

THE DEVELOPMENT OF A TESTING PROCEDURE FOR
EVALUATING THE DYNAMIC CUSHIONING
CHARACTERISTICS OF LOOSE FILL
CUSHIONING MATERIALS

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY
ROBERT MAX FIEDLER
1971

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ABSTRACT

THE DEVELOPMENT OF A TESTING PROCEDURE FOR EVALUATING THE DYNAMIC CUSHIONING CHARACTERISTICS OF LOOSE FILL CUSHIONING MATERIALS

By

Robert Max Fiedler

The thesis evaluates existing testing procedures of resilient sheet cushioning materials to determine their adequacy in evaluating loose fill materials. They were found to be inadequate. Therefore, a test procedure was specifically developed for loose fill materials incorporating the beneficial characteristics of the resilient sheet tests.

The developed procedure utilizes a simulated package with a dummy product inside surrounded by the loose fill material. The package is subjected to controlled shock inputs from a shock machine and the dummy product monitored with accelerometers to determine the effective cushioning provided by the loose fill.

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INTRODUCTION

Thesis Design

The problem, as stated in the title, was to develop a testing procedure for use in evaluating the dynamic cushioning characteristics of expanded polystyrene loose fill cushioning materials. The approach used was to evaluate the existing testing procedures used to evaluate resilient sheet cushioning materials and to determine their acceptability as tests for loose fill materials. Adaptations of two existing testing procedures were evaluated, improved upon, and re-evaluated in an attempt to derive a satisfactory testing procedure. When testing difficulties still were present, further testing designs were developed and evaluated.

The testing procedures were evaluated within a framework of two criteria. The first criteria was that the resulting data derived from the testing procedure must correlate with the performance of the material within the shipping environment. This point becomes critical when considering that the use of the materials as a cushion will be based upon the results obtained from the tests. If in fact the resultant test data does not correlate with the

cushion's performance in packaging applications, the test procedure can not be utilized as a predictive method for designing for the optimum product protection.

The second criteria used to evaluate the testing procedures was to determine if the procedure was reproducible and could be easily duplicated with different samples, with various types of materials, and with different testing facilities. In contrast, is the use of the Conbur tester which provides a means of comparing various package designs within a testing facility, but because the equipment is not uniform enough within different facilities, it is difficult to exchange test data between them. The results obtained from tests of different samples of the same materials should be obtainable with a low variance in results.

CHAPTER I

PLATEN DROP TEST

The first chapter is a critique of the platen drop test method as a suitable procedure for evaluating the dynamic cushioning characteristics of loose fill cushioning materials.

Two test specifications used to evaluate resilient sheet or slab cushion materials are the ASTM D1596-64 and the military specification MIL-C-26861A(USAF). These specifications utilize either a platen drop test or a pendulum tester as the basis for determining the dynamic cushioning data. An adaptation of the ASTM specification was drafted by the Dow Chemical Company in response to a request from the Navy. A modified platen drop test method was used as the basis for the dynamic tests. (The specification is reproduced in part in Appendix I.)

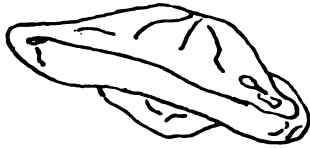
The ASTM specification (ASTM D1596-64) was modified to evaluate loose fill materials by allowing a dropping head of a size smaller than the sample material, to drop on a sample contained within a plywood box 1/2 inch longer on each side than the dropping head. This provided for a

bearing area equal to the ASTM method, but with a different confining arrangement. The test procedure using the platen drop tester was evaluated utilizing four loose fill materials and one resilient sheet cushioning material.

The materials evaluated were used as a basis for evaluating all of the test procedures and not for the purpose of providing a set of final data for the manufacturer's use. The materials were: "Space Discs," manufactured by the Sinclair Koppers Company; "Pelaspan Pac-F," manufactured by the Dow Chemical Company; "Stars," manufactured by the Pakon Manufacturing Company; "Saddles," manufactured by the Alta Industries; and 3 inch expanded polystyrene sheet, manufactured by the Sinclair Koppers Company.

The shapes of the materials and their relative size are shown in Figure 1.

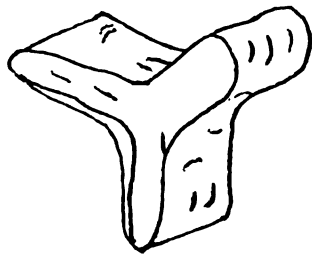
Some modifications in the procedure presented in Appendix I were required to facilitate the testing. The apparatus used is shown in Figure 2, and consists of a guided vertical drop tester with a load range of 0.045 - 1.0 psi. The impact velocity of the platen was measured and calibrated to provide an equivalent 24 inch drop height (136 inches per second) with a Sanborn linear velocity transducer at each loading. The acceleration measuring and recording instrumentation consisted of: a Kistler 818 piezoelectric accelerometer; a coupler; a Krohn-Hite



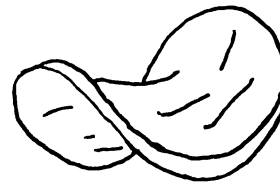
"Space Discs"
Sinclair Koppers Co.



Pelaspan Pac "F"
Dow Chemical Co.



"Stars"
Pakon Manufacturing Co.



"Saddles"
Alta Industries

Figure 1
Loose Fill Cushioning Materials Tested



Figure 2
Platen Drop Test Equipment Setup

band-pass filter with the upper limit set at 500 cycles per second which filtered out the noise in the system generated by the platform guide bearings, without affecting the data signal which had maximum pulse frequencies of 100 cycles per second; and a Tektronix model 564B storage oscilloscope triggered with a microswitch arm. The frequency cut off filter was set at 500 cycles per second so that it would not filter out any of the data signals.

The materials to be tested were placed into 3/4 inch plywood boxes with inside dimensions of 9x9x5 inches. These boxes provided a space of 1/2 inch on each side of the platen when dropped.

The boxes were modified with the use of a comb-like structure constructed of 10 mil cellulose acetate which was placed around the edges of the box to prevent the loose fill materials from scattering when the platen impacted the materials. The acetate structure consisted of alternating 1/4 inch wide teeth which extended toward the center of the box 1/2 inch with 1/4 inch spaces. The teeth did not affect the drop velocity, and allowed the air to escape from the box without allowing an excessive quantity of material to be displaced. Both the box and the comb-tooth structure are illustrated in Figure 3.

Three samples of each material were loaded to a depth of 3 inches rather than the 4 inches specified in the procedure in Appendix I, so that comparisons could more easily

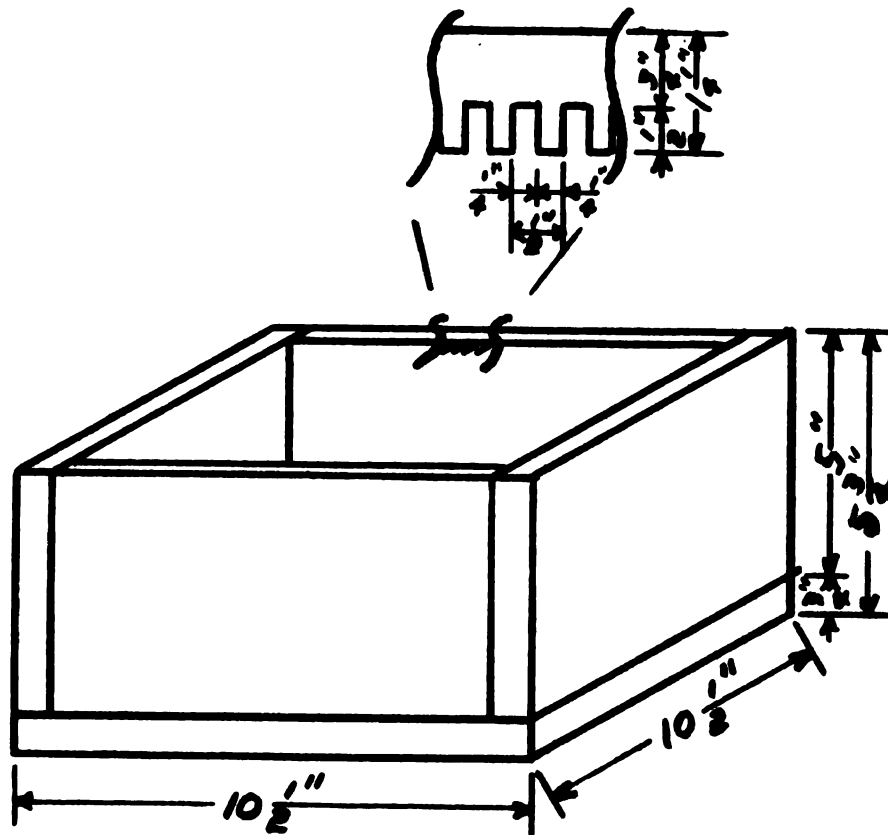


Figure 3

Platen Drop Test Sample Box and
Particle Restraint

be made with the other testing procedures. The boxes were rocked back and forth on the edges for 30 seconds to settle the materials. Additional material was then added as necessary to bring the depth back up to 3 inches. The same materials were used for each static stress loading until a 10 per cent dynamic set had occurred, at which time the material was discarded at the end of the set of drops. The dynamic set was measured in the center of the box with a vertical ruler and a straight edge placed across the top of the box.

The testing procedure consisted of loading the platen to seven static stress loads to provide a range of peak "g" vs. static stress points. At each loading five drops were made on three identical samples for a total of fifteen drops per loading.

The test procedure called for discarding the first drop and averaging the peak "g" levels of the second through the fifth drops. Then, reaveraging the average of the three samples together to obtain each point of a peak "g" vs. static stress curve.

Findings

When conducting the platen drop tests on loose fill cushioning materials two procedural difficulties were encountered. The first was when repeated drops were made on static-free samples, a considerable amount of static electricity was generated causing the sample particles to cling

to all the surfaces of the apparatus. The static electricity was greatly reduced by coating the surfaces of the sample boxes and the dropping head with a 10 per cent solution of liquid dish washing detergent.

The second procedural difficulty was to confine the particles within the sample boxes during the tests. As the dropping head impacted the sample and rebounded, several particles either were displaced around the sides of the head when the air was displaced on impact, or followed the head out of the box when the head rebounded. By utilizing a comb-tooth cellulose acetate barrier around the edges of the box, the particles were prevented from escaping during the impact, but this procedure proved less effective when the head rebounded above the top of the box bringing with it several particles of the materials. The particles of the materials were replaced between each drop, but depending on the amount of static charge which had built up, the particles often tended to adhere to the walls of the box when replaced.

When evaluating the data generated utilizing the platen drop test procedure, two discrepancies were noted from data generated from the other methods and than what was expected. The first obvious difference occurred at the low static stress loadings. When the loading that is applied to a material is too light to cause the cushioning materials to flex or "work" a characteristic high peak "g"

level is usually observed. When the loose fill cushioning materials were tested with the platen drop tester, no initial high peak "g" levels were observed and the levels decreased as the static stress decreased. This was in contrast to the characteristic "U" shaped curves shown in Figure 4, derived with the same materials tested in an enclosed container with a pre-load applied during the platform drop test.

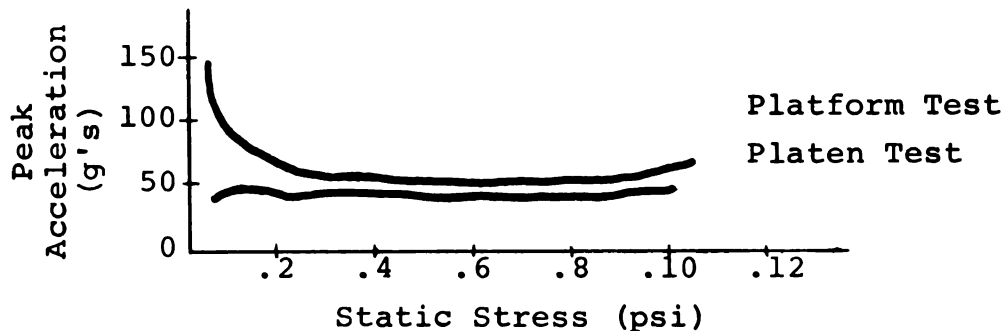


Figure 4

Comparison of Test Results of Two Test Methods

The curves shown in Figure 4 were characteristic of all four loose fill cushioning materials evaluated with the platen drop test method. But, not for the 3 inch expanded polystyrene which performed in the characteristic manner of high "g" levels at low static stress points. The results indicate that the cushioning values obtained at the low loadings result from the particles being displaced into a more dense configuration upon impact rather than by being

flexed. This condition is not evident in the tests where a pre-load is applied which caused the particles to be compacted prior to the drops.

The low peak "g" levels at the lower static stresses is the biggest deficiency of the platen drop test, as tests utilizing dummy products in shipping containers indicate that the loose fill materials do not perform the way the platen tests indicate.

The second discrepancy noted between the platen test method and other testing methods evaluated, occurred from a static stress of 0.3 psi and above. The data resulting from the platen drop test method fell consistently 10-15 "g"s below the results obtained from the tests conducted utilizing a pre-loaded container dropped from a platform drop tester. This occurred when either a rigid 1/2 inch plywood or a corrugated container was utilized, and with all five materials tested. The results differed uniformly enough so that a conversion factor could almost bring the results into a unity in most cases, but there is no basis for establishing an exact conversion factor.

The major advantage associated with the use of the platen drop test method is the reproducible nature of the results. When three samples of the same materials were interchanged, the results obtained for each drop were almost identical. This results from the repetitive nature of the impact head drops and the ease of preparing identical samples for testing.

CHAPTER II

PLATFORM DROP TEST AND SHOCK MACHINE METHOD

The second chapter is a critique of the platform drop testing method for use in evaluating the dynamic cushioning characteristics of loose fill cushioning materials, and the development of a new proposed testing procedure.

The major draw-back of utilizing the platen drop test method previously described, was that the data did not appear to correlate with what was expected from the cushioning materials' performance in packaging applications. The attempt of this chapter was to evaluate testing procedures which more closely measure the performance of the materials as they are used.

The Government Services Administration's (GSA) Standards Division has been in the process of developing a standard specification for loose fill cushioning materials since 1963. In the last Proposed Interim Federal Specification (PPP-C-001426 (GSA-FSS) Proposed) dated in May of 1969, a platform drop test method was specified as the method for evaluating the dynamic cushioning characteristics of the materials. This procedure, which is duplicated in

part in Appendix II, was the basic starting point for developing a platform drop testing procedure.

The method, briefly described, consists of placing a dummy load into a container and surrounding the dummy load with the cushioning material that is to be evaluated. The outer container is dropped from a vertical platform drop tester from a pre-established height. The acceleration of the interior dummy load is measured and recorded when the exterior container impacts the ground surface. By altering the weight of the dummy load, a plot of the peak "g" responses against the static stress loads can be made.

Two changes in the procedure as presented in Appendix II were warranted. The basic changes were in the construction of the exterior container and in developing a means of measuring the displacement of the dummy load resulting from the pre-load and the dynamic set.

The procedure in Appendix II specified using an exterior container constructed of 1/2 inch plywood with a hinged lid fitted with a latch or a hook. See Figure 5. The procedure for applying a pre-load to the material consisted of over-filling the container with an excessive amount of material such that when a 50 pound weight was placed upon the front edge of the lid it would "just" close. This method was found to be inconsistent and difficult to repeat accurately. With each material a differing amount of overfill was required and with some, it was impossible

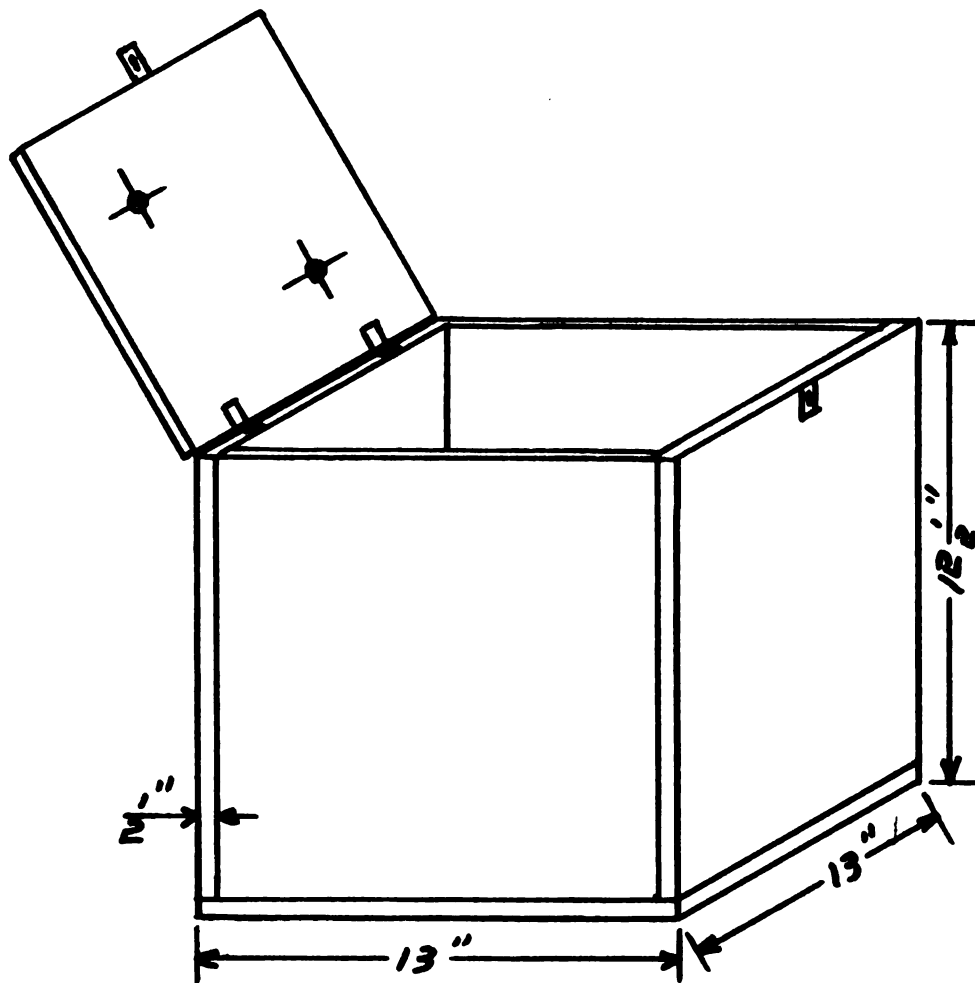


Figure 5

Platform Drop Test Sample Box with Hinged Lid

to keep the material out of the hinged area or from along the front and side edges. Also, by placing the bulk of the overfill material either closer to the hinged area or to the latch area, different amounts were needed.

In order to determine the effects that the pre-load had on the displacement of the dummy load when the hinged lid was used, a different procedure was tried. On two opposite corners of the dummy load, flexible metal rods (wands) were mounted vertically for 10 inches (shown in Figure 6). Holes were then drilled in the top of the lid in line with the wands. After filling the outer container and settling the material to 3 inches, the dummy load was positioned in the center of the container. The container was filled level with additional material and the lid closed. The wands were marked 2 inches above their protrusion through the lid. Additional material was then added to the container to apply a pre-load when the 50-pound weight was placed on the front edge of the lid.

When the extra material (approximately 1-1/2 to 2 inches for Space Discs) was placed near the front of the lid, the dummy load was displaced downward $\frac{3}{8}$ of an inch both in the front and in the back. But, when the extra material was placed near the hinged edge, the dummy load was displaced downward $\frac{7}{16}$ inches in the back and only $\frac{5}{16}$ inches in the front.

The actual difference was not that great, but it did indicate that the pre-load applications with a hinged lid

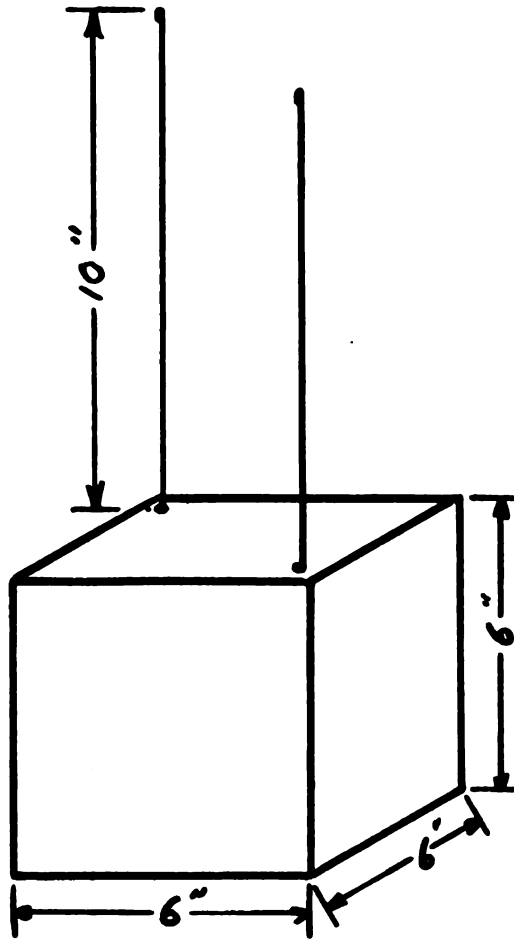


Figure 6

Platform Drop Test Dummy Load with Wands Attached

might not always be uniform which could result in non-repeatable drops from test to test and a variable pre-load throughout the container.

To reduce the possibility of a non-uniform pre-load, another container was designed. The container was constructed 15 inches deep with a lid which fit within the walls. A barrel bolt latch was placed on each side of the lid with holes placed in the container sides so that it would lock in place at a depth of 12 inches. The container is shown in Figure 7.

The container was then filled and settled by rocking, to a depth of 12 inches. The lid was rested on top of the material and for each material the 50-pound weight was placed on the lid and the amount of settling of the lid recorded. This measurement was then utilized as the pre-load overfill required.

When this procedure was used to determine the amount of dummy load settling with Space Discs, the front and back settled only $3/16$ of an inch.

The use of wands was also incorporated into the measurement of the displacement of the dummy load during the dynamic cushioning tests to prevent displacement resulting only from the pre-load being accounted to a dynamic set displacement.

The basic testing equipment used consisted of a LAB model 5D-100 platform drop tester, the dummy load, the

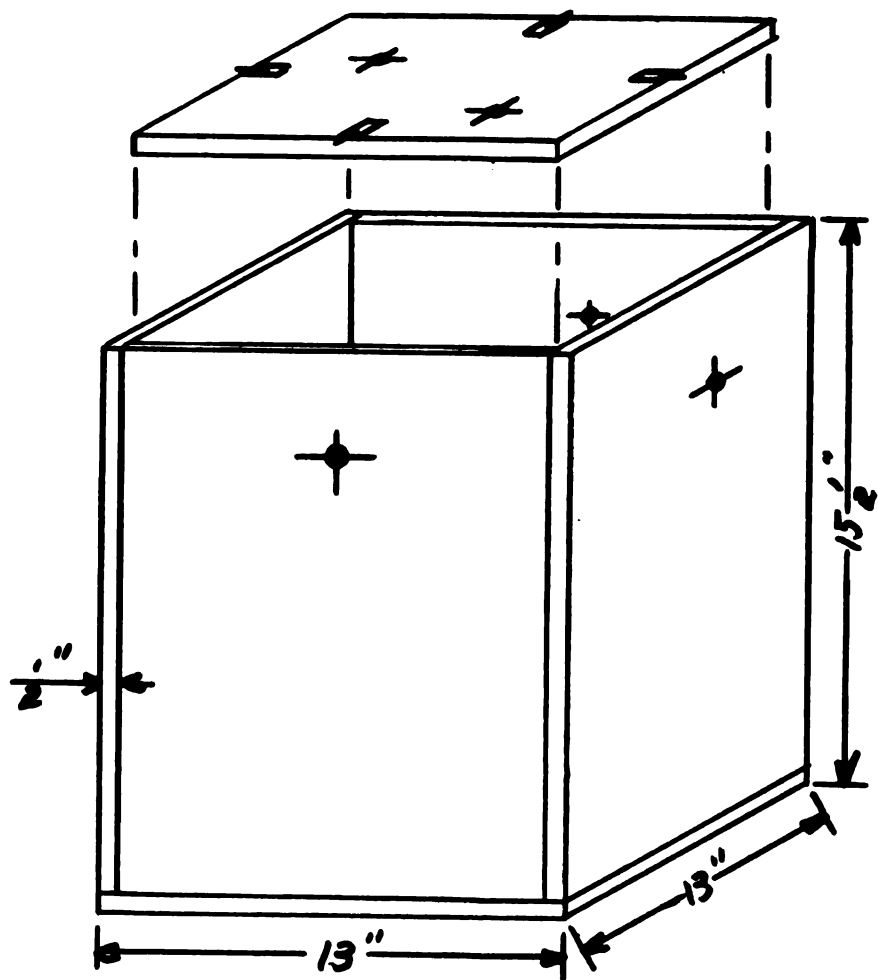


Figure 7

Platform Drop Test Sample Box with
Internal Fitting Lid

exterior container, and the acceleration measuring equipment, and are shown in assembled form in Figure 8.

The dummy load was designed to cover the range from 0.05-1.20 psi static stress. Two boxes were utilized. For the low loading an aluminum box was used and for the higher loadings, a steel box. The boxes measured 6 x 6 x 6 inches and contained a threaded stud in the bottom to attach lead weights securely inside for the various static stress levels required. The flexible metal wands were attached to opposite corners of the lid extending vertically 10 inches. Refer again to Figure 6.

The exterior container was constructed of 1/2 inch plywood and had interior dimensions of 12 x 12 x 15 inches. The lid containing two holes for the wands was 12 x 12 inches and fastened shut with four barrel bolts. Refer again to Figure 7.

The acceleration measuring equipment consisted of three Kistler model 818 piezoelectric accelerometers mounted on the three perpendicular axis of a 2 inch mahogany block mounted on the lid of the dummy load. The accelerometers were connected to a coupler, and the primary vertical channel was filtered through a Krohn-Hite band-pass filter with the upper limit again set at 500 cycles per second. The signals were recorded on a Tektronix model 564B storage oscilloscope triggered with a light-beam device.

Three samples of each material were tested at each static stress loading. Three inches of material were

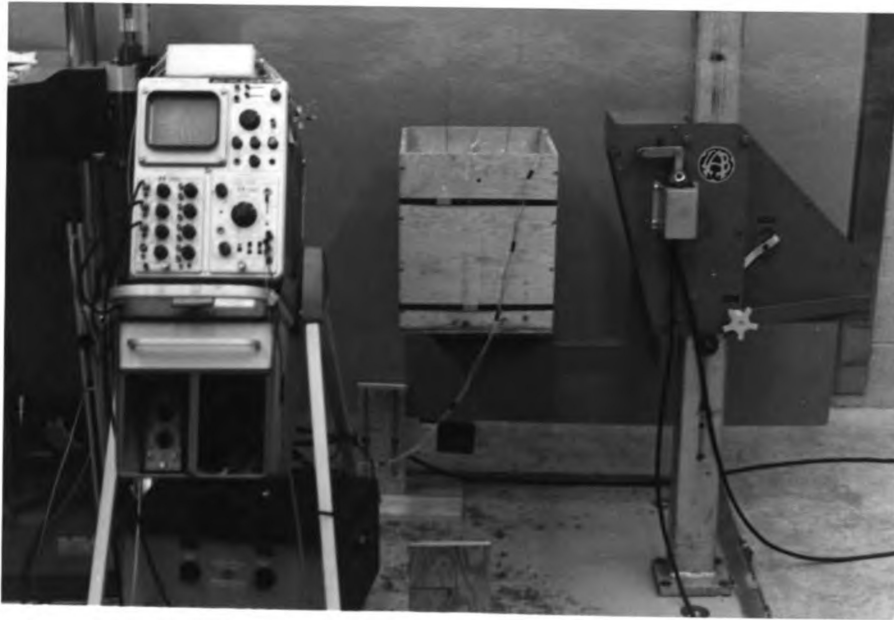


Figure 8
Platform Drop Test Equipment Setup

placed in the bottom of the exterior container and the container dropped three times from a height of 6 inches to settle the material. Additional material was added as necessary to bring the level to 3 inches. The dummy load was then centered in the container and additional material filled around the dummy load to a depth required to produce the pre-load when the lid was pressed and locked into position.

The same materials were used for each static stress load unless a 10 per cent dynamic set had occurred, at which time the material was discarded.

The dummy loads were weighted to provide seven static stress loads. At each load, the three samples each received five drops. The process being repeated for each material being tested. The initial and final position of the dummy loads were noted and the dynamic set as well as the acceleration time curves were recorded.

The calculations made to prepare peak "g" vs. static stress curves consisted of discarding the first drop value and averaging the second through the fifth drops. The averages of the three samples were then averaged to obtain the peak "g" points at each static stress level.

Findings

The two criteria used to evaluate the testing procedures were: does the test simulate the environment, and are the results repeatable.

The platform drop testing concept was designed to duplicate as close as possible a package being dropped. By placing the loose fill materials within a container as it will be used, and by monitoring the effect it had on protecting a dummy product, a closely identical situation to the shipping environment was created.

Tests conducted utilizing a corrugated container instead of the plywood box show only a 5 "g" variation between the two sets of results through the range of 0.215-1.0 psi static stress loadings. Below that range the plywood box peak "g" values are about 35 "g"s higher and above that range the peak "g" values are about 15 "g"s lower as shown in Figure 9. This indicates that the plywood box is a suitable substitute for corrugated containers for the purposes of the tests. The plywood box was utilized to

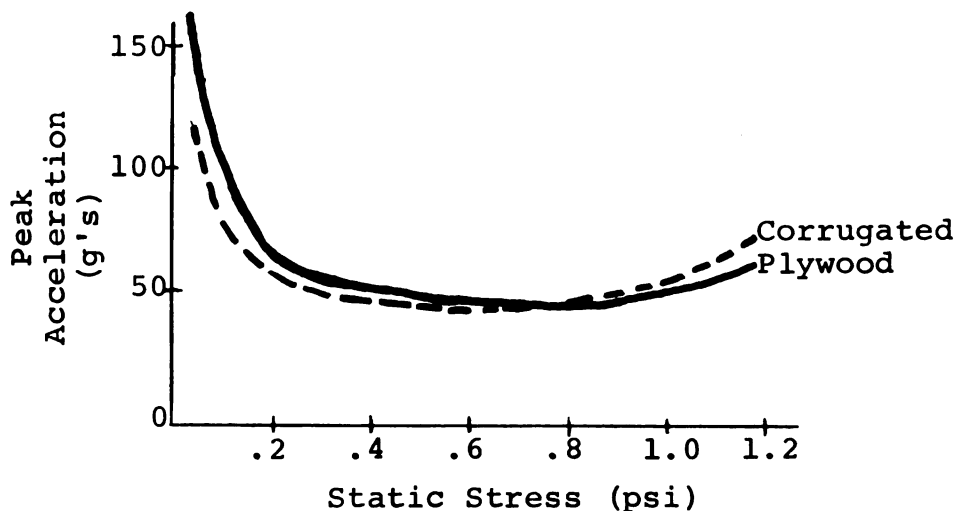


Figure 9

Test Results Comparing Plywood and
Corrugated Containers

eliminate the effects of the corrugated containers breaking down after repeated drops.

The platform drop testing procedure utilizing a plywood box does then fulfill the requirement for simulating the environment, and, the results obtained can be used to design a suitable package. The major problem associated with the use of the test was to obtain repetitive test results. When tests were conducted on three different samples of the same material, the peak "g" value for the same drops, first drop, or second drop etc., at times differed as much as 50 "g"s.

Three variables were evaluated to determine their effects upon the variability of the results. They were the input shock, the compression pre-load, and material depth variations.

The input shock which the container receives is at a maximum when the box impacts the floor in a completely flat drop. If any rotational movement is applied to the box when it is released from the platform, an edge or corner drop may result. When this happens the resultant impact with the floor produces an equivalent impact shock, but the vertical component will be less than for a complete flat drop. This was shown to be the case in several drops by monitoring the accelerometers on the horizontal axis.

To provide a repeatable one directional impact shock into the system, another procedure utilizing a shock machine

was tried. The shock machine is a device used to provide an equivalent free fall impact shock. The change in velocity resulting from an actual free fall drop is either measured or calculated, then the shock machine table is programmed to produce an equivalent change in velocity. By mounting the container on the shock machine table and dropping the table, one directional input shocks can be repetitively produced. The calculations and procedure utilized are shown in Appendix III. Figure 10 shows the sample box mounted upon a Mark 2424 Monterey shock machine.

The results of the test using the shock machine show less variance from sample to sample, but they still show some variance. This indicated that eliminating the variance in the input shock pulses into the container does not in itself eliminate all the variance in the test results.

Next the effects of variations which might occur during the pre-loading were evaluated. All the tests were conducted with a 0.5 psi static stress dummy load with a range of pre-load compressions applied. The shock machine equipment was used to provide constant input pulses. And, a precise 3 inch depth was maintained throughout the tests. When the pre-load applied was varied from 0 to 1 inch in overfill, the peak "g" level varied only 5 "g"s, indicating that the pre-load has little effect on the variance of the peak "g" level when applied by the overfill.

The third variable that was evaluated was the material depth, to determine how critical it was to maintain a

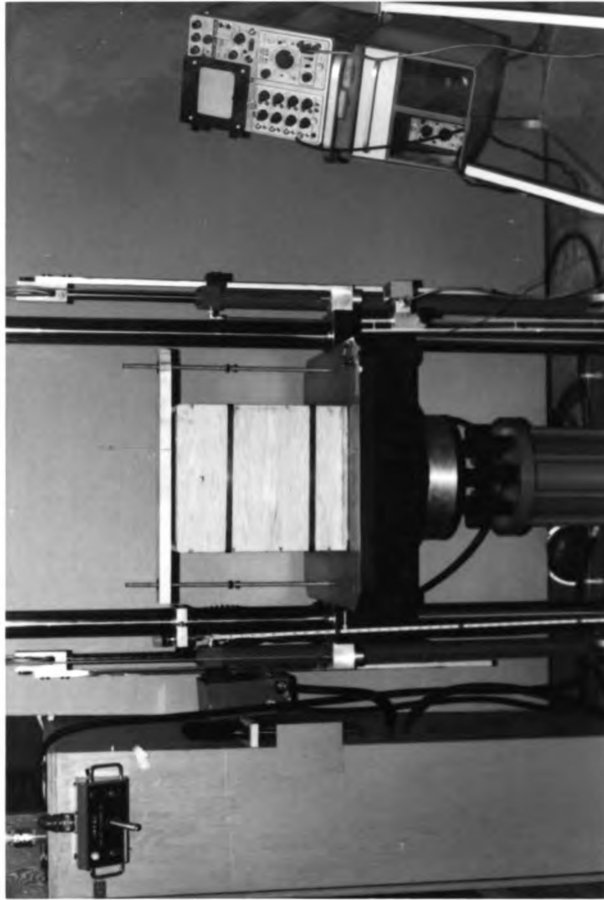


Figure 10
Shock Machine Test Equipment Setup

constant depth. The tests again were conducted with a 0.5 psi static stress dummy load. The shock machine was used to provide constant input pulses and a 1/2 inch overfill pre-load maintained. When the depth of the material was varied from 2-1/2 to 3-1/2 inches, the peak "g" level varied 14 "g"s indicating that one of the most important variables is the material depth.

When the two major variables, material depth, and input pulse were closely controlled, the repeatability of the results was greatly increased indicating that duplication of test results was possible.

CHAPTER III

PROPOSED TESTING PROCEDURE

Chapter Three is a proposed testing procedure for evaluating the dynamic cushioning characteristics of loose fill cushioning materials.

The following proposal was developed from the research conducted and presented in the first two chapters of the thesis. It is a composite of the various procedures previously developed and meets the two criteria stated as prerequisites for a valid testing procedure. The results obtained from the tests can be utilized to design protective packages as the materials are tested in a manner similar to their use. And, the results are repeatable as the variable factors have been reduced to a minimum. By closely following the testing procedures, results from different testing facilities and results from tests at different times should be relatively identical.

Proposed Testing Procedure for Evaluating the
Dynamic Cushioning Characteristics of Loose
Fill Cushioning Materials for Packaging
Applications

Test Method

The loose fill materials to be evaluated are placed into an exterior plywood container (see Figure 11) surrounding a dummy load of variable weight (see Figure 12) which has accelerometers mounted on it. The exterior container is mounted securely on a shock machine (see Figure 13) which generates pulses equivalent to a 24-inch free fall impact. The peak "g" level of the impact pulse is recorded from the dummy load and is plotted against the static stress exerted by the dummy load. The peak "g" vs. static stress curve generated is then a record of the loose fill cushioning material's ability to protect a product against a 24 inch drop.

Test Equipment

The basic equipment required consists of a shock machine, the dummy load, an exterior container and the acceleration measuring and recording equipment.

The dummy load should be designed to cover the range from 0.05-1.50 psi static stress loads. Two rigid boxes constructed of aluminum or steel can be used to cover the range. The boxes should measure 6 x 6 x 6 inches and be equipped with threaded studs in the bottom with which to secure lead weights inside. The top surface should be



Figure 11
Plywood Sample Box

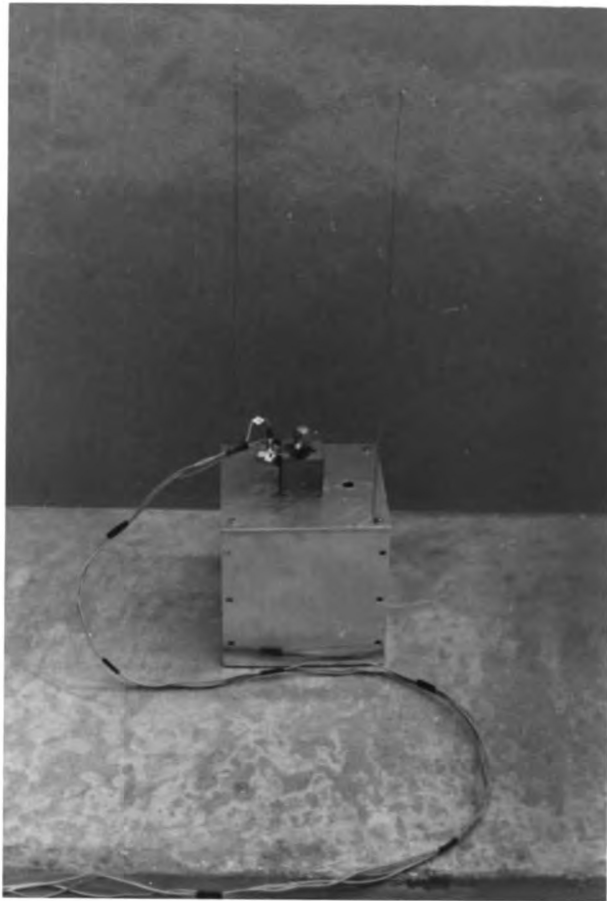


Figure 12

Dummy Load with Accelerometers Mounted

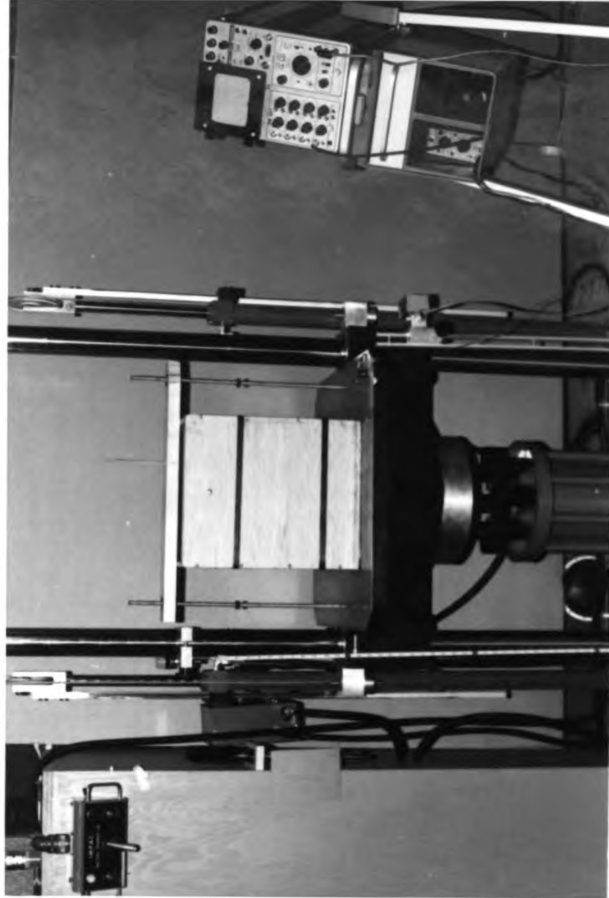


Figure 13
Shock Machine Equipment Setup

constructed of rigid steel to provide a non-flexing surface on which to mount the acceleration measuring equipment. Flexible metal wands should be attached to two opposite corners of the lid to extend vertically 10 inches to be used to measure the position of the dummy load within the exterior container (refer to Figure 11).

The exterior container should be constructed of 1/2 inch plywood with interior dimensions of 12 x 12 x 15 inches. The lid should measure 12 x 12 inches and fit within the walls. The lid should be secured in a position 12 inches from the bottom of the container with four barrel bolts on the lid fitting into holes on the four sides. Holes 1/2 inch in diameter should be placed in the lid in alignment with the wands extending from the dummy load (refer to Figure 12).

The shock machine should be capable of producing repeatable two millisecond shock pulses at a peak "g" level of 282 "g"s as shown in Appendix III. The table must be large enough to support the 12 x 12 inch container and any apparatus used to hold the container rigidly on the surface (refer to Figure 13).

The acceleration measuring equipment shall consist of a tri-axial accelerometer or three accelerometers mounted on the three perpendicular axis of a block on the lid of the dummy load. The recording equipment shall be capable of storing the acceleration time curves until they can be

permanently recorded. All of the acceleration measuring and recording equipment shall have a frequency response adequate to record acceleration pulses with an accuracy of plus or minus 5 per cent.

Test Samples

Three samples of each material will be tested for each static stress loading. The same materials will be used for each static stress load unless a 10 per cent dynamic set occurs, at which time new samples will be used. The materials will be conditioned for twenty-four hours at 73°F and 50 per cent relative humidity.

Test Procedure

The dummy load should be weighted to provide a minimum of five static stress loads. At each load, three samples will receive five drops each for each material tested. The samples are prepared by placing 3 inches of material in the bottom of the exterior container and dropping it three times from a height of 6 inches to settle the particles. Additional material will be added as necessary and the process repeated. The dummy load is then centered in the container, and its position re-checked to ensure it is 3 inches from the bottom. Additional material is then filled around

the dummy load to a depth required¹ to produce the pre-load when the lid is pressed down and locked into position.

The exterior container is securely mounted on the shock machine table and the initial position of the wands recorded. The table is dropped five times for each test set and the acceleration time curves recorded. The final position of the wands are measured and the percentage of dynamic set calculated as a percentage of the original 3 inch thickness.

Test Calculations

The peak "g" vs static stress curves are derived from the data as follows: the first drop of each test set is discarded and the second through the fifth drop peak "g" levels are averaged. The averages of the three sets at each static stress loading are then averaged to determine the peak "g" value for each static stress loading.

¹The required pre-load overfill depth is obtained by filling the empty exterior container with the material to a depth of 12 inches. A 50-pound load is applied to the lid, and the percentage of compression observed is the percentage of overfill used for the testing. (Although this method provides a constant pre-load for all materials, a more meaningful pre-load may be developed from the results obtained from vibrational settling tests.)

CHAPTER IV

SUMMARY AND CONCLUSIONS

Chapter Four consists of a brief summary of the thesis problem and conclusions.

The thesis problem consisted of developing a method for evaluating the dynamic cushioning characteristics of loose fill cushioning materials. Chapter Three proposes a method which will evaluate the dynamic cushioning characteristics of the loose fill cushioning materials as they are being used for product protection in packaging. The method produced reproducible results and could be used as an industrial standard.

The testing procedure developed, lends itself more readily to evaluating the loose fill cushioning material's ability to protect products from a predictive standpoint, rather than as a method of monitoring the quality of the material. In other words, from the data derived from the tests, a packager will be able to determine the optimum amount of loose fill material to use to protect his products. While other testing procedures may be more practical in determining if a specific lot of material meets the quality standards expressed in the purchase specifications.

The desire of industry to have only one testing procedure for all cushioning materials can be met with this method. But, for extruded or formed sheet cushioning materials, this method may not produce any more accurate results than a platen drop testing method which may be more easily applied.

APPENDICES

APPENDIX I

(PROPOSED) MILITARY SPECIFICATION CUSHIONING
MATERIAL, LOOSE FILL, BULK, POLYSTYRENE
FOAM (FOR PACKAGING PURPOSES)

APPENDIX I

(PROPOSED) MILITARY SPECIFICATION CUSHIONING MATERIAL, LOOSE FILL, BULK, POLYSTYRENE FOAM (FOR PACKAGING PURPOSES)

Proposed June 4, 1970 in a military format by the Dow Chemical Company for consideration by the Navy.

Selected sections pertaining to the dynamic cushioning properties of loose fill cushioning materials.

1.2 Classification. The cushioning material shall be classified as to class and grade as shown below:

- Class 1. Very light loading range
- Class 2. Light loading range
- Class 3. Medium loading range
- Class 4. Heavy loading range
- Class 5. Very heavy loading range
 - Grade A. Very low peak acceleration
 - Grade B. Low peak acceleration
 - Grade C. Medium peak acceleration
 - Grade D. High peak acceleration

1.2.1 The classification shall be determined from a peak acceleration static stress curve, established for a 24 inch drop height as required herein. The class and grade are determined by the boundaries designated in Figure 14. To be classified within a particular grade and class, the curve must occur completely below the boundary for the grade and through the entire stress range represented by the class.

3.3 Dynamic Cushioning. Material shall meet the class and grade specified.

4.3.3 Dynamic Cushioning. Peak acceleration versus static stress data. The data to plot peak acceleration in multiples of g versus static stress in pounds per square inch from a drop height of 24 inches shall be established in accordance with Appendix I.

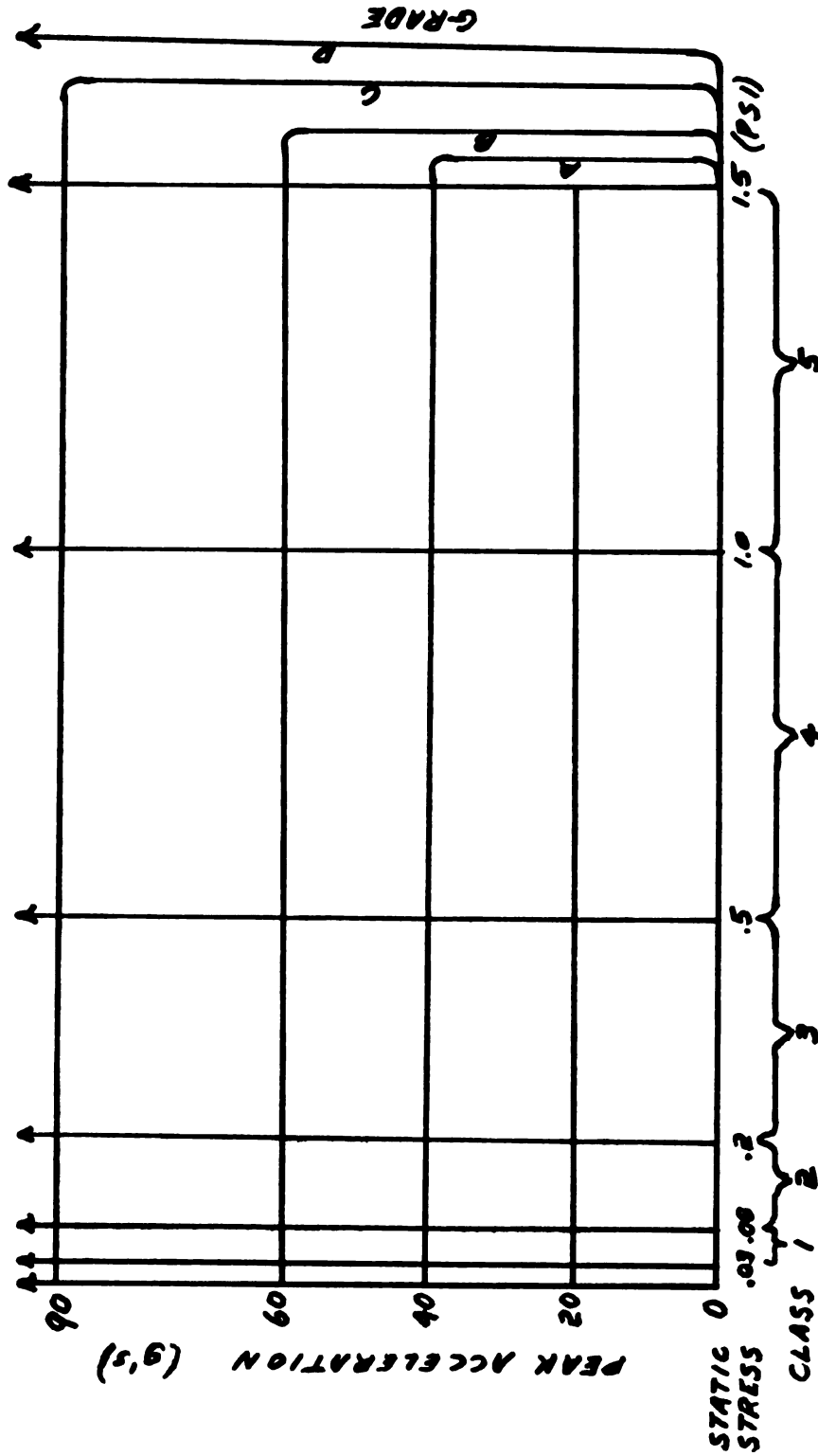


Figure 14
Cushioning Material Classification

Scope and Purpose of Appendix I

This appendix covers a method of determining dynamic energy absorption properties of loose fill package cushioning materials. The test apparatus consists of any testing machine having a dropping head and impact surface for dynamic loading of a cushion to simulate impact received in rough handling. A sensing element is mounted on the dropping head so that a complete acceleration time curve may be recorded. From this curve, characteristics of the cushioning material that affects its performance can be obtained. Dynamic data obtained in this manner are applicable to cushion and not necessarily the same as obtained in a complete pack. In addition to the outer pack, the data can also be influenced by load bearing area, thickness, and loading rate.

Definitions

Displacement. The magnitude of movement of a body, point or surface from a fixed reference point, measured in inches.

Velocity. The rate of change of position of a body with respect to time, measured in inches per second.

Acceleration. The rate of change of velocity of a body with respect to time, measured in inches per second.

g. Symbol for the acceleration due to the effects of the earth's gravitational pull. It is usually considered a constant value of 386 inches per second.

G. Symbol for the ratio between an acceleration of a body in length-time units and the acceleration of gravity in the same length-time units.

G-factor. The ratio of the maximum acceleration that an object can withstand to the acceleration of gravity. It is equivalent to the ratio of the maximum acceleration force that the object can withstand to the weight of the object. The G-factor for an object depends on the time duration of the accelerating force.

Dynamic Test. A load-displacement test simulating the free fall of an object during rough handling. A dynamic test in this document refers to a loading rate of 7900 inches/minute or 136 inches/second. The rate of loading for static load displacement tests, as run in a compression tester, is generally at the rate of 1 inch per minute.

Test Equipment

Testing Machine

Any type of dynamic testing apparatus that will produce test conditions conforming to the requirements listed under "Dynamic Test" is acceptable. However, the dynamic tester shall consist of a flat dropping head having a somewhat smaller surface than that of the cushion to be tested and a massive impact base or surface which is parallel to the dropping head. The cushioning material may be loaded into a suitable container mounted on the impact base. The basic type of dynamic testing equipment that has been found suitable is the guided vertical drop tester. For any dynamic testing machine, it is important that the dropping head and the impact base or surface of the equipment have sufficient rigidity. Lack of rigidity can cause undesirable vibrations in the acceleration-time curve, and this condition can produce discontinuities in dynamic data. Occasionally excessive flexing of the apparatus can be detected and corrected with the aid of highspeed movies. The impact surface or base shall be at least fifty times more massive than the most massive dropping head. All dynamic dropping heads are influenced by friction due to either air or guides, or both. The significance of this effect varies not only with the type of apparatus, but with the various weights used in a given apparatus. For this reason, the drop height is specified as being equivalent to a free fall in a vacuum, based on the impact velocity (a 24 inch free fall is equivalent to 136 inch/second). The impact velocity shall be measured to an accuracy of plus or minus 2 per cent.

Recording Equipment

The selection of specific acceleration-time recording equipment is optional. However, all recording equipment (including both transducers and recorders) shall have a frequency response adequate to record acceleration transients with an accuracy of plus or minus 5 per cent. The acceleration-time pulse is generally a transient approximating a sinusoidal half-wave length at low cushion displacements and becoming triangular or even spike like for impacts reaching high cushion displacements. Adequate frequency response for measuring these transients involves broader bandwidth than might be suspected from analysis of the acceleration-time pulse, assuming it to be equivalent to a continuing sinusoidal vibration.

Adequate Frequency Response

Often the chief limiting factor of frequency response of complete transducer-recording systems is the inherent ability of the mechanical spring-mass elements to respond to applied waves. As a guide to adequate frequency response of such systems the following rule is recommended for the upper limit: to obtain an accuracy of better than 5 per cent of the peak acceleration in the use of a damped spring-mass system it must have a natural period of no more than one-third the duration of the acceleration pulse and a damping constant of 0.4 to 0.7 of the critical value. The actual pulse duration obtained during test depends on the particular combination of drop height, cushion thickness, and cushioning material, and will usually range from 5 to 25 milliseconds. This would require an accelerometer damped between 0.4 and 0.7 of the critical value and have a natural frequency not less than 300 cycles per second.

Accelerometers

When strain-gage type accelerometers are used, the lower end of the frequency response need not be considered since their response is flat to zero cycles per second. However, crystal accelerometers have a definite decrease in response at low frequencies. Although crystal accelerometers have a definite decrease in response at low frequencies. Although crystal accelerometers have been used successfully, it is important that the impedance into which the crystal signal is fed by sufficiently high to give adequate low-frequency response.

Test Samples

Size

Each sample to be tested will be loaded into a rectangular test container whose length and width dimensions are 1 inch longer than the corresponding dimensions of the dropping head. The container shall be 5 inches deep and the material to be tested shall be loaded into the container to a level depth of 4 inches. The container may be constructed of 3/4 inch plywood.

Number

Three samples of each material will be tested.

Test Procedures

Conditioning

All specimens should be preconditioned for twenty-four hours at 73 degrees Fahrenheit and 30 to 40 per cent relative humidity and then conditioned for at least sixteen hours or until constant weight is attained 73 degrees plus or minus 2 degrees Fahrenheit and 50 plus or minus 2 per cent relative humidity. Constant weight shall be defined as the condition where the difference between two successive weighings conducted at one-hour intervals is less than 1 per cent of the average specimen weight. When constant weight has been attained, the specimens should be tested immediately at 73 degrees plus or minus 2 degrees Fahrenheit and 50 plus or minus 2 per cent relative humidity. (If testing cannot be conducted under these conditions, the test measurements should be completed as soon after removal from the conditioning chamber as is practicable. Any deviation from these conditions should be reported.) Testing at various extreme temperatures shall be conducted as described herein when so specified.

Area and Weight

Area and weight measurements shall be made with apparatus yielding values accurate to plus or minus 1 per cent of the true value.

Dynamic Test Procedure

The test container shall be located on the impact base so that the edges of the dropping head are equidistant (1/2 inch) from the respective sides of the test container. Impact tests shall be so conducted on each sample that the dropping head compresses the specimen at an initial velocity of 136 plus or minus 2 inches/second. The acceleration-time record of the dropping head during compression of the cushion shall be recorded for each drop. With the dropping head at the lowest weight range, five consecutive drops shall be made on each of three specimens comprising the sample of a material (a total of fifteen drops on the sample). At least one minute shall elapse between drops to permit the specimen to regain its shape. A quantity of weight shall then be added to the dropping head and five consecutive drops again made on each of the three specimens. Several more such increments of weight shall be added. After the addition of each weight increment, the

dropping procedure shall be repeated. The increments of weight shall be chosen so that the acceleration-static stress curve is clearly defined. Usually five to nine points will be required to establish the curve. When the dynamic set following drop tests at any weight increment exceeds 10 per cent, a set of new specimens shall be employed for tests at all succeeding weight increments and this fact contained in the test report. The dynamic set may be calculated as follows:

$$\text{Dynamic set} = \frac{t_o - t_d}{t_o} \times 100\%$$

Where:

t_o = original thickness
 t_d = thickness after dynamic test.

Computations

The first reading obtained from each set of five drops shall be discarded and the peak acceleration readings of the remaining four shall be averaged. The three average values, one for each specimen, shall then be averaged to obtain one value at each weight increment for the sample. The average peak acceleration for each given weight shall be plotted directly against the corresponding static stress.

APPENDIX II

PROPOSED INTERIM FEDERAL SPECIFICATION
CUSHIONING MATERIAL, PLASTIC, LOOSE
FILL BULK FOR PACKAGING APPLICATIONS

APPENDIX II

PROPOSED INTERIM FEDERAL SPECIFICATION CUSHIONING MATERIAL, PLASTIC, LOOSE FILL BULK FOR PACKAGING APPLICATIONS

The latest revision to PPP-C-001426 (GFA-FSS) proposed dated May 1969.

Selected sections pertaining to the dynamic cushioning properties of loose fill cushioning materials.

1.2 Classification. The cushioning material shall be classified as to class and grade as shown below:

Class 1. Light loading range

Class 2. Medium loading range

Class 3. Heavy loading range

Grade A. Low peak acceleration

Grade B. Medium peak acceleration

Grade C. High peak acceleration

1.2.1 The classification shall be determined from a peak acceleration-static stress curve, established for a 24 inch drop height as required herein. The class and grade are determined by the boundaries designated in Figure 15. To be classified within a particular grade and class, the curve must occur completely below the boundary for the grade and through the entire stress range represented by the class.

4.6.3 Dynamic Cushioning. Each loose fill material will be tested at room temperature using a cushion thickness of 3 inches on all sides of a dummy load. The exterior container encompassing the dummy load shall be made of rigid plywood so as not to influence the cushioning effect of the loose fill packaging on the interior dummy package and shall have a hinged lid fitted with a latch or hook. The package drop assembly shall consist of a 1/2 inch thickness plywood box, interior dimensions of 12 x 12 x 12 inches, containing within the loose fill material a rigid dummy load 6 x 6 x 6 inch outer dimensions, to provide a 36 square inch bearing area on the loose fill cushion. The dummy load shall be a

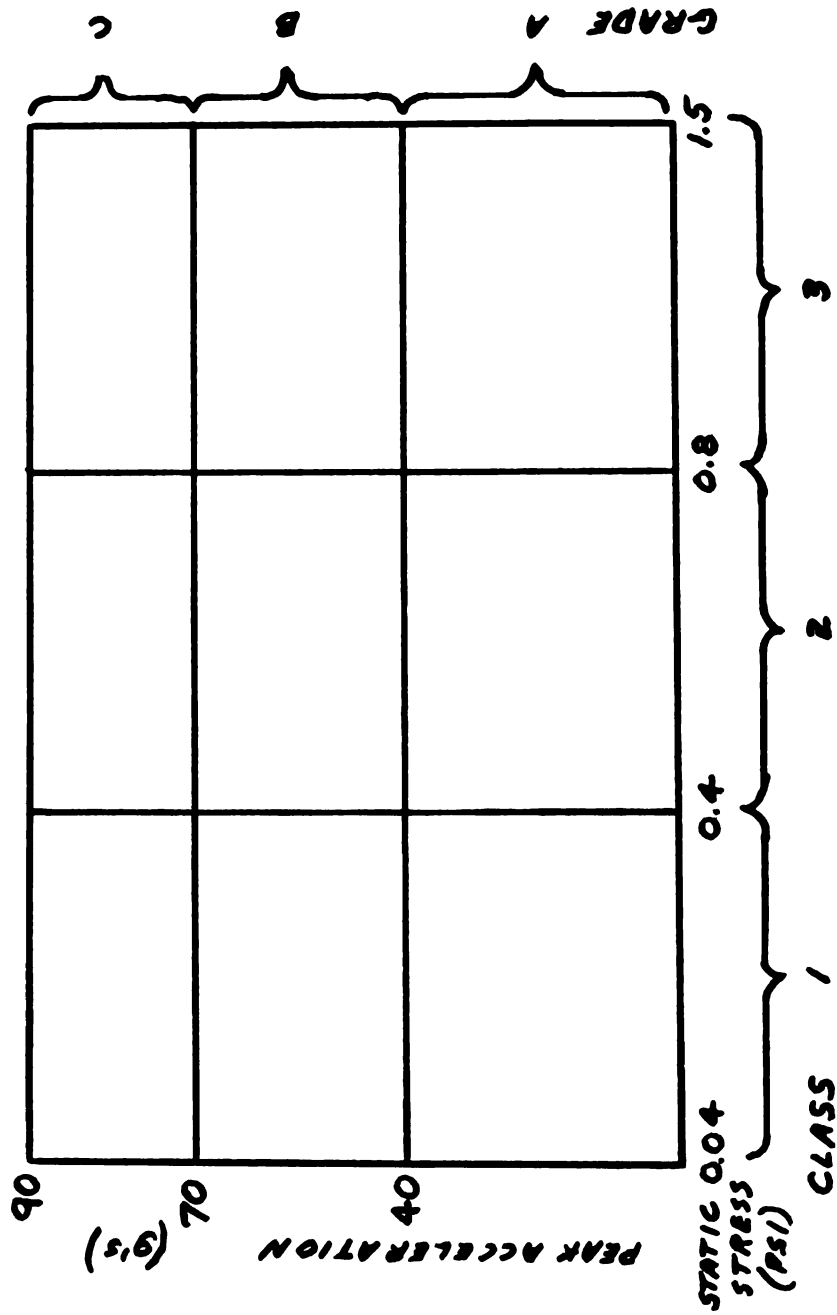


Figure 15
Cushioning Material Classification

rigid metal box, with a screw attached lid on which is mounted a multi-axial accelerometer to measure the "g" forces encountered while testing. Two dummy load boxes will be required to permit testing over the static stress range required. For the lower psi levels (less than 0.25 psi), the box should be fabricated from 1/16 inch thick aluminum sheet; for the higher psi levels (more than 0.25 psi), the box is fabricated from 7/64 inch thick steel sheet. The lid (on which the accelerometer is mounted) is used for both boxes and is fabricated from 1/4 inch thick steel sheet. However, if testing at less than 0.10 psi is desired, a lighter lid made of heavy gauge aluminum may be used. Variable weights shall be placed snugly¹ inside the dummy load to encompass the range of 0.04 psi to 1.5 psi.

The inside bottom of the outer box will be covered with a uniform 3 inch layer of the loose fill material to be tested. Fill the container to the required 3 inch depth and achieve a uniform layer by dropping the box from a 6 inch height three times to allow settling. Add additional material as required after each impact to provide for the required 3 inch cushion depth. Position the dummy load as close as possible to 3 inches from the bottom of the box, centered from the sidewalls, and leveled on the cushion of loose fill beneath. Add more of the packaging material to the box until full, providing a 3 inch thick cushion on all sides of the inner package, taking care to fill all voids without altering the position of the load. To the level full box, an additional portion of the loose fill material shall be compressed into the box by adding an extra amount sufficient so that a 50-pound weight placed on the front top of the exterior box lid will just close it. Secure the top of the assembled package with a hook or latch. The assembled package shall be placed on a platform drop tester and dropped from a height of 24 inches (equivalent free fall height) measured to the bottom of the test container. (Any other factors encountered while using other testing apparatus, such as bearing friction, and wind resistance, or any other factors inherent to the drop apparatus used which affect the velocity of the package shall be compensated for.) Each assembled package, representing one cushioning material at a specific static stress level, will be dropped

¹A rigid threaded rod attached to the bottom of the box over which the weights can be positioned in the center of the box and firmly tightened down with a wing nut has found to be satisfactory. (The allowable deviation of each dummy load from the specified psi is ± 5 per cent.)

five consecutive times at approximately one minute intervals. The "g" force to which the dummy load is subjected (i.e., the vector sum of the three accelerometer outputs) shall be recorded for each drop. A plot of "g" force (linear scale) versus psi static stress (linear scale) shall be made using the average of the vector sum "g" values for the five drops. A minimum of five static stress levels shall be used for the particular class under which the material is to be certified.

APPENDIX III

SHOCK MACHINE UTILIZATION

APPENDIX III

SHOCK MACHINE UTILIZATION

The utilization of a shock machine as a source of repeatable equivalent free fall shock impulses is developed here.

The change of velocity observed from a free fall drop is:

$$\Delta V = (1 + e) \sqrt{2gh}$$

where "e" equals the coefficient of restitution which is defined as the ratio of upward velocity to downward velocity in a drop test, being zero for inelastic materials and 1.0 for perfectly elastic materials. And where, "h" equals the free fall height. The coefficient of restitution "e" was assumed to be zero for all the drops. When actual free fall drops were measured the rebound ranged from 0 to 15 per cent depending upon the weight of the dummy load inside. A constant coefficient of restitution of zero was maintained because the measurable rebound was dependent on too many factors: the material in the box; the weight of the dummy load; and the number of drops.

The calculated value for the change of velocity of a 24 inch free fall with a zero coefficient of restitution then is 136 inches per second. The duration of the impact on the floor is 2 milliseconds determined by conducting several drop tests with accelerometers mounted on the base of the exterior container.

To duplicate the free fall impact with the shock machine, it is then necessary to program the duration of the shock machine to 2 milliseconds and to determine a means of duplicating the velocity change.

With a pulse duration of 2 milliseconds and a velocity change of 136 inches per second, the observable peak "g" level should be 282 "g"s derived from the equation:

$$\Delta V = \frac{2}{\pi} \times a d$$

where "a" equals the peak acceleration, and "d" equals the pulse duration.

By measuring the "g" levels at various drop heights of the shock machine table, a drop height can be found which will produce the 282 "g" 2 millisecond pulse. The Monterey Shock Machine shown in Figure 16 required an 11-1/2 inch equivalent drop height to produce the equivalent 24 inch shock pulse.

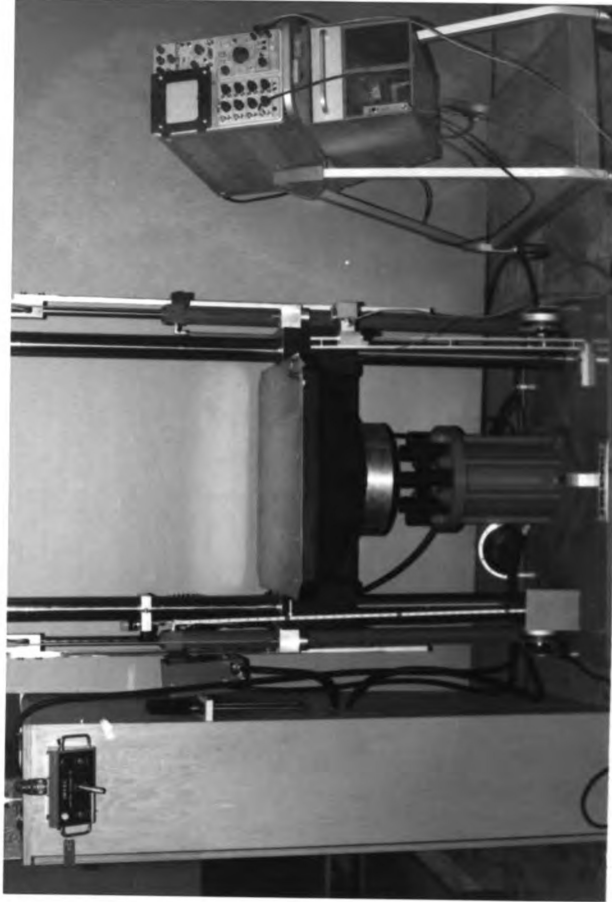


Figure 16
Shock Machine

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