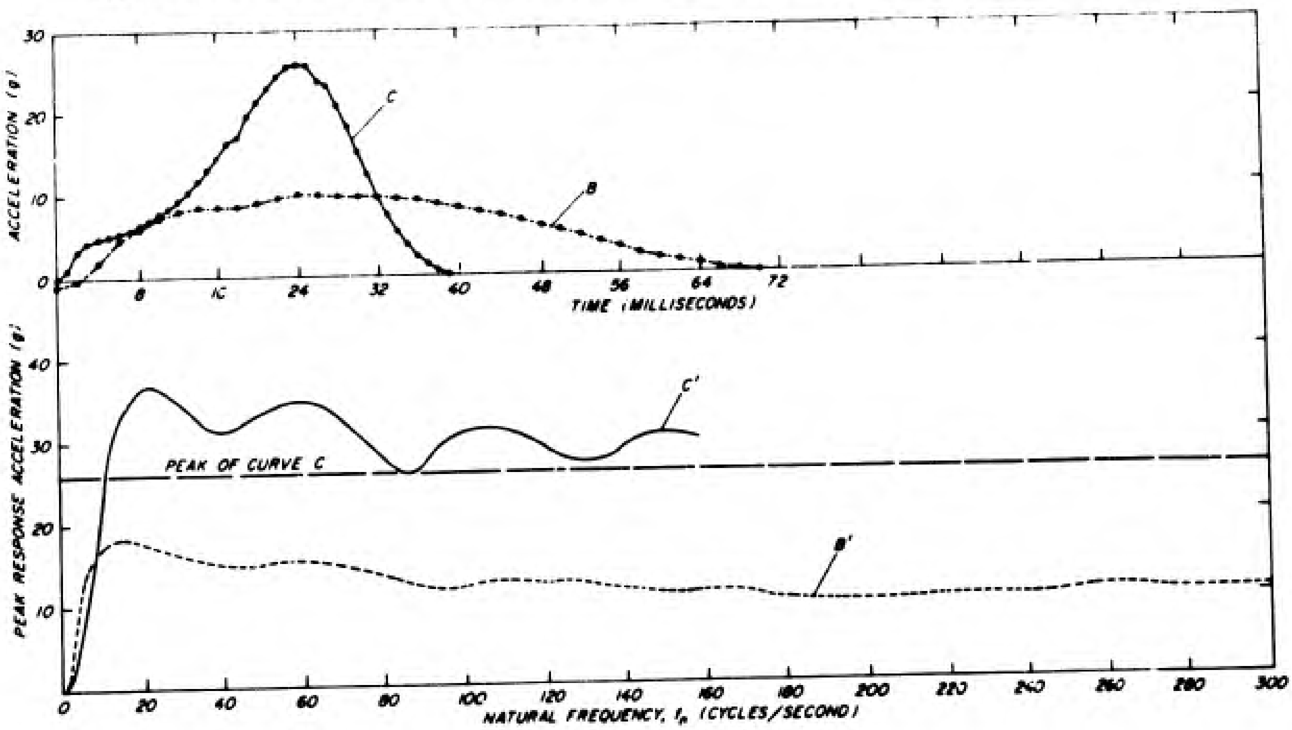


Figure 14.--Shock in diagonally cornerwise (bottom corner) drop of fiberboard box B compared to shock of cushion alone C. Static stress was 0.42 p.s.i. (load of 10.5 pounds and 5-inch-square cushions. B' and C' are corresponding shock spectra. (M 133 151)

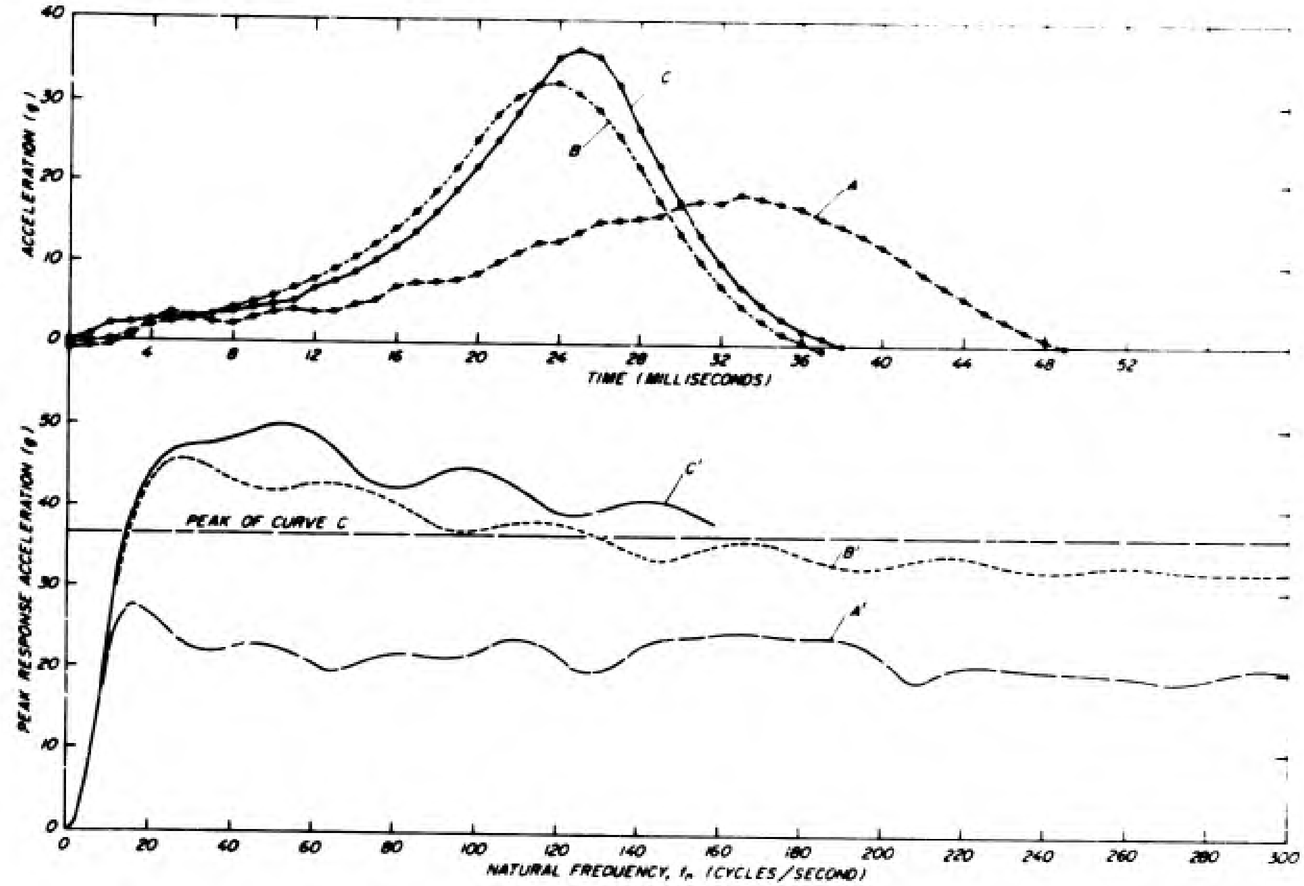


Figure 15.--Shock in flatwise (bottom) drop of cleated plywood box A and fiberboard box B compared to the shock of cushion alone C. The static stress was 0.[illegible]95 p.s.i. (17.35-pound load and 5-inch-square cushions). A', B', and C' are corresponding shock spectra.

(M 133 149)

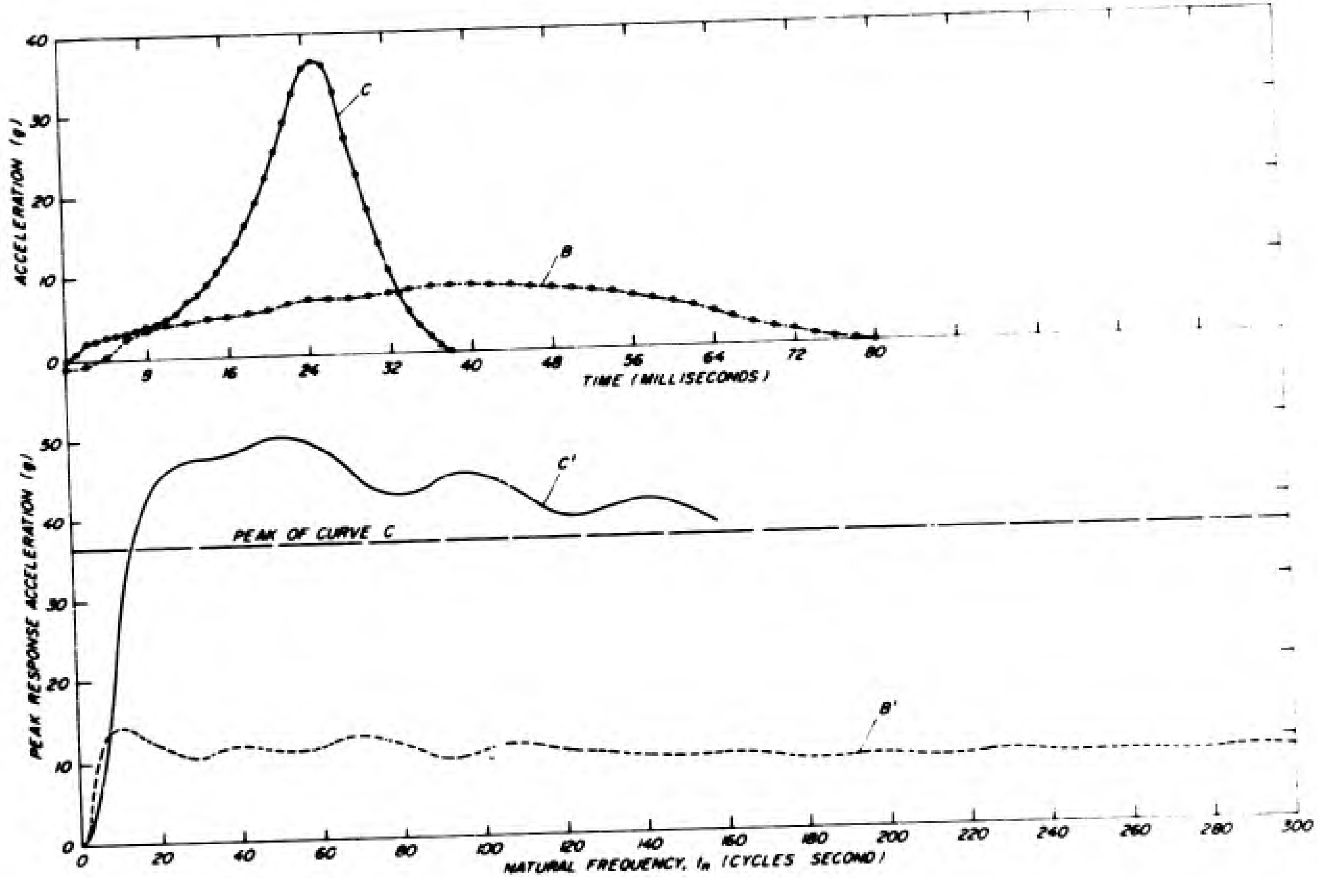


Figure 16.--Shock in edgewise (bottom edge) drop of fiberboard box B compared to shock of cushion alone C. Static stress was 0.695 p.s.i. (load of 17.35 pounds and 5-inch-square cushions). The corresponding shock spectra are B' and C'.

(M 133 148)

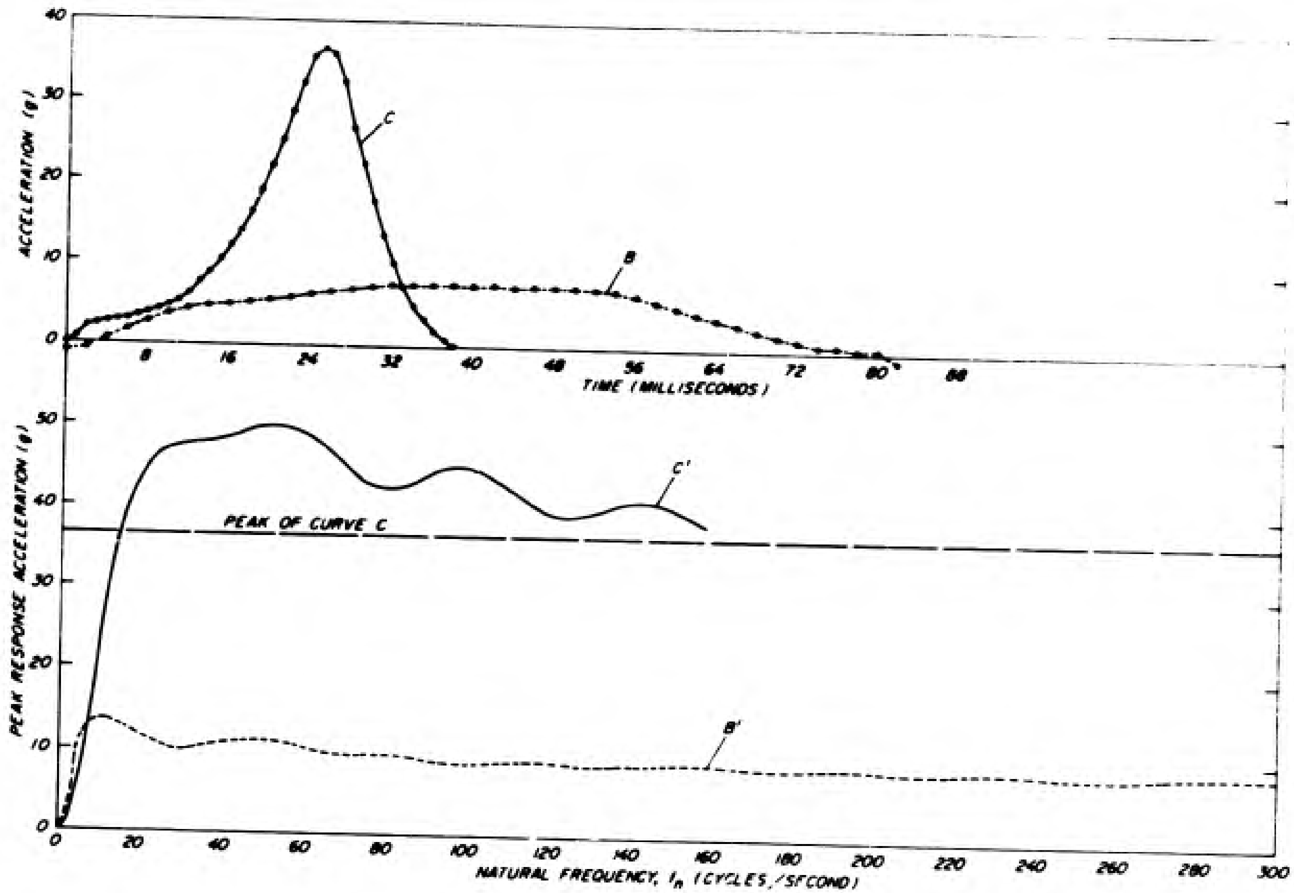


Figure 17.--Shock in diagonally cornerwise (bottom corner) drop of fiberboard box B compared to shock of cushion alone C. Static stress was 0.695 p.s.i. (load of 17.35 pounds and 5-inch-square cushions). The corresponding shock spectra are B' and C'.

(M 133 147)

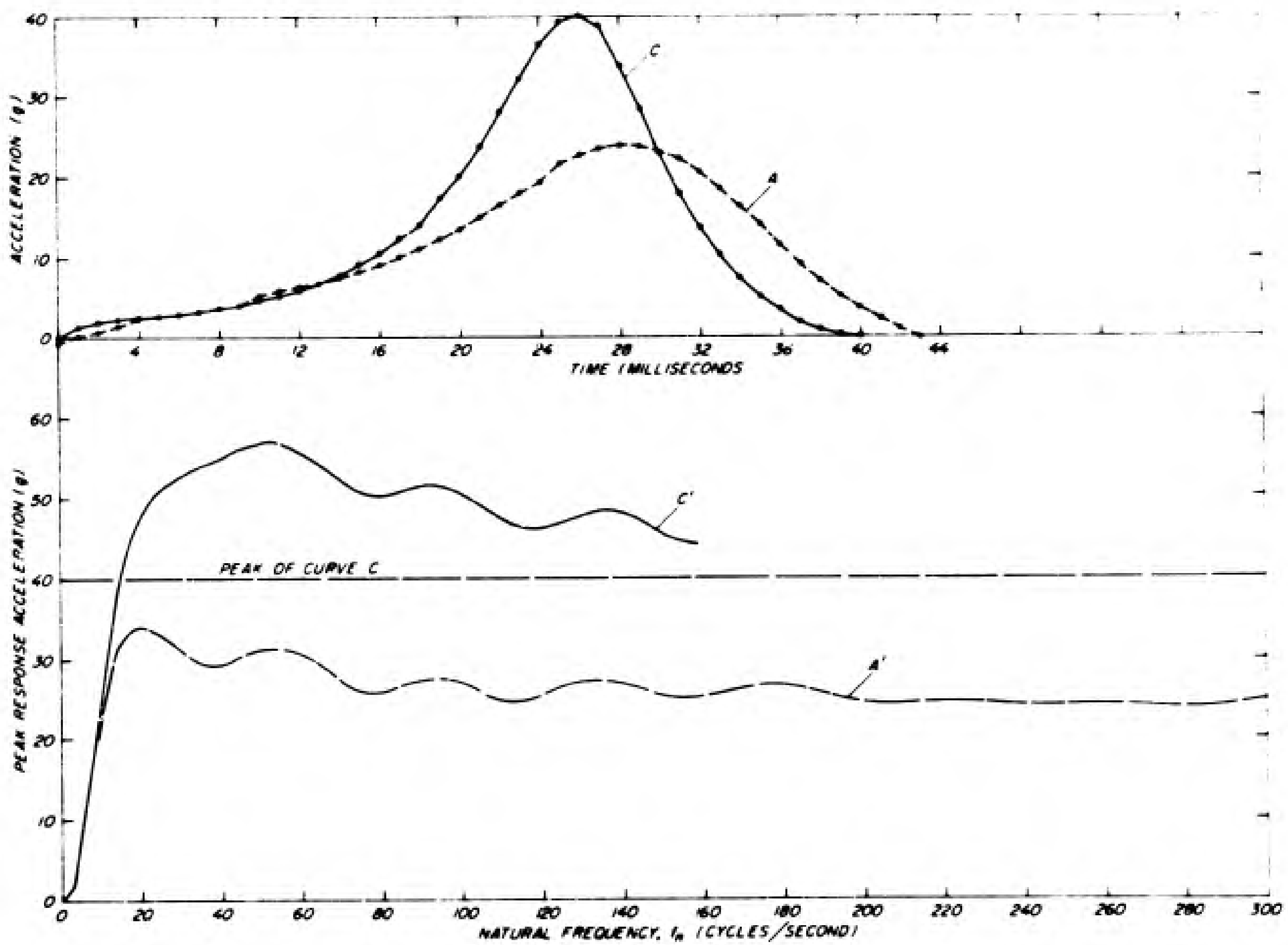


Figure 18.--Shock in flatwise (bottom) drop of cleated plywood box A compared to shock of cushion alone C. The static stress was 0.80 p.s.i. (19.85-pound load and 5-inch-square cushions). The corresponding shock spectra are A' and C'.

(M 133 150)

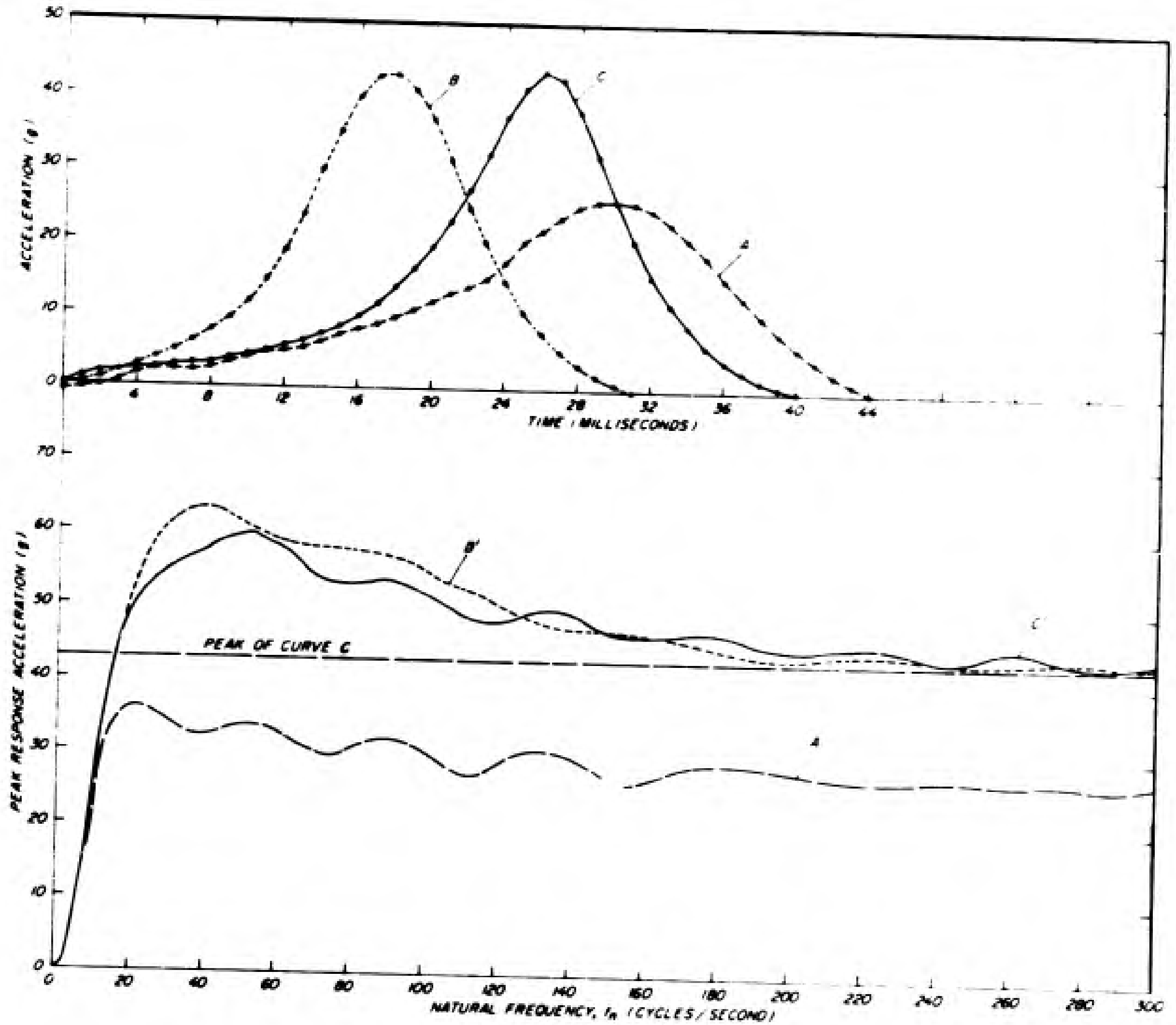


Figure 19.--Shock in flatwise (bottom) drop of cleated plywood box A and fiberboard box [illegible] compared to shock of cushion alone C. The static stress was 0.89 p.s.i. [illegible] load and 5-inch-square cushions). A', B', and C' are corresponding shock spectra.

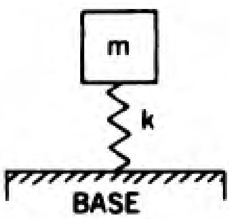
(M 133 146)

APPENDIX 1

Shock Spectrum

The shock spectrum concept was first proposed by M. A. Biot[11] as a means of evaluating the damage potential of earthquake shocks to buildings. It is useful for comparing shock severities in many other fields, including packaging. A brief explanation of the nature of shock spectra follows.

Consider the idealized simple undamped single-degree-of-freedom mechanical system illustrated below.



A concentrated mass m is attached to a supporting base through a spring having spring-constant k. The spring itself is assumed to have negligible mass. If the base experiences a sudden upward motion (impulse or shock[12]), the spring will be compressed a certain amount. How much depends on the magnitude of the mass m, the stiffness k of the spring, and the time-related nature of the base motion. (A downward base motion could have been assumed, as well, resulting in stretch of the spring.) The magnitude of the mass and the stiffness of the spring together determine the free-vibration rate (natural frequency) of the spring-mass system. The mathematical relationship for this is

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

where f_n is the natural frequency of the system, in cycles per second; k is the spring stiffness, in pounds per inch of deflection; and m is the magnitude of the mass, in pounds.

This is the frequency at which the system will continue to oscillate after the base has ceased its motion.

Now, suppose that the base motion (applied shock) is repeated exactly, time after time, but each time with a different undamped spring-mass system attached; each time the maximum compression of the spring (maximum relative displacement of the mass with respect to the base) would be noted. Suppose further that the masses and corresponding spring rates are chosen so that, collectively, they represent an adequate sampling of natural frequencies ranging from zero to several hundred cycles per second. A plot of the resulting data in the form of maximum response (maximum relative displacement) versus natural frequency is one form of the zero-damping shock spectrum for the applied base motion or shock. Velocity spectra are somewhat artificially defined as the displacement response multiplied by $2\pi f_n$. Acceleration spectra, likewise, are defined as the displacement response multiplied by $(2\pi f_n)^2$.

Damping was purposely omitted from the foregoing discussion. The main effect of damping in the responding systems is the reduction of the response amplitude. Therefore, the zero-damping shock spectrum represents the limiting condition beyond which the response usually will not go. Since the structural systems that require cushioning during shipment usually exhibit relatively little damping, the maximum responses of these systems are reasonably well shown by the undamped spectrum.

11 Biot, M. A. A Mechanical Analyzer for the Prediction of Earthquake Stresses. Seismological Society of America, Bulletin 31:151. 1941.

12 The experimental shocks dealt with herein are defined in terms of their acceleration-time histories.

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Container effects in cushioned packages: Urethane foam cushioning applied as side pads, by C. A. Jordan. Madison, Wis., F.P.L., 1968. 21 p. (U.S. FS res. paper FPL 91)

The container effect was important in the performance of cushioned packages using the side-pad method of cushion application. If such cushioned packages were satisfactory on the basis of their flat-drop performance, they seem likely to provide adequate protection against edgewise and diagonally cornerwise impacts as well.

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