THE DEVELOPMENT OF A TEST METHOD FOR LOOSE FILL CUSHIONING MATERIALS

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ABSTRACT

THE DEVELOPMENT OF A TEST METHOD FOR LOOSE FILL CUSHIONING MATERIALS

By

Ronald R. Holland

Methods to determine the cushioning characteristics of loose fill are either non-existent or do not give repeatable results. A test method was developed using Dow Pelaspan.

The developed procedure utilizes a 3/4" plywood sample box such that the inside dimensions are 12" x 12" x 12" and a 6" dummy product, with the capabilities of changing its weight or psi. The package was subjected to controlled vibration or shock inputs, simultaneously the vibration or shock inputs transmitted through the loose fill was monitored by an accelerometer mounted in the dummy product. Thus the effect of varying overfill and psi (loading of the loose fill) could be observed.

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Nora, without her undying devotion, I would not have made it.

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INTRODUCTION

The problem was to develop a testing procedure to evaluate the dynamic cushioning characteristics of loose fill cushioning materials. Dow Pelaspan was the loose fill material used to develop the testing procedure.

A number of methods are presently being used to package products in loose fill. Usually, the packaging process provides for some degree of overfill. Depending on the company and the particular situation the product would be packaged with varying amounts of overfill. A variety of methods such as: the level of overfill varies from 0" to 1", the level of overfill that could be compressed by a given individual on the packaging line, vibrating a shipping container to promote settling, and dropping a shipping container to promote settling. No thought is given to the relationship of overfill to the weight of the product, or the loading in pounds per square inch (psi) of the cushioning material.

Therefore, a prime prerequisite was to derive a testing procedure that produced information on the performance of the material during testing which could be related to the performance of the material during shipping. This information must be consistent and reproducible.

The research procedure consisted of determining the effect of overfill on resonant vibration, on shock transmissibility, and on settling. The effect of overfill was monitored through a range of cushion loadings.

CHAPTER I

COMPRESSION TESTING

Numerous methods exist to condition a shipping container with loose fill cushioning material. After the shipping container is conditioned the product is inserted or the product is contained within the shipping container and the entire unit is conditioned. Upon completion of the conditioning phase the shipping container is closed and sent on its way.

Two of the most prominent methods for conditioning are: (1) shaking the shipping container to induce settling of the loose fill; (2) dropping the shipping container to induce settling of the loose fill.

By inducing settling, the loose fill is compacted and thus a greater density of material is achieved. A greater density is desired to minimize the amount of settling and shifting of the packaged product. Thus the loose fill can better perform its protective function.

To evaluate the respective conditioning methods, a test to simulate shaking and dropping conditioning procedures was derived.

Establishing a Compression Control

A sample box, Figure 1, constructed of 1/2" plywood with inside dimensions of 12" x 12" x 12" was utilized as a test shipping container. The sample box was filled with one cubic foot of loose fill. A cover with dimensions of 12" x 12" x 12" was placed on top of the loose fill. The cover would move in a verticle direction within the sample box when a compressive force was placed on the center of its surface. The compressive force was placed in the center of the cover to facilitate a uniform compressive force on the loose fill.

Compression Tester equipped with a 100 pound load cell produced the required compressive force, Figure 2. In order to determine the effect of shaking and dropping on the creep of loose fill a control was constructed.

The control was constructed by applying an initial compressive force to the sample box containing one cubic foot of loose fill. A 60 minute test duration was monitored on a recorder connected with the load cell. After 60 minutes the final compressive force was recorded. Varying the initial compressive force from 100 pounds to 20 pounds by increments of 10 pounds for 60 minutes and recording the results a control was generated, Figure 3.

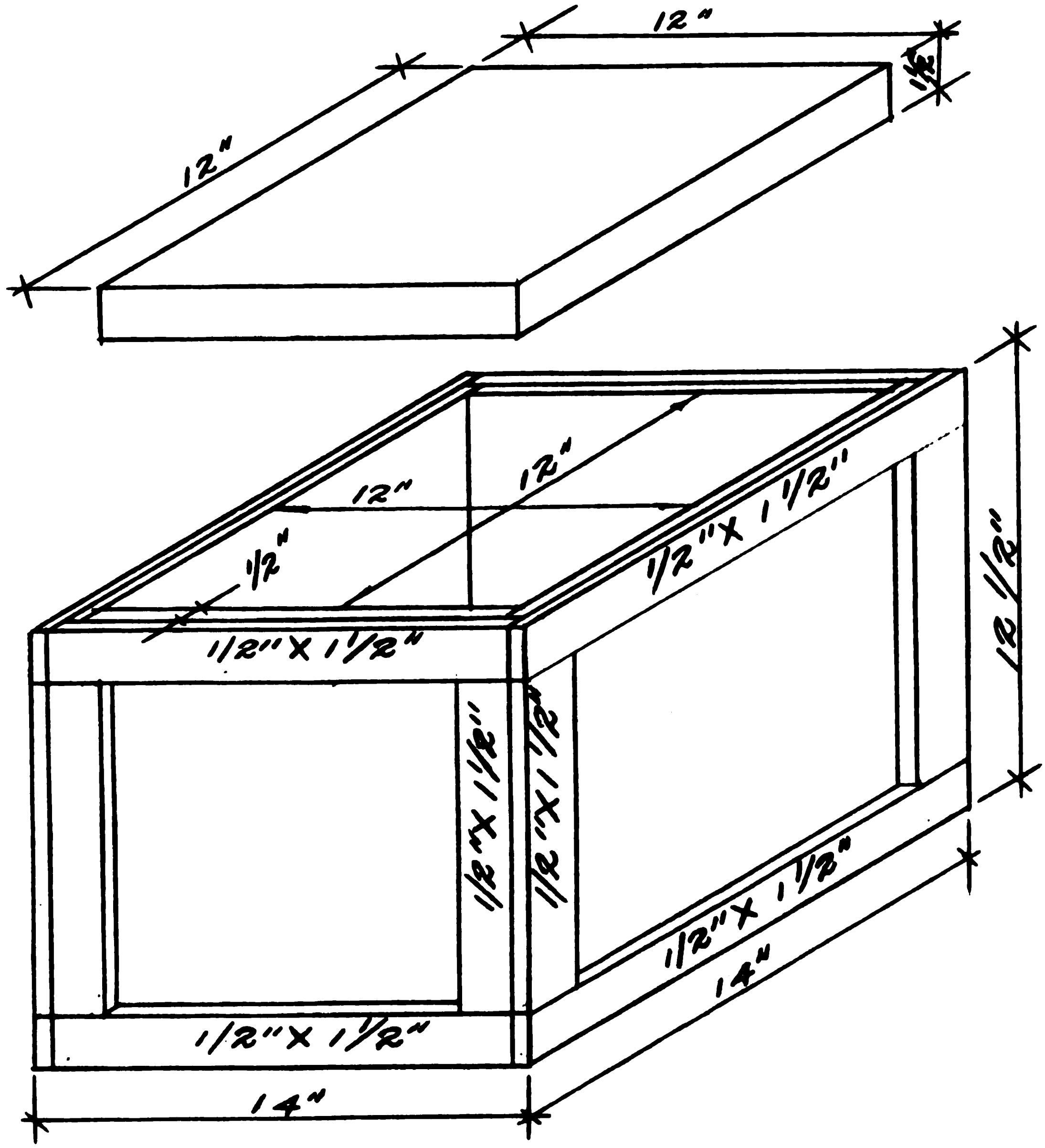

Figure 1

Compression Sample Box

Figure 2

Compression Tester

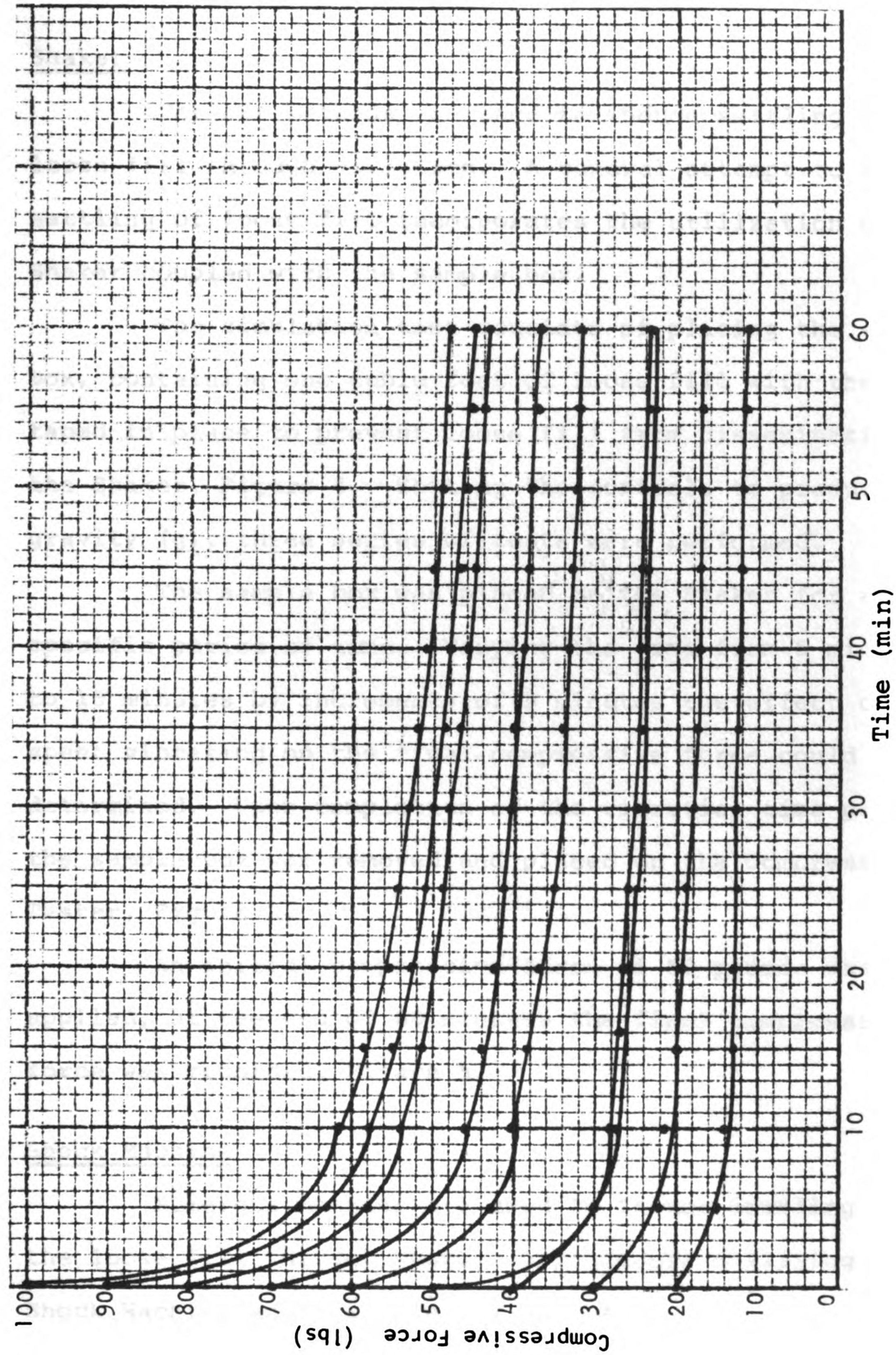

Figure 3

Compressive Force vs Time

Test Procedure

Shaker

Various methods are used to induce settling of loose fill through vibration. A general attempt to simulate settling of loose fill incorporates the utilization of a Shaker coupled with the sample box.

The simulation test consists of placing the sample box, containing one cubic foot of loose fill with the cover taped in place to prevent loose fill from disseminating, on the Shaker, Figure 4. Setting the controls to produce 1 gravity (g), three series of tests were performed.

The sample box was placed on the Shaker for a specific period of time. Varying the time from 5 minutes to 15 minutes by increments of 5 minutes the effect of time spent vibrating on the final compressive force could be determined. Upon completion of the vibration time period the sample box was removed and placed on the Compression Tester, Figure 2.

An initial compressive force of 50 pounds was applied, at the end of 60 minutes the final compressive force was recorded, Figure 5.

Shock Machine

Numerous methods are used to induce settling of the loose fill through shock. A procedure utilizing a Shock Machine and a sample box was used.

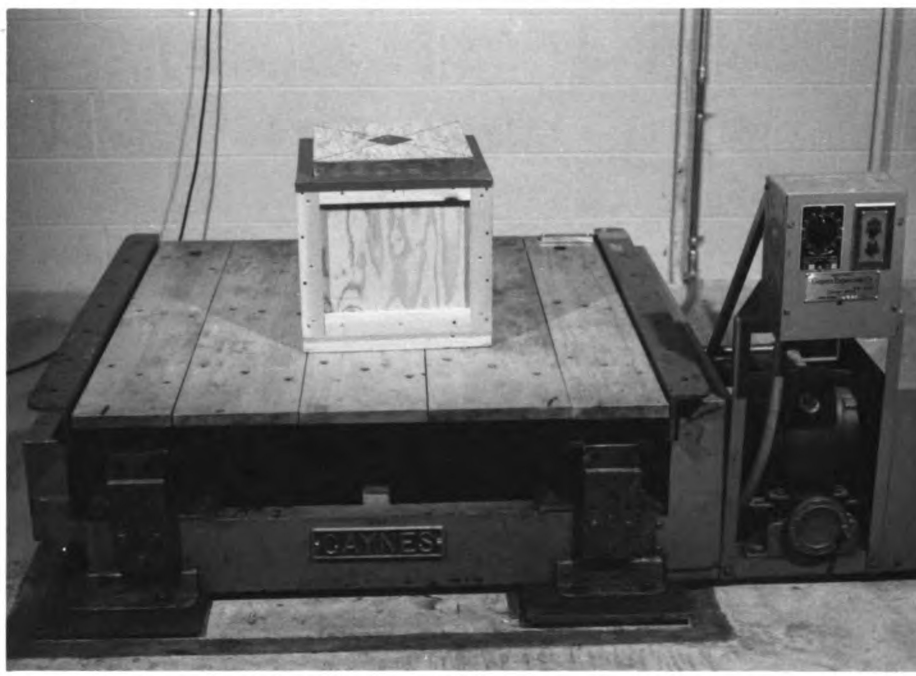

Figure 4

Shaker

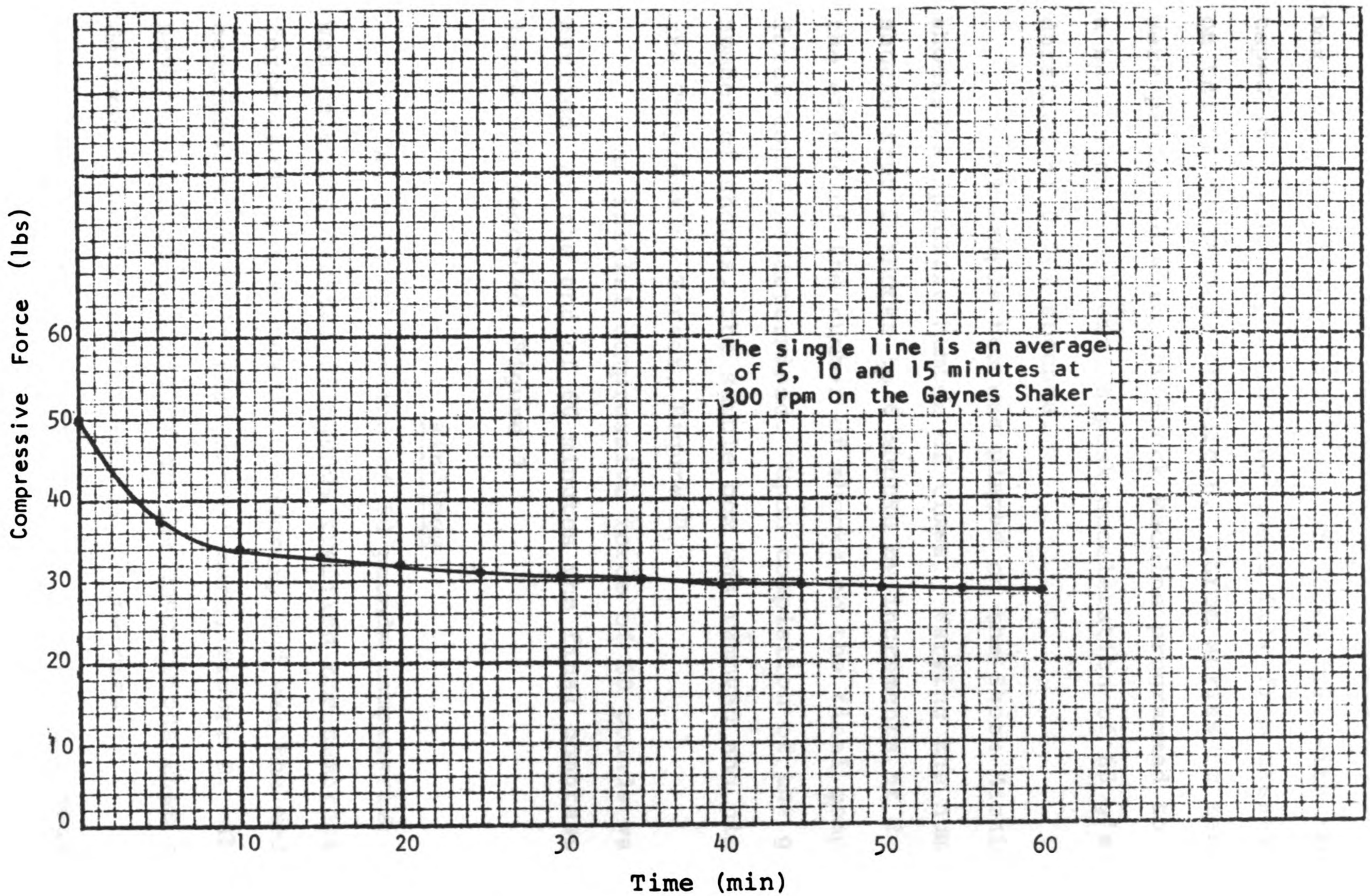

Figure 5

Compressive Force vs Time on Shaker

The simulation test consisted of placing the sample box, containing one cubic foot of loose fill with the cover taped in place to prevent the loose fill from disseminating, on the Shock Machine, Figure 6. Three series of tests were performed with the Shock Machine programmed to produce a half sine shock with a peak acceleration of 60 g's for a duration of 0.002 seconds.

The sample box was placed on the Shock Machine and shocked a specific number of times. Varying the number of shocks from 2 shocks to 6 shocks by increments of 2 shocks the effect of the number of shocks on the final compressive force could be determined. Upon completion of the given number of shocks, the sample box was removed and placed on the Compression Tester, Figure 2.

An initial compressive force of 50 pounds was applied, at the end of 60 minutes the final compressive force was recorded, Figure 7.

Findings

An initial loading of 50 pounds compressive force was selected because 50 pounds typified the compressive force used as a standard in industry and was the median compressive force in the control data, Figure 2. There are several limitations placed on the conclusions that can be derived from the interpretation of the data.

First, creep of the loose fill was only measured for 60 minutes. Initially, to determine a creep test

Figure 6

Shock Machine

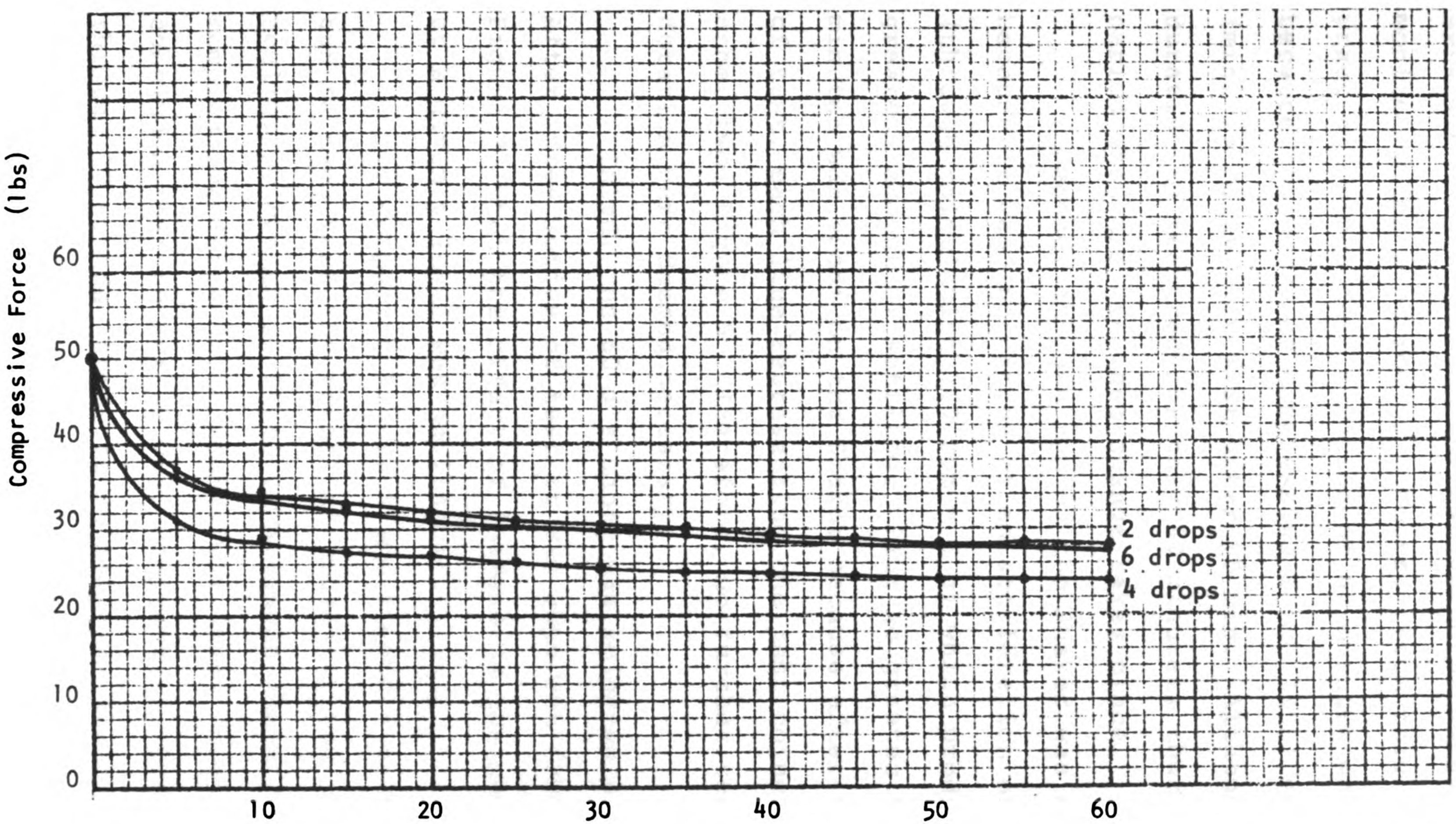

Figure 7

Number of Drops @ 60 g's vs Loading @ 50 Pounds Compressive Force duration an initial compressive force of 50 pounds was monitored for a period of 8 hours. From this data a practical creep test duration of 60 minutes was selected because the curve of compressive force (lbs) versus time (min) is relatively flat after 60 min. Although the duration is measured for only 60 minutes, that is the time period when the greatest change takes place.

Second, the 300 rpm on the Shaker was selected because it was indicative of an acceleration of 1 g (through calculation 260 rpm = 1 g) which produces the greatest amount of settling. Plus no greater time than 15 minutes was spent on the Shaker because after three series of test, each line representing one test coincided with the other two, Figure 5. Therefore, no further test of longer duration were deemed necessary.

Third, the 60 g's shock was selected arbitrarily. After three series of test it was apparent from the data, Figure 7, that the effect of increasing the number of drops at a given g level was negligible.

By comparing Figure 5 and Figure 7 to Figure 3 it can be seen that the effect of vibration and shock had a negligible change in final compressive force when an initial compressive force of 50 pounds was used. Therefore, it was concluded that no matter what compressive force, 100 pounds through 20 pounds, there is no need for conditioning because it has no effect on the final compressive force.

Through the use of a graph, final compressive force versus initial compressive force, Figure 8, coupled with the knowledge of the compressive force desired to package the product, the initial force required can be determined. For example if a 40 pound compressive force is required to package a product, verticle axis, an initial compressive force of approximately 76 pounds is required, horizontal axis, to allow for creep.

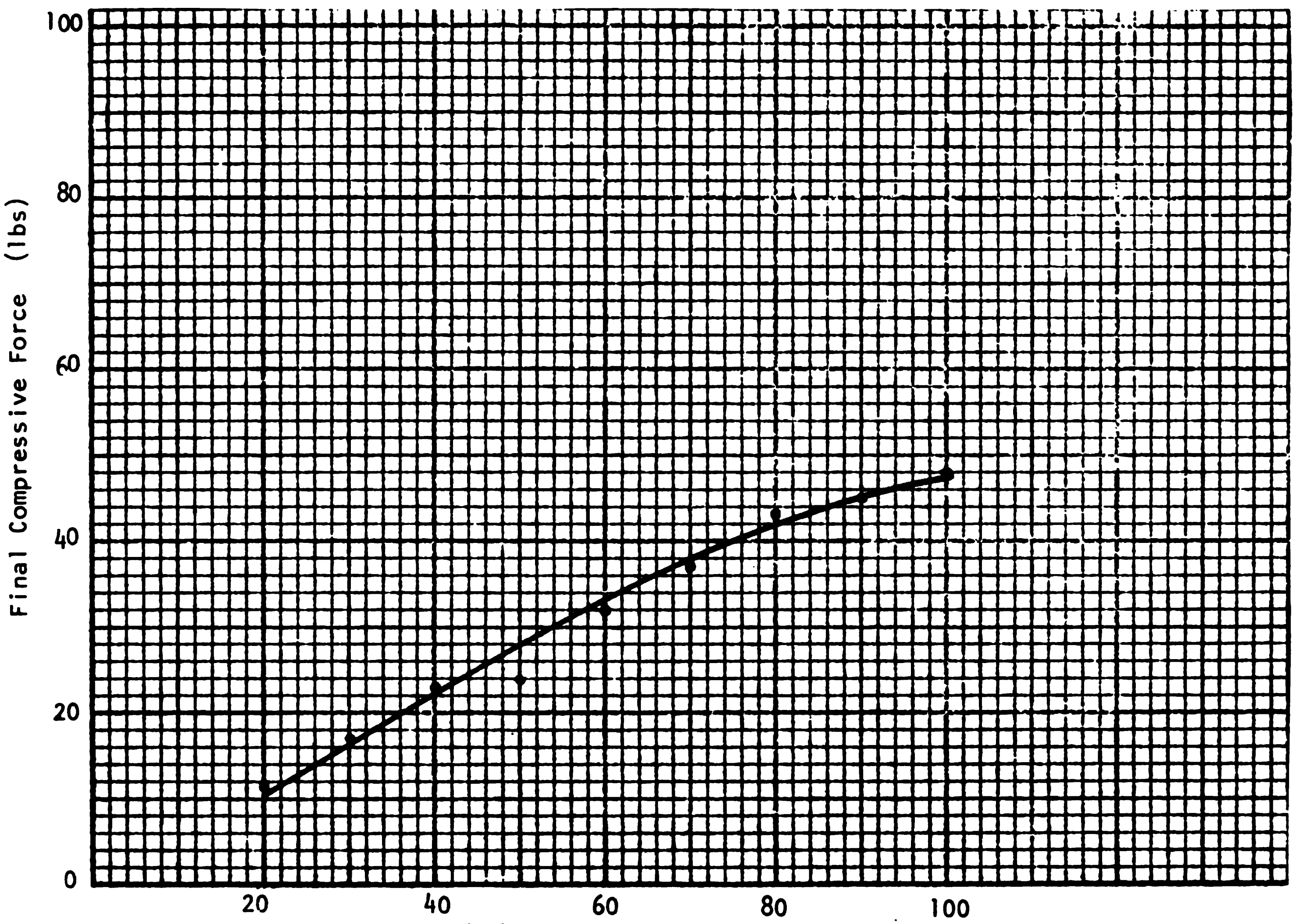

Figure 8

Initial vs Final Compressive Force

CHAPTER II

VIBRATION TESTING

With the results of Chapter I in mind, some sort of standard method of preloading loose fill material had to be selected. Overfill is the level of loose fill material that exceeds the height of the shipping container. If a shipping container has a height of 12" and an overfill of 1/2" is required than 12 1/2" of loose fill is placed in the shipping container.

Three levels of overfill (0", 1/2", and 1") were selected to determine their respective effects on 6 loadings of the test block (0.083 psi, 0.150 psi, 0.200 psi, 0.320 psi, 0.420 psi, and 0.590 psi). The weight of the test block was adjusted to produce a given loading on the cushion. The sample box, with the test block inside, was vibrated to determine the resonant frequency, ratio of input to output, and settling of test block.

Test Apparatus

Test Block

The cover of the test block was constructed from a single piece of 6" x 6" x 3/4" plywood. A strip 1/2" wide x 1/4" deep is cut from the outside edge to ensure a snug fit when coupled to the body of the test block, Figure 9. A 6" machined accelerometer mounting block is bolted diagonally on the underside of the cover. An Endevco 2622 accelerometer with a frequency range of 1 Hz to 10,000 Hz and an acceleration range of $\pm$ 5 g's is bolted to the accelerometer mounting block. Because the accelerometer is quite sensitive a 5" x 5" x 2" piece of Dow Ethafoam 220 was used to protect it, Figure 10.

The bottom of the test block is constructed identical to the top. The 3/8" threated rods are bolted to the bottom along the diagonal, 1" from the inside corner. Preweighed lead weights (5" x 5", thickness depends on weight) with holes conforming to the threaded rods are bolted to the bottom to minimize their movement during the vibration test, Figure 11. Depending upon the loading the amount of lead weights will change. Figure 12 shows the test block prepared for placement within the sample box.

Sample Box

The cover to the sample box is constructed with a frame of wood and top and bottom of plywood. The cover has a height of 5", since the sample box has an inside

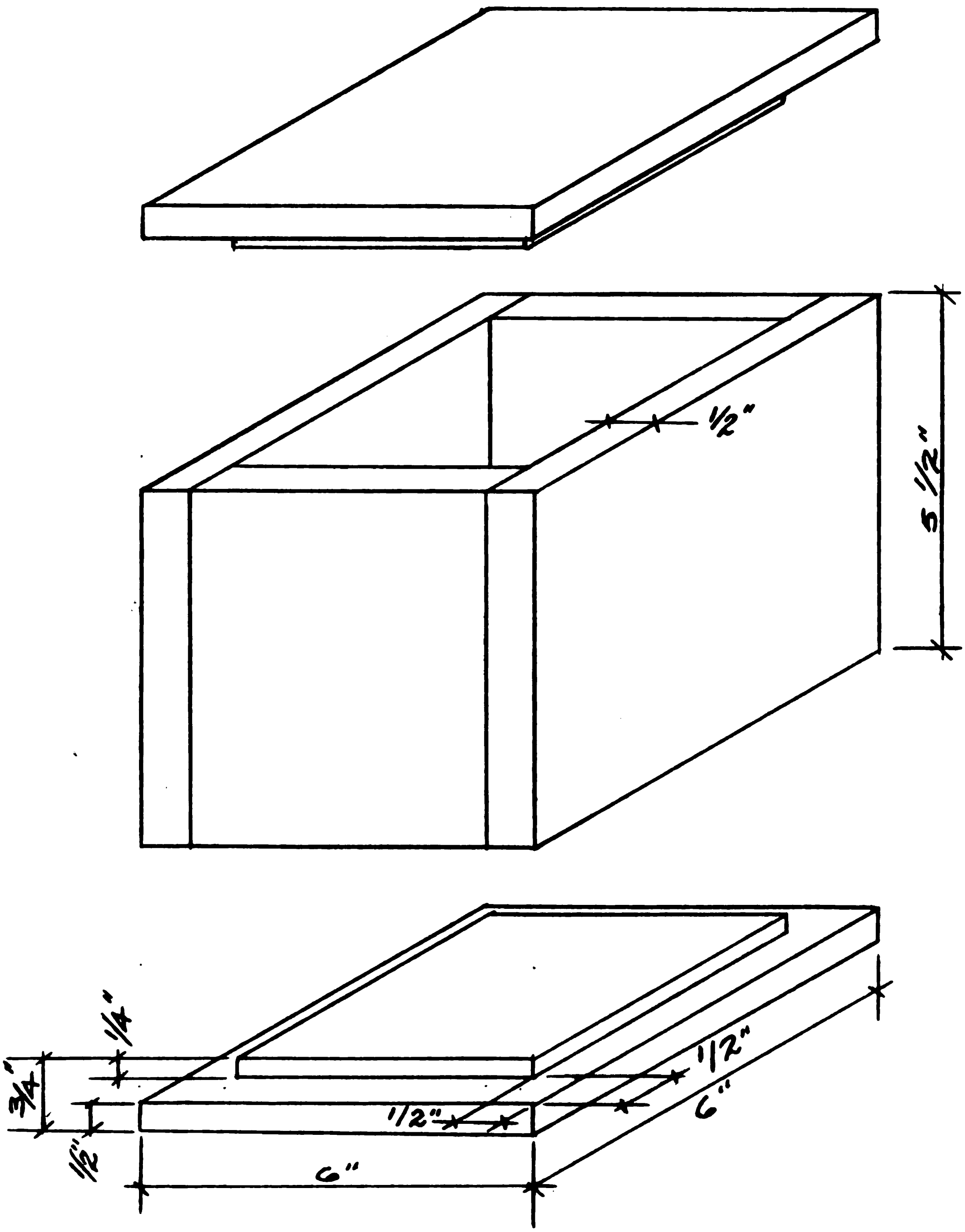

Figure 9

Test Block

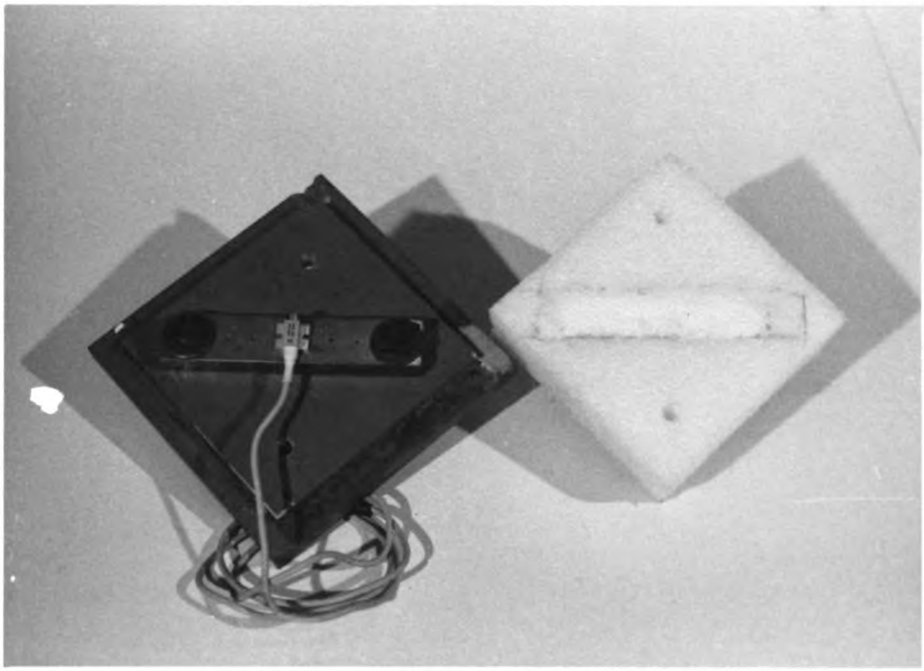

Figure 10

Mounted Accelerometer

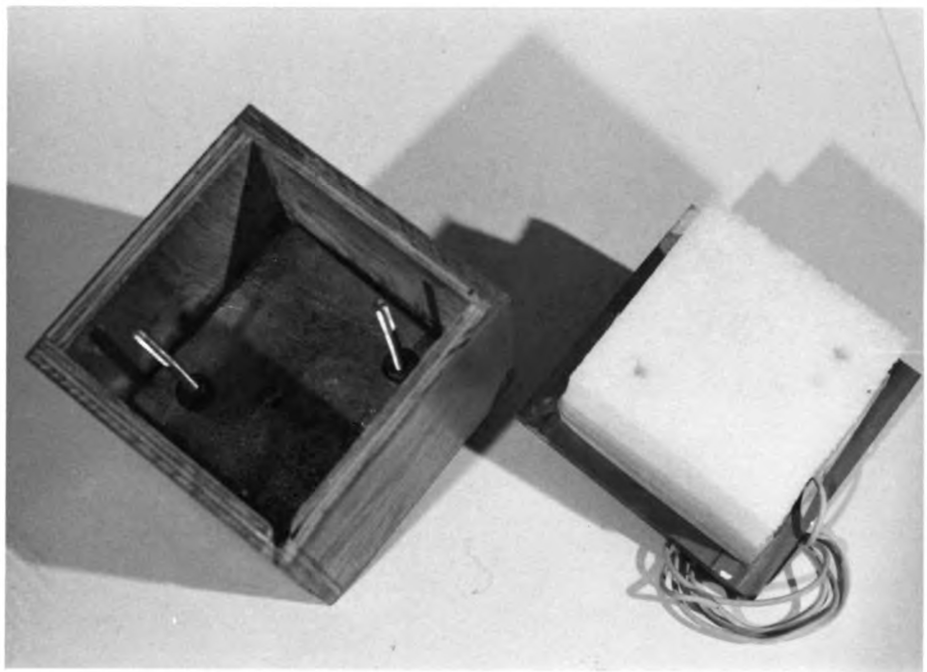

Figure 11

Test Block With Lead Weights

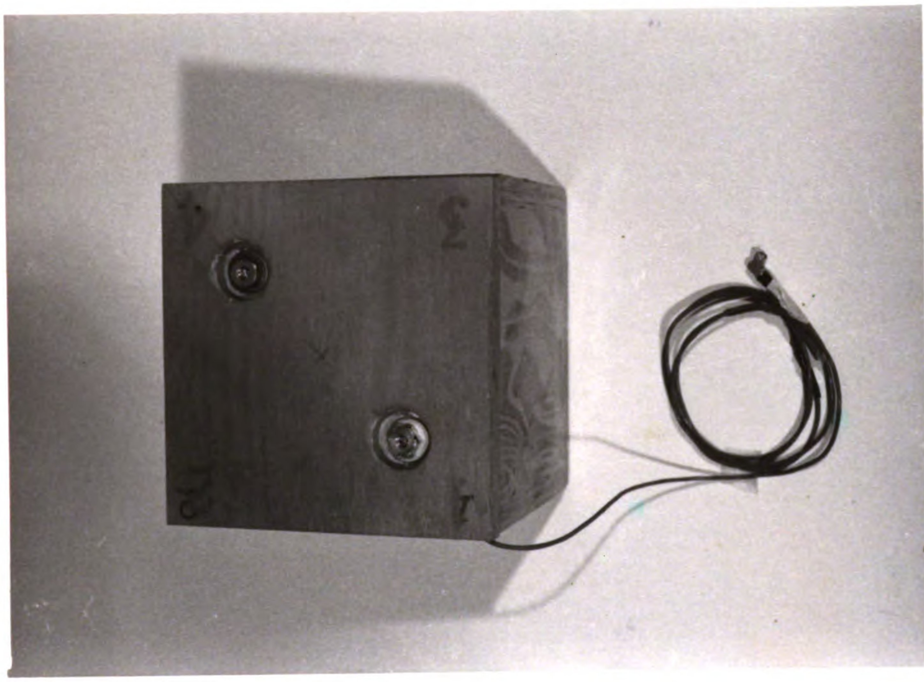

Figure 12

Prepared Test Block

height of 15", a horizontal line 3" above the bottom is drawn around the parameter to facilitate placement of the cover of the sample box, ensuring a constant one cubic foot volume. Two pieces of steel angle are secured to the top so that it can be bolted to the sample box, Figure 13.

The sample box is constructed from 3/4" plywood, with inside dimensions of 12" x 12" x 15". To facilitate the measurement of the quantity of loose fill to obtain a given level of overfill, horizontal lines are drawn around the inside parameter at heights of 12" (0" overfill), 12 1/2" (1/2" overfill), and 13" (1" overfill).

Fixtures

A single piece of 24" steel angle positioned between the steel angle of the cover was used to securely hold the sample box in position during each test, Figure 14.

Test Block Orientation Procedure

It is imperative that the test block be positioned exactly in the center of the sample box. Using the following orientation procedure, placement can be within ± 1/16" of center.

Step 1. An initial layer of approximately 3" is placed in the bottom of sample box. The weight of the test block must be taken into consideration. Regardless of the weight (the greater the weight the greater the compression of loose fill, thus a higher initial layer) the top of the test block must be 6" from the top edge of the

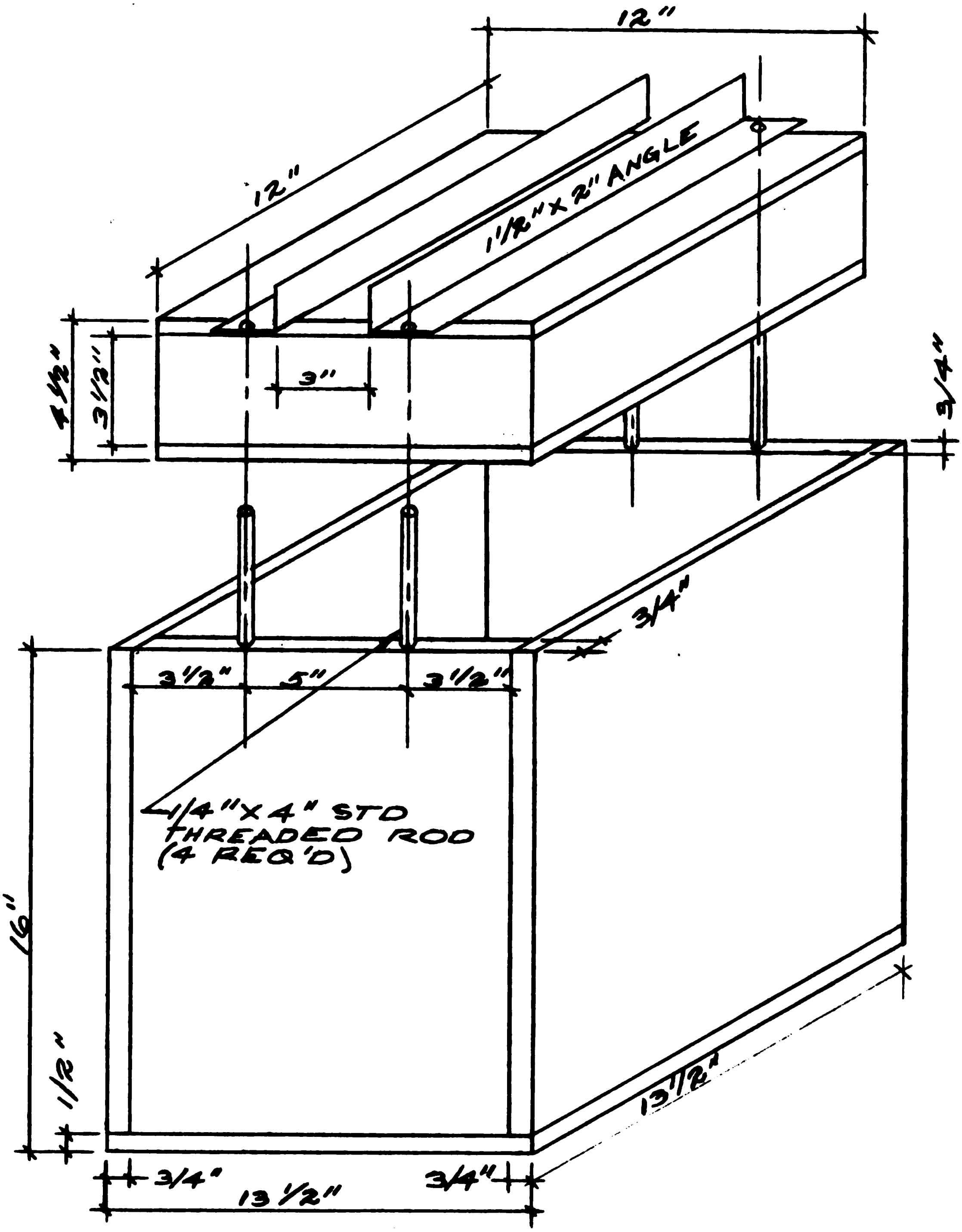

Figure 13

Sample Box

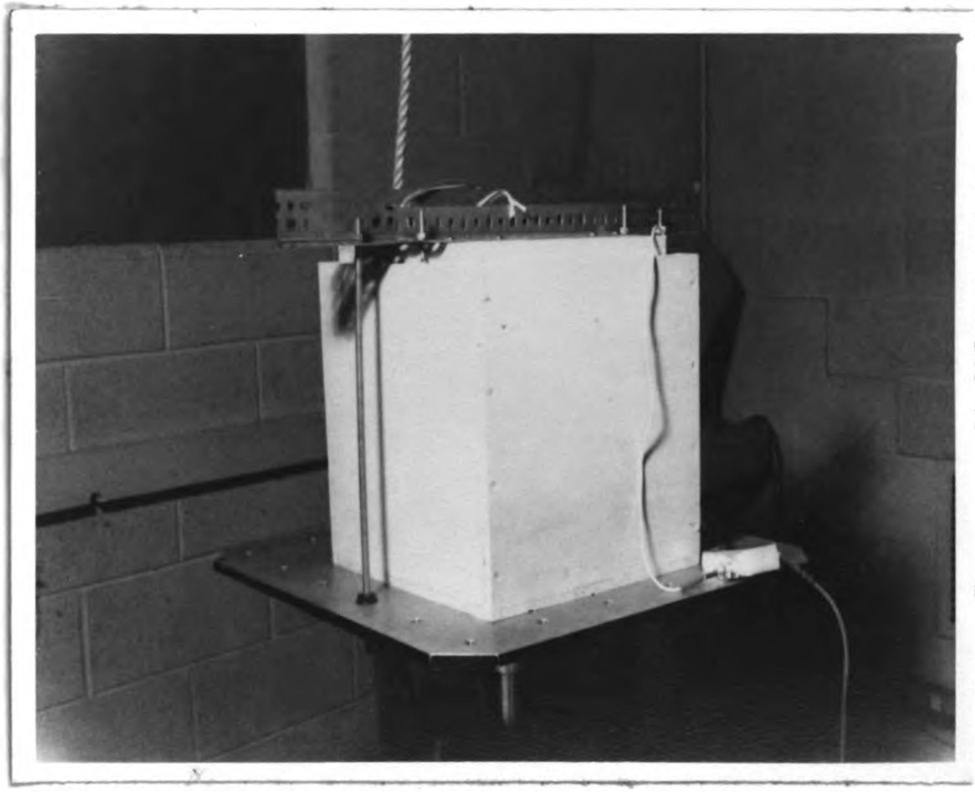

Figure 14

Sample Box Positioned for Vibration Test sample box. Locating a level board across the edges of the sample box and measuring the depth from the board's edge to each of the test block's corners the test block is vertically centered, Figure 15.

Step 2. Once the test block is vertically centered it can be horizontally centered. Placing a 12" ruler along an edge of the test block it is centered by aligning the perpendicular edges with the 3" and 9" divisions of the ruler. It is only necessary to perform this procedure on one pair of opposite edges. Now the test block is centered, 3" on all sides, Figure 16.

Step 3. With the test block centered in the sample box the predetermined level of overfill can be added. The loose fill is poured into the sample box until its level coincides with the appropriate horizontal line scored on the inside of the sample box, Figure 17.

Step 4. Regardless of the amount of overfill the volume of the sample box will be one cubic foot after the cover is bolted in place, Figure 18. One corner of the cover is beveled to prevent the accelerometer cable from being pinched.

Test Instrumentation and Test Procedure

Test Instrumentation

The sample box is rigidly mounted to a Electro-Hydraulic Vibrator. This machine had a frequency range of

Figure 15

Vertically Centering the Test Block

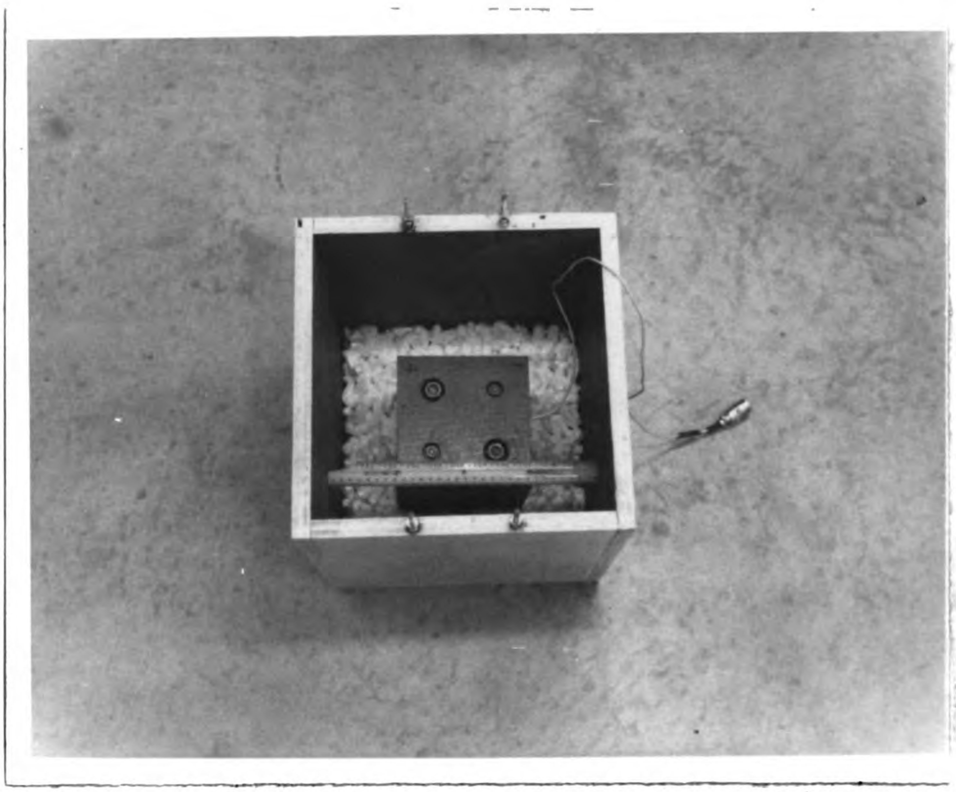

Figure 16

Horizontally Centering the Test Block

Figure 17

Adjusting the Level of Overfill

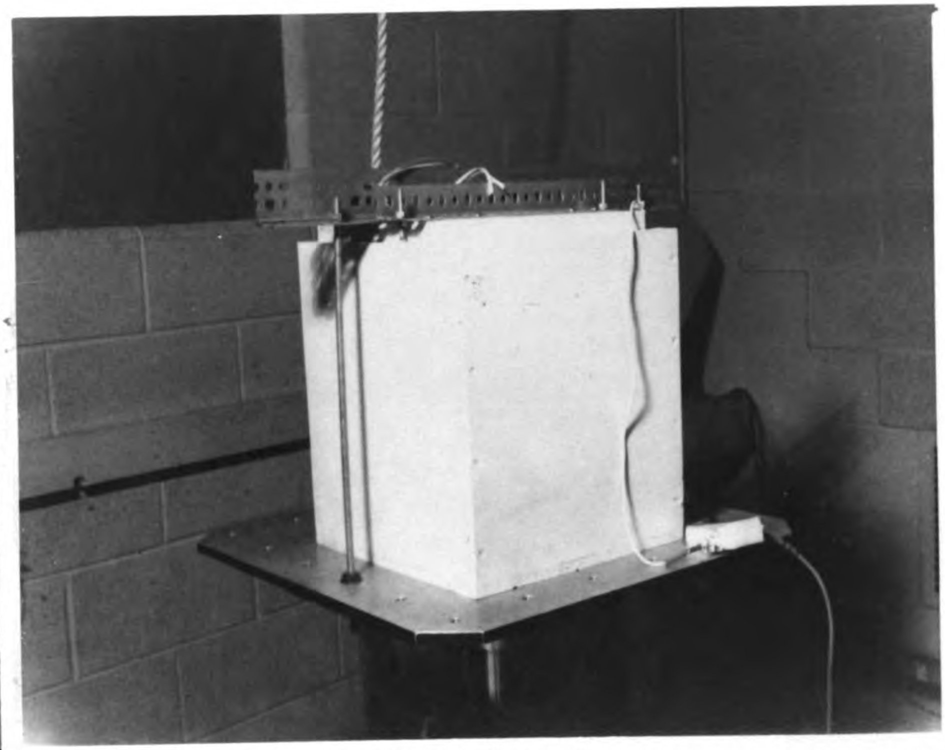

Figure 18

Sample Box Ready for Vibration Testing

1 H_z to 200 H_z and a variable amplitude. A sinusoidal motion was used as an input.

Piezoresistive accelerometers (Endevco Model 2265-20) were used to monitor the input to the loose fill and the response of the test block. The outputs from the accelerometers were fed into an analog computer for analysis. In the computer the signals were full wave rectified and filtered to get their D. C. equivalents. The D. C. voltages were then fed through a divider circuit to give a ratio of the response acceleration to the input acceleration. This output was a D. C. voltage and was read on a digital voltmeter as a ratio of response to input (see Technical Report No. 21, Appendix).[1] The test check set-up is shown in Figure 19.

Test Procedure

There were two variables, cushion loading and overfill. Six loadings (0.083 psi, 0.15 psi, 0.20 psi, 0.42 psi, and 0.59 psi) were coupled with three levels of overfill (0", 1/2", and 1") throughout the testing.

One test series began with a loading of 0.083 psi and an overfill of 0". Maintaining an input to the vibration table of 1/2 g O-P the frequency was varied from

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[1]Stephen R. Pierce and John Wambaugh, Vibration Transmissibility of Resilient Package Cushioning Materials, Technical Report No. 21, Michigan State University, School of Packaging, 1973.

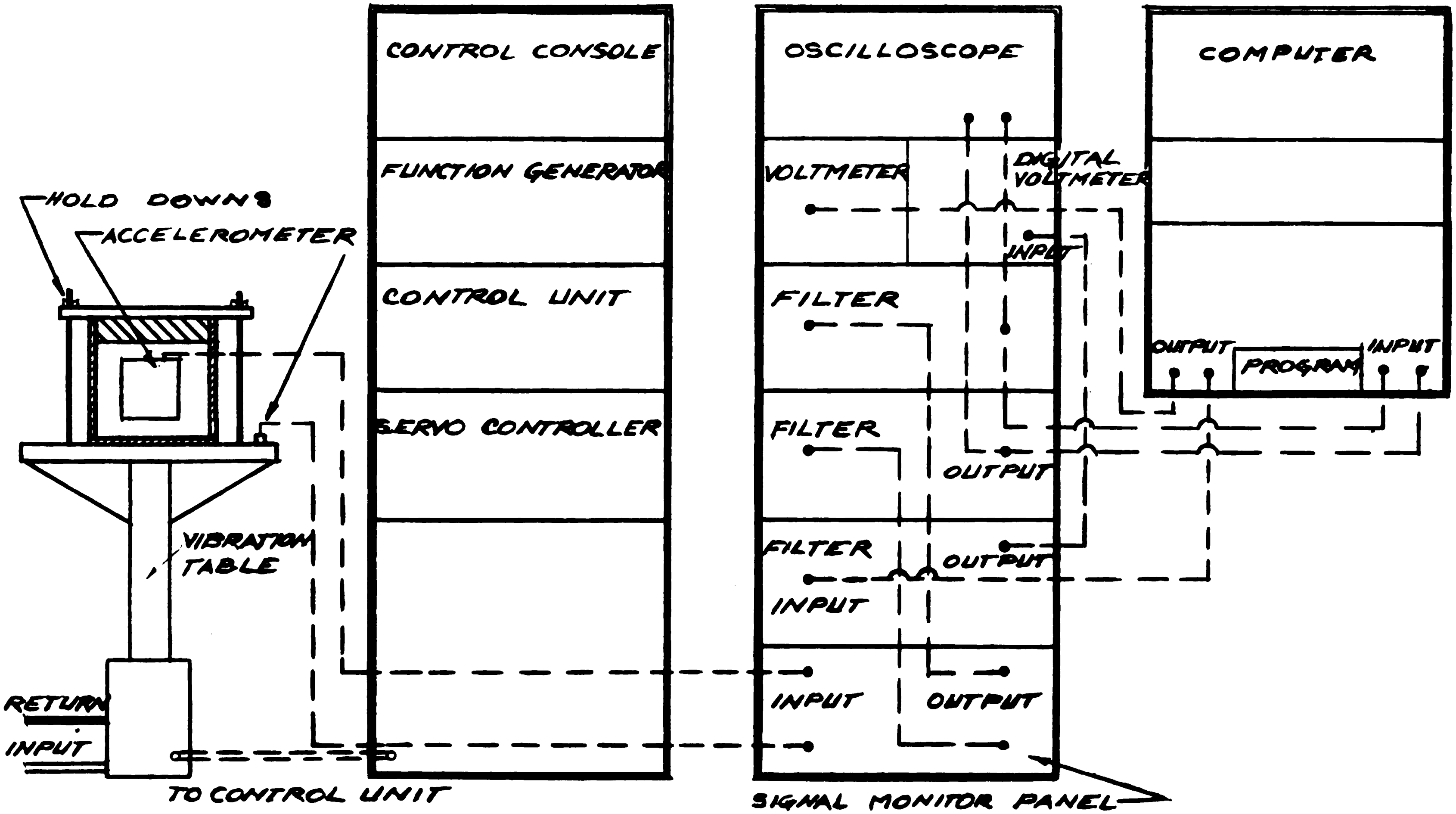


Figure 19

Vibration Test Instrumentation Schematic

1 H_z to 100 H_z. Simultaneously the digital voltmeter was monitored, the resonant point was indicated by the highest value. Although resonance will be reached before the complete 1 H_z to 100 H_z frequency sweep is completed, the frequency sweep is continued. Upon reaching 100 H_z a second frequency sweep from 100 H_z to the frequency indicative of the peak resonance. When the peak resonance was reached the values were recorded as: initial frequency and initial A_O/A_I (ratio of output acceleration to input acceleration). The sample box is vibrated at the initial resonant frquency for 15 minutes. During this 15 minute period the frequency may be changed slightly to maintain the initial A_O/A_I at its highest value. The sample box is vibrated at its resonance point for 15 minutes to determine the effect of time has on the values of initial frequency and initial A_O/A_I. As a result of resonant vibration the test block will settle.

After 15 minutes a second frequency search was performed. The purpose of the second frequency search was to determine the effect of time on the resonant frequency and the A_O/A_I values. The frequency search was performed by varing the initial frequency by $\pm$ 25 H_z. Thus if vibrating the sample box at its resonance point had any effect, it could be detected through the change in values of the initial frequency and initial A_O/A_I. The values arrived at through the second frequency search are final frequency and final A_O/A_I.

Three series of tests were performed to assure consistent results. After the three series of tests were completed the level of overfill was changed from 0" to 1/2" to 1", and three series of test were performed at each overfill level.

Upon completion of a test within a series the cover was removed from the sample box and the degree of settling was measured following the same procedure utilized when centering the test block. The data arrived at through the previous test was averaged and compiled in Table 1.

Findings

From the data contained in Table 1, Figure 20 and Figure 21 were drawn. All the information contained in Table 1, Figure 20, and Figure 21 was averaged (three tests were performed for each loading of the cushion and level of overfill).

Keeping a given level of overfill constant and increasing the loading of the cushion, the resonant frequency and A_O/A_I decreases, this is true for all three overfill levels, Figure 20. Although the higher the level of overfill the higher the respective initial frequency (resonant frequency) and initial A_O/A_I values.

Keeping a given level of overfill constant and increasing the loading of the cushion caused an increase in settling, Figure 21. The amount of settling decreased as the level of overfill increased. One point of interest

Table 1

Composite Vibration Data

Loading of the Cushion (PSI)	Level of Overfill (IN)	Initial Frequency (H_z)	Initial A_O/A_Z	Final Frequency (H_z)	Final A_O/A_Z	Settling of Test Box (IN)
0.083	0	53.4	624	51.5	663	0.063
0.15	0	12.8	357	14.6	399	0.594
0.20	0	11.4	356	11.4	312	0.875
0.32	0	10.2	366	14.0	368	1.792
0.42	0	10.0	363	13.2	372	2.167
0.59	0	10.3	366	17.6	344	2.583
0.083	1/2	68.5	880	67.6	890	0.208
0.15	1/2	51.5	878	50.0	909	0.240
0.20	1/2	44.3	586	43.8	580	0.325
0.32	1/2	28.3	575	18.0	481	0.732
0.42	1/2	22.1	572	16.2	549	0.417
0.59	1/2	11.0	422	12.1	390	2.365
0.083	1	81.8	947	80.7	944	0.479
0.15	1	59.1	1013	58.1	988	0.406
0.20	1	49.3	637	49.0	641	0.425
0.32	1	41.2	707	39.8	710	0.500
0.42	1	34.6	675	32.4	685	0.531
0.59	1	27.3	575	23.1	597	0.500

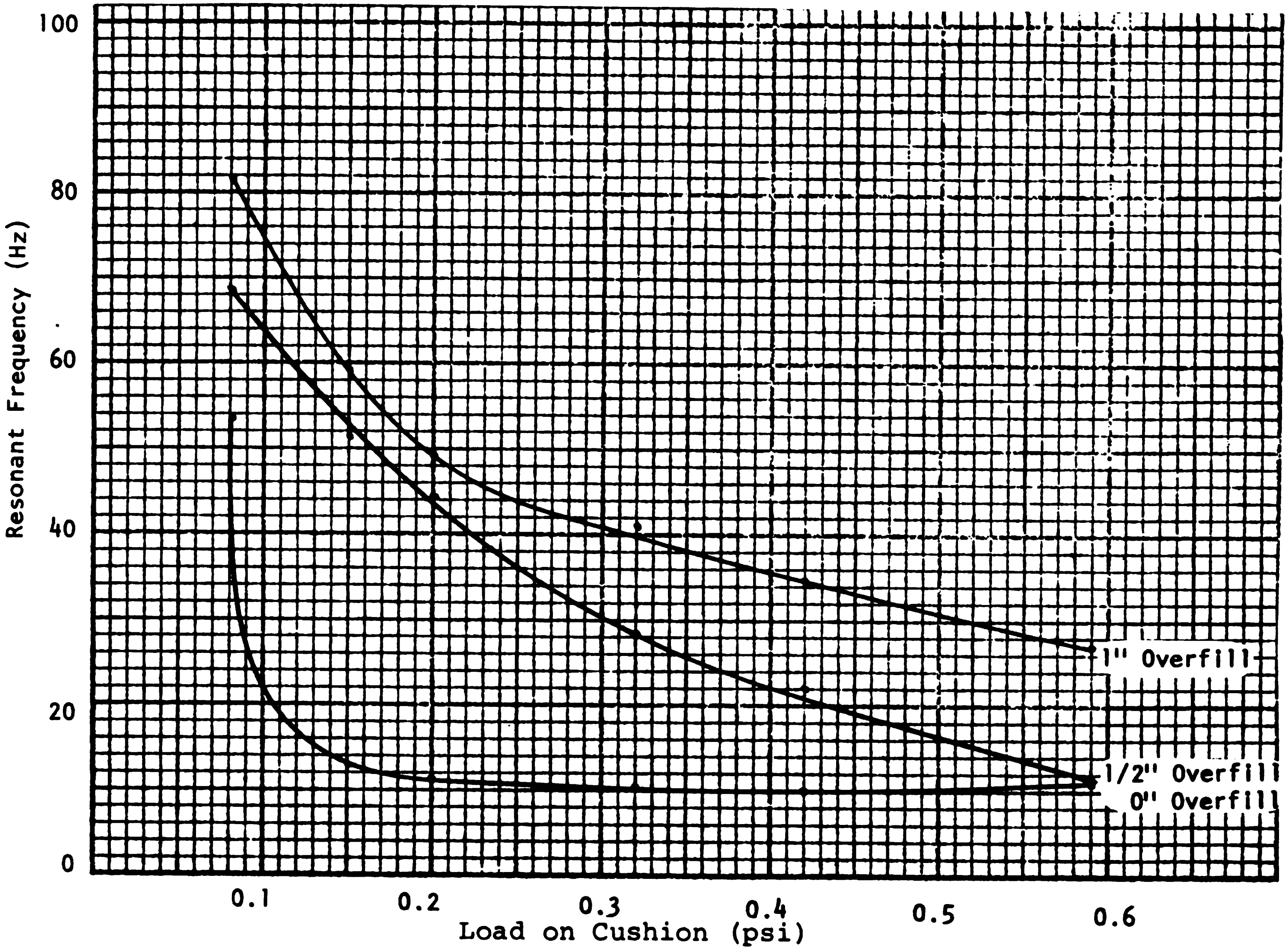


Figure 20

Effect of Overfill on Resonant Frequency, Composite

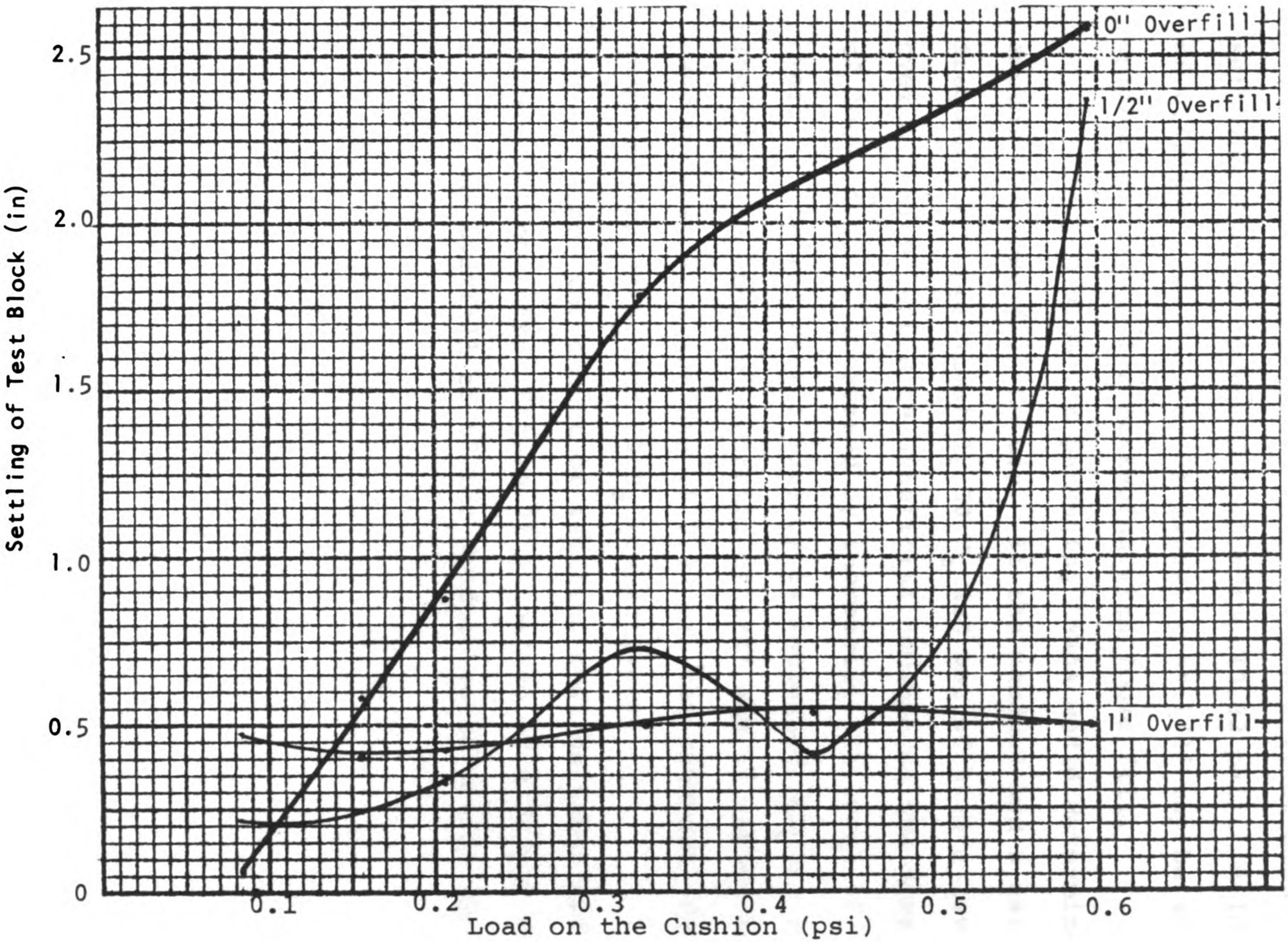


Figure 21

Effect of Overfill on Settling of the Test Block During Resonance is a loading of 0.42 psi with a level of overfill of 1/2", because it is the only loading that has a lower amount of settling than its preceeding loading (0.32 psi). A loading of 0.42 psi with a level of overfill of 1/2" may be an optimum situation for packaging with loose fill.

An individual's packaging needs would determine the amount of loose fill to use. If the product had a natural frequency of approximately 50 H_z and psi of 0.20 a level of overfill of 0" would be beneficial because as the density of loose fill is increased by increasing the level of overfill its resonant frequency is increased, Figure 20. Therefore, a level of overfill of 1/2" and 1" cannot be used because at a loading of 0.20 psi the resonant frequencies are 44 H_z and 59 H_z respectively.

Also, the amount of settling must be taken into consideration. From Figure 21 a loading of 0.20 psi with a level of overfill of 0" the product would settle approximately 0.875".

CHAPTER III

SHOCK PROCEDURE DETERMINATION

Chapter II discusses the alternative drop height sequences and the procedure used to determine which sequence is appropriate for shock transmissibility testing.

The test block and sample box were redesigned because of the high acceleration forces placed on them.

Test Apparatus

Test Block

The components which made up the test block are displayed in Figure 22. The accelerometer mounted in the test block was an Endevco 818 which has a shock response from 0 g's to 200 g's. The accelerometer was mounted on the bottom of the test block so that acceleration forces would not be as likely to dislodge it, Figure 23. An 1/2" plywood cutout and a 3/4" plywood false bottom, Figure 24, Figure 25, and Figure 26, are used to protect the accelerometer from damage. The false bottom is beveled on one corner to prevent crimping of the accelerometer cable.

Figure 22

Test Block Component Display

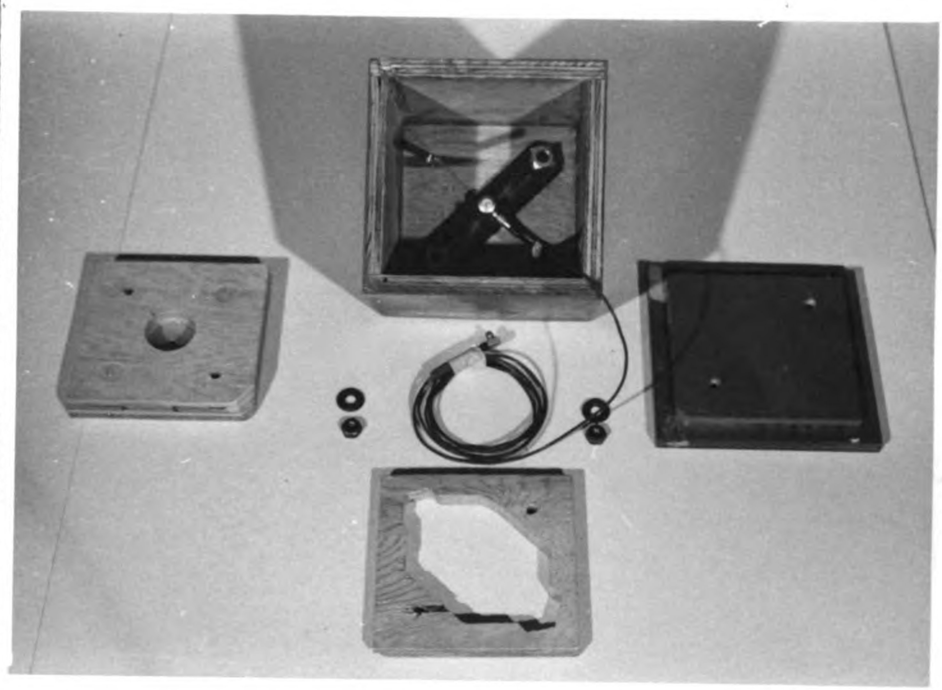


Figure 23

Test Block With Accelerometer Mounted

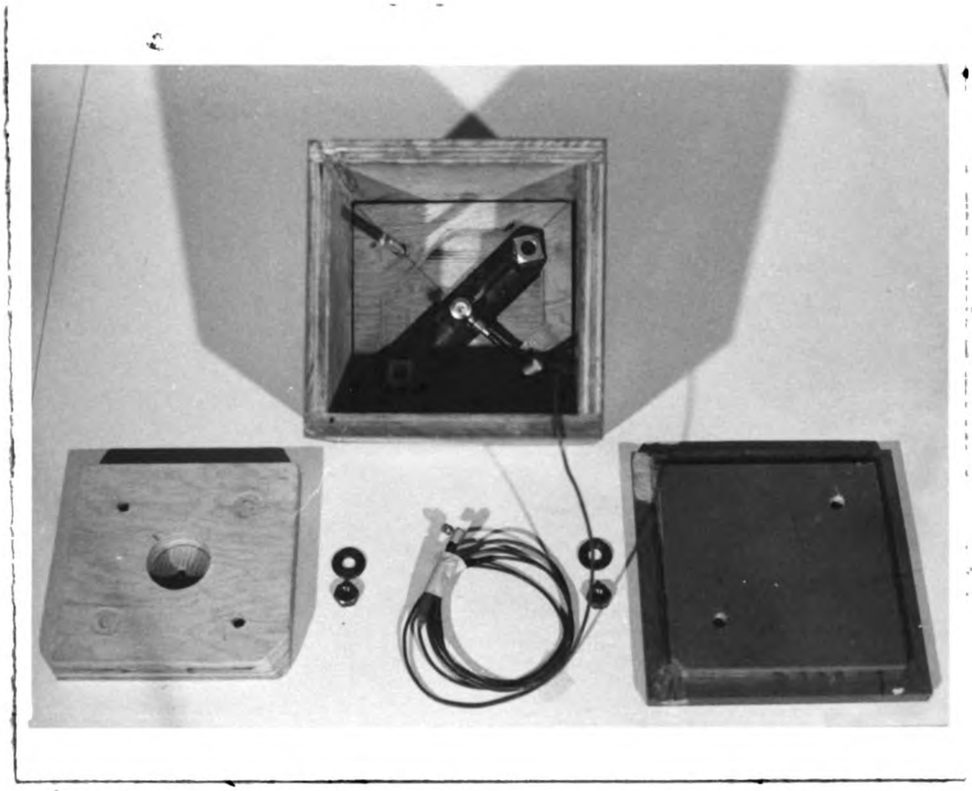


Figure 24

Test Block With Coutout in Place

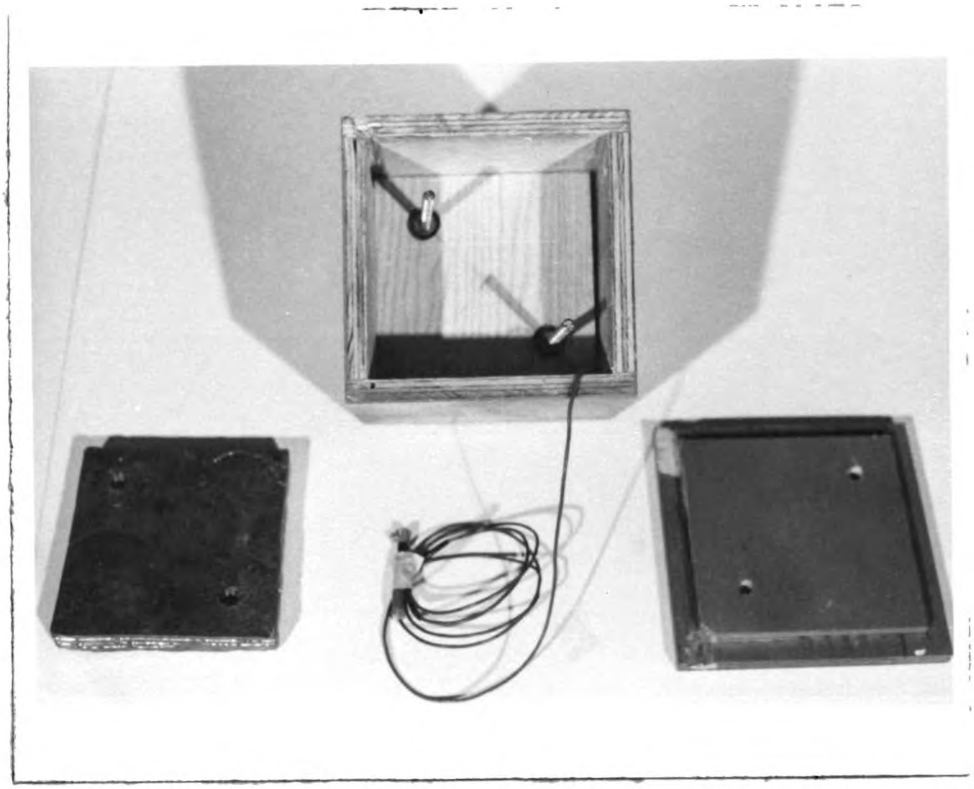


Figure 25

Test Block With Cutout and False Bottom in Place

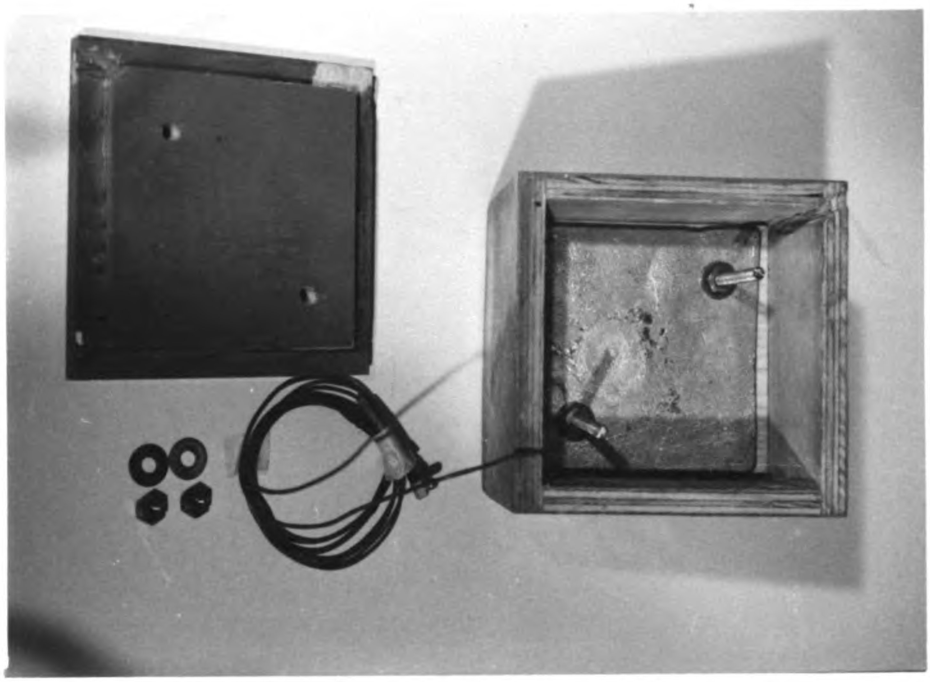
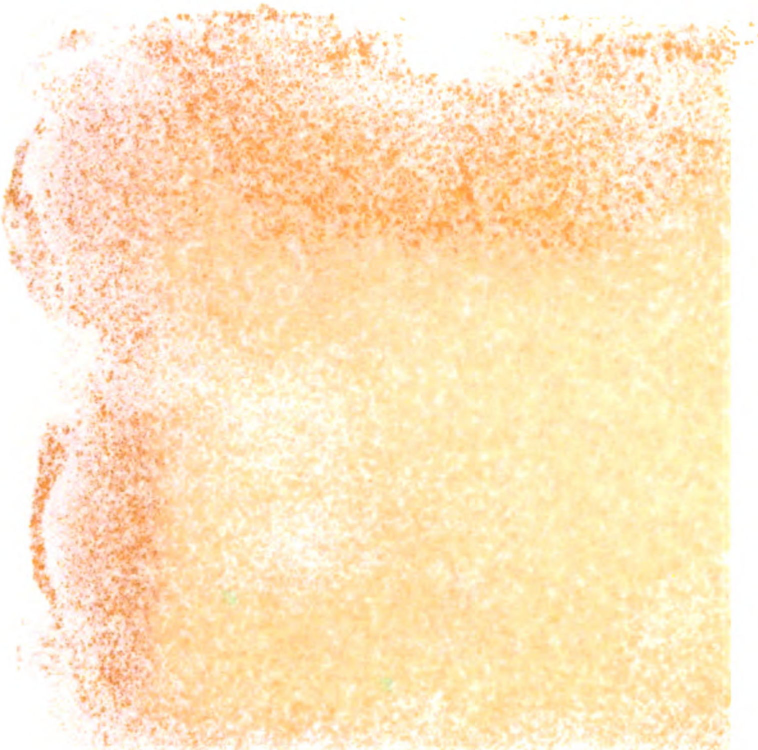


Figure 26

Test Block With Lead Weights in Place



Lead weights to provide the test block with its prescribed loadings were bolted to the false bottom, Figure 26, to minimize as much as possible any extraneous shocks or movement within the test block. With the lead weights securely in place the cover is bolted on and the accelerometer cable routed through the beveled corner.

Sample Box

Wood was placed along the upper edge of the sample box and along the top of the cover, Figure 27.

Fixtures

The mounting fixtures consisted of two 20" 2" x 4" 's, each with a 12" x 1 1/2" section removed and four 22" x 3/8" threaded rod, Figure 28. The 2" x 4" 's were positioned over the cover of the sample so that the ends rested on the edge of the sample block. Wing nuts and washers were used to secure the sample box to the table for shock testing, Figure 29.

Test Block Orientation Procedure

See Chapter II, Test Block Orientation Procedures, page 23.

Test Instrumentation and Test Procedure

Test Instrumentation

The sample box is rigidly mounted to a shock machine. The shock machine was programmed to produce

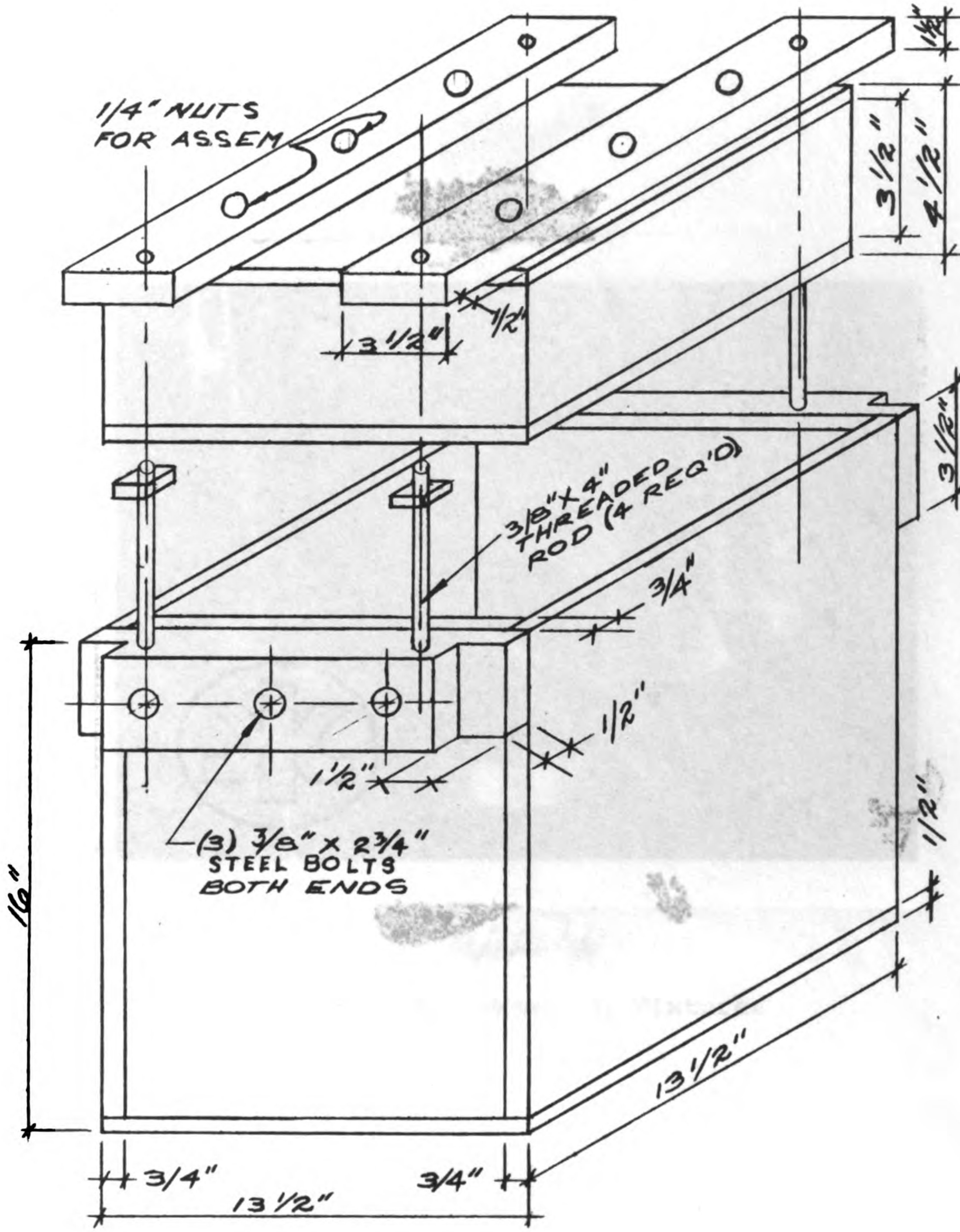


Figure 27

Sample Box and Cover

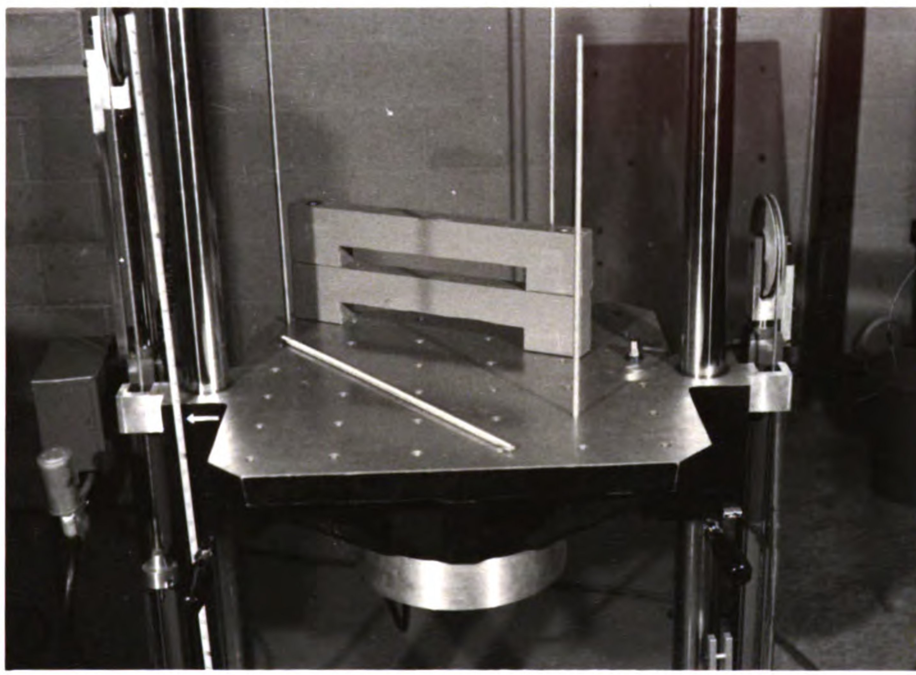


Figure 28

Sample Box Mounting Fixtures

a half sine (high acceleration) constant shock duration (0.002 sec) (see Appendix III, Technical Report No. 19).[2]

A piezoresistive accelerometer (Endevco Model 2242) was used to monitor the input to the loose fill. It was mounted on the surface of the shock table, Figure 29.

A piezoelectric accelerometer (Kistler Model 818) was used to monitor the input to the test block. It was mounted inside the test block, Figure 23.

In order to compare the acceleration input to the shock table and the acceleration input to the test block the accelerometers had to be calibrated. The test block with the Kistler Model 818 mounted (without any weights), was fastened to the shock table. The shock table with the Endevco Model 2242 mounted was dropped from an arbitrary drop height. Since the output of both accelerometers was identical the accelerometers were considered calibrated, Figure 30.

A Tektronix Dual Trace oscilloscope was used to visually monitor the input to the loose fill and the input to the test block. The respective physical values were read directly from the oscilloscope and recorded, Figure 31.

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[2]Robert Max Fiedler and Stephen R. Pierce, The Development of a Testing Procedure for Evaluating the Dynamic Cushioning Characteristics of Loose Fill Cushioning Materials, Technical Report No. 19, Michigan State University, School of Packaging, 1971.

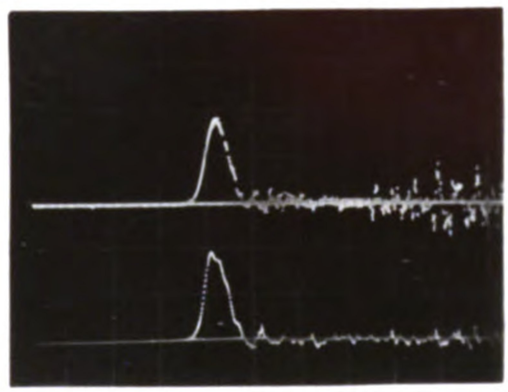

Figure 30

Accelerometer Calibration

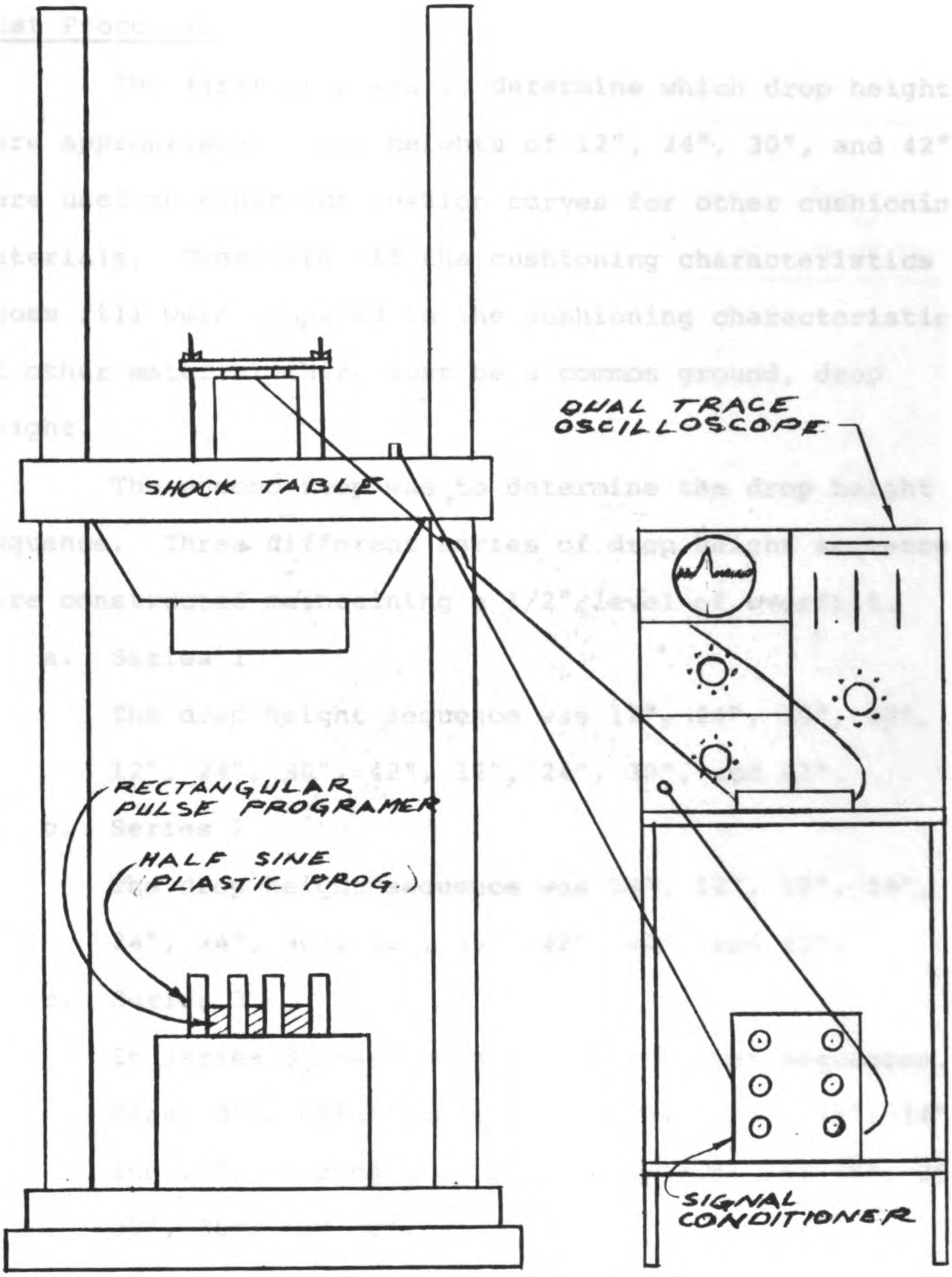

Figure 31

Shock Test Instrumentation Schematic

Test Procedure

The first step was to determine which drop heights were appropriate. Drop heights of 12", 24", 30", and 42" were used to construct cushion curves for other cushioning materials. Therefore, if the cushioning characteristics of loose fill were compared to the cushioning characteristics of other material there must be a common ground, drop height.

The second step was to determine the drop height sequence. Three different series of drop height sequence were constructed maintaining a 1/2" level of overfill.

a. Series 1

The drop height sequence was 12", 24", 30", 42", 12", 24", 30", 42", 12", 24", 30", and 42".

b. Series 2

The drop height sequence was 12", 12", 12", 24", 24", 24", 30", 30", 30", 42", 42", and 42".

c. Series 3

In Series 3 there were two drop height sequences. First drop height sequence was 24", 24", 24", 24", and 24". Second drop height sequence was 30", 30", 30", 30", and 30".

After each drop height sequence the loose fill was changed and the test block oriented. Three drop height sequences were performed per series. The results were averaged and recorded in Table 2.

Table 2

Sequence Determination Data

Test Number	Loading of the Cushion (PSI)	Level of Overfill	Drop Height	Input to Shock Tables (g's)	Input to Test Box (g's)	Duration of Shock (ms)
Series 1						
1	0.328	1/2	12	230	19	22
1	0.328	1/2	24	340	30	22
1	0.328	1/2	30	360	35	24
1	0.328	1/2	42	430	39	24
1	0.328	1/2	12	200	19	24
1	0.328	1/2	24	320	29	24
1	0.328	1/2	30	360	34	24
1	0.328	1/2	42	440	44	24
1	0.328	1/2	12	220	17	24
1	0.328	1/2	24	320	28	24
1	0.328	1/2	30	360	33	24
1	0.328	1/2	42	440	43	24
Series 2						
1	0.328	1/2	12	220	15	22
1	0.328	1/2	12	240	17	23
1	0.328	1/2	12	240	18	22
1	0.328	1/2	24	320	25	22
1	0.328	1/2	24	320	25	21
1	0.328	1/2	24	320	25	22
1	0.328	1/2	30	360	30	21
1	0.328	1/2	30	360	30	21
1	0.328	1/2	30	360	29	21
1	0.328	1/2	42	431	41	21
1	0.328	1/2	42	420	40	21
1	0.328	1/2	42	416	40	21
Series 3						
1	0.328	1/2	24	300	23	22
1	0.328	1/2	24	310	24	23
1	0.328	1/2	24	320	24	23
1	0.328	1/2	24	320	24	23
1	0.328	1/2	24	315	25	22
2	0.328	1/2	30	360	23	23
2	0.328	1/2	30	360	28	23
2	0.328	1/2	30	360	29	22
2	0.328	1/2	30	360	30	22
2	0.328	1/2	30	360	29	22

Findings

To determine the effect on the input to the test block, thus which series to use. Results from a drop height of 24" were analyzed for each series. For Series 1, 24" drop height the average input to the test block was 29 g's; Series 2, 24" drop height the average input to the test block was 25 g's; Series 3, 24" drop height the average input to the test block was 24 g's. Because there was no significant amount of difference in the input to the test block it was concluded that it was irrelevant which drop height sequence was used. Since it is extremely unlikely that a package would experience repeated drops from a specific height, Series 1 was used for testing as described in Chapter IV.

CHAPTER IV

SHOCK TESTING

The purpose of shock testing was to observe the effect of drop height, level of overfill and loading on the shock transmissibility of loose fill.

Test Apparatus

Test Block

Same as Chapter III, Test Apparatus, page 39.

Sample Box

Same as Chapter III, Test Apparatus, page 45.

Fixtures

Same as Chapter III, Test Apparatus, page 45.

Test Block Orientation Procedure

Same as Chapter II, Test Block Orientation Procedure, page 23.

Test Instrumentation and Test Procedure

Test Instrumentation

Same as Chapter II, Test Instrumentation and Test Procedure, Test Instrumentation, page 26.

Test Procedure

a. Calibrate accelerometer, see Chapter III, page 49, paragraph three.

b. The cushion was loaded to a specific amount by the addition of lead weights to the test block. Six loadings (0.087 psi, 0.156 psi, 0.206 psi, 0.328 psi, 0.428 psi, and 0.595 psi) were used.

c. Initially the level of overfill was 0". Upon completion of a test series the level of loose fill was changed. The level of loose fill was increased from 0" to 1/2", from 1/2" to 1". After the test series utilizing a level of overfill of 1", the loading was changed.

d. Employing the drop height sequence of 12", 24", 30", 42", 12", 24", 30", 42", 12", 24", 30", and 42" the test series were ran.

e. A test series consisted of a loading, a level of overfill, and a drop height sequence. For example, a loading of 0.087 psi, a level of overfill of 0", and the predetermined drop height sequence were used.

The test block with a loading of 0.087 psi is oriented within the sample box. Three inches of loose fill is placed over the top of the test block giving a level of overfill of 0". The cover to the sample box is bolted into place giving a volume of one cubit foot. The sample box is fastened to the shock table. Utilizing the predetermined drop height sequence, the drop height had to be adjusted accordingly after each drop. Initially the shock table height is set at 12" and dropped once, readjusted to 24" and dropped once, readjusted to 30" and dropped once, readjusted to 42" and dropped once. Then the table is readjusted to 12" and the sequence performed two more times. Upon completion of the third 42" drop the sample box is removed from the shock table; the cover of the sample box was removed and enough of the top layer of loose fill to expose the test block. Thus the amount of settling due to shock can be measured. The procedure used to orient the test block prior to testing was used to measure its degree of settling.

Findings

During the shock test an oscilloscope camera was used to photograph the traces of the input to the table and the input to the test block. Since the duration of the shock input to the table is a constant 0.002 sec no further reference to it will be made. The duration of the shock input to the test block was variable, a continual reference will be made to it. Throughout the photographic series (Figure 33, Figure 34, Figure 35, Figure 36, Figure 37, and Figure 38) a level of overfill of 1/2" was maintained. Each figure contains four photographs. They are representative of the four drop heights. Each figure is representative of a specific test block loading. With this information a good pictorial cross reference can be made of what happens to the input to the test block (acceleration and pulse duration) as the drop height and loading are changed. Figure 32 explains the traces of the photographic series.

The information contained in Table 3 and Table 4 was obtained from condensing the raw shock data.

Effects of Loading

a. Shock transmissibility composities Figure 39, Figure 40, and Figure 41 respectively represent 0", 1/2", and 1" level of overfill. Each figure displays the four drop heights (12", 24", 30", and 42"). Through observation it can be seen what happens to the input to the cushion as the loading of the test block was changed and as the drop height was changed.

b. Duration of shock pulse felt by the test block, Figure 40, Figure 42, and Figure 44 respectively represent 0", 1/2", and 1" level of overfill. Each figure displays the four drop heights. Through observation it can be seen what happens to the

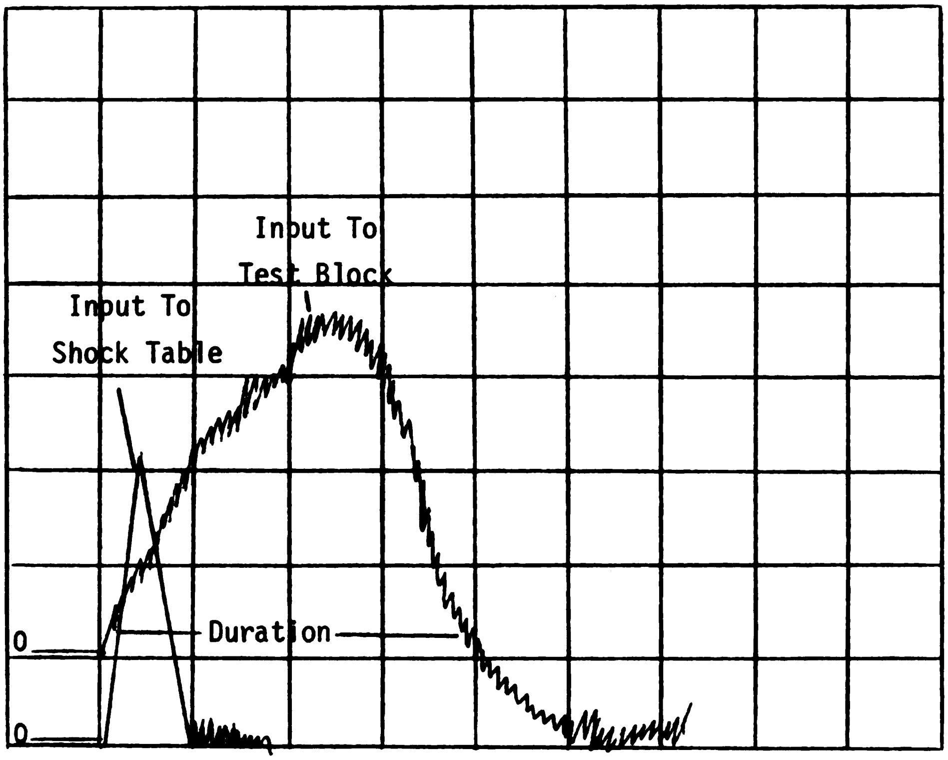

Figure 32

Photograph Information Schematic

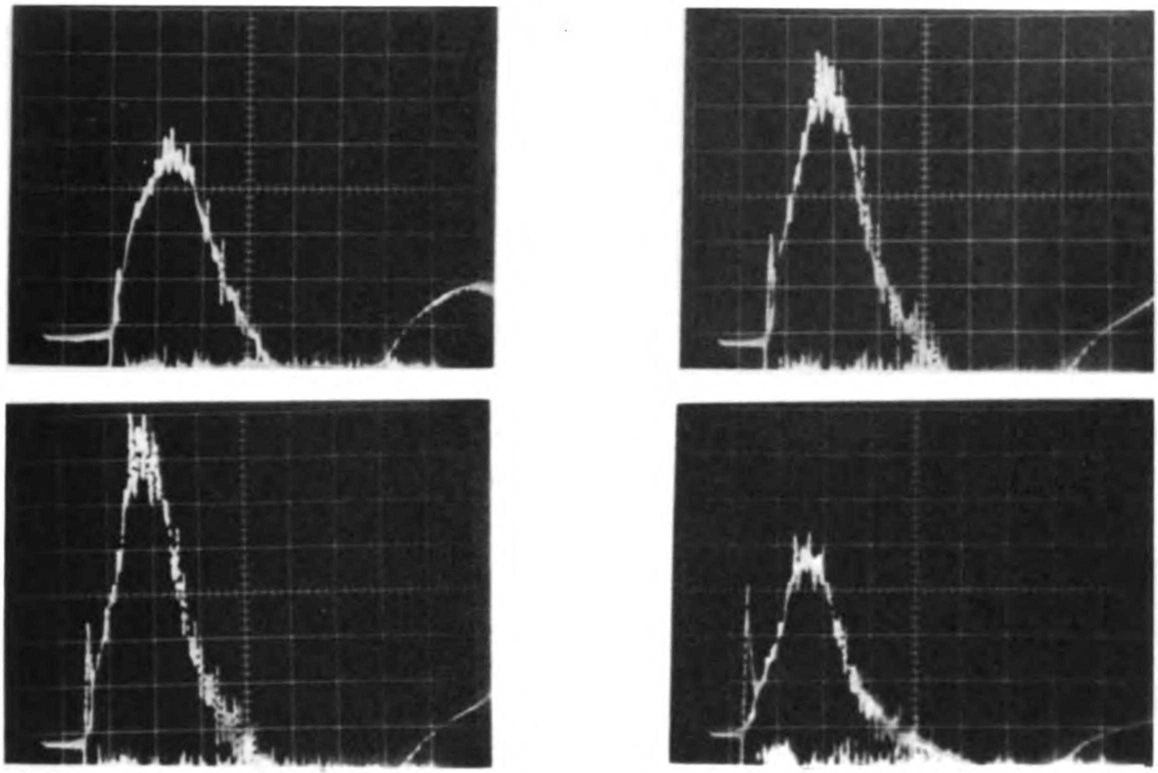

FIGURE 33

Loading of the Cushion 0.087 (PSI)

1

a) Drop height 12 inches

b) Input to shock table 220 g's.

c) Input to test box 38 g's.

d) Duration of shock 15 ms.

2

a) Drop height 24 inches.

b) Input to shock table 320 g

c) Input to test box 57 g's.

d) Duration of shock 17 ms

3

a) Drop height 30 inches

b) Input to shock table 340 g's

c) Input to test box 64 g's.

d) Duration of shock 16 ms.

4

a) Drop height 42 inches.

b) Input to shock table 410 g

c) Input to test box 75 g's.

d) Duration of shock 17 ms.

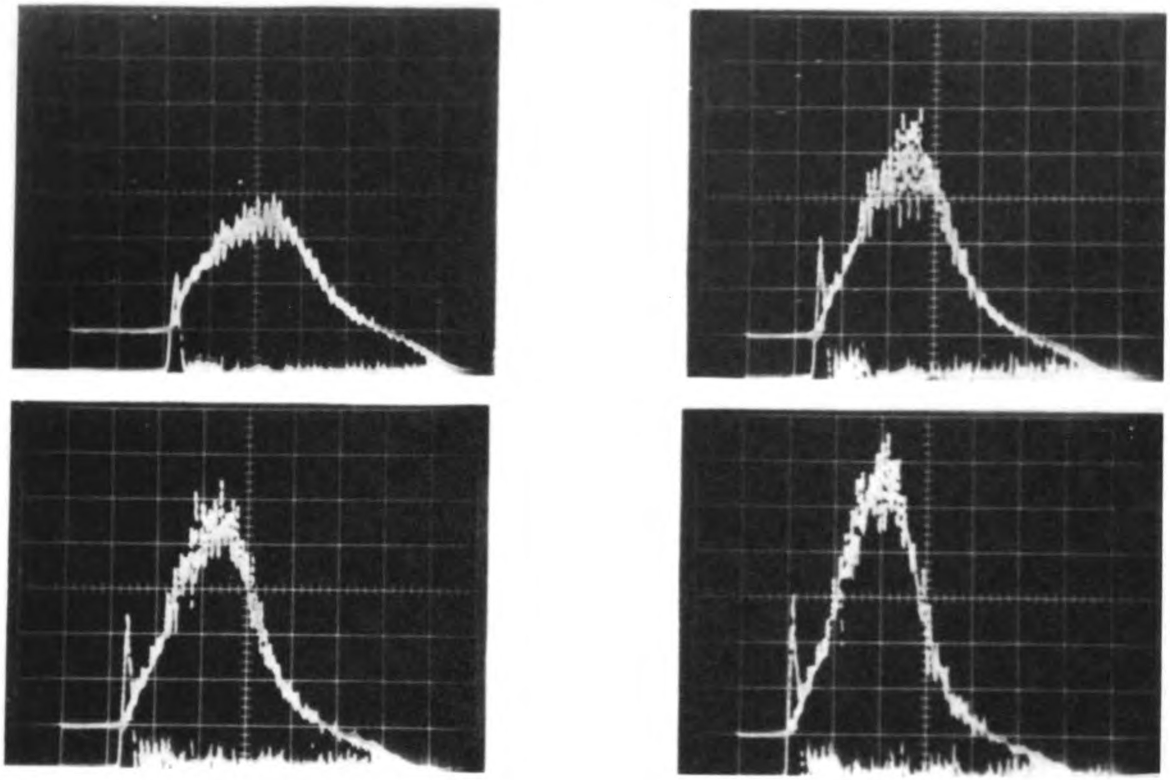

FIGURE 34

Loading of the Cushion 0.156 (PSI)

1

a) Drop height 12 inches.

b) Input to shock table 240 g's.

c) Input to test box 28 g's.

d) Duration of shock 20 ms.

2

a) Drop height 24 inches.

b) Input to shock table 340 g's.

c) Input to test box 41 g's.

d) Duration of shock 20 ms.

3

a) Drop height 30 inches.

b) Input to shock table 370 g's.

c) Input to test box 49 g's.

d) Duration of shock 20 ms.

4

a) Drop height 42 inches.

b) Input to shock table 450 g's.

c) Input to test box 60 g's.

d) Duration of shock 20 ms.

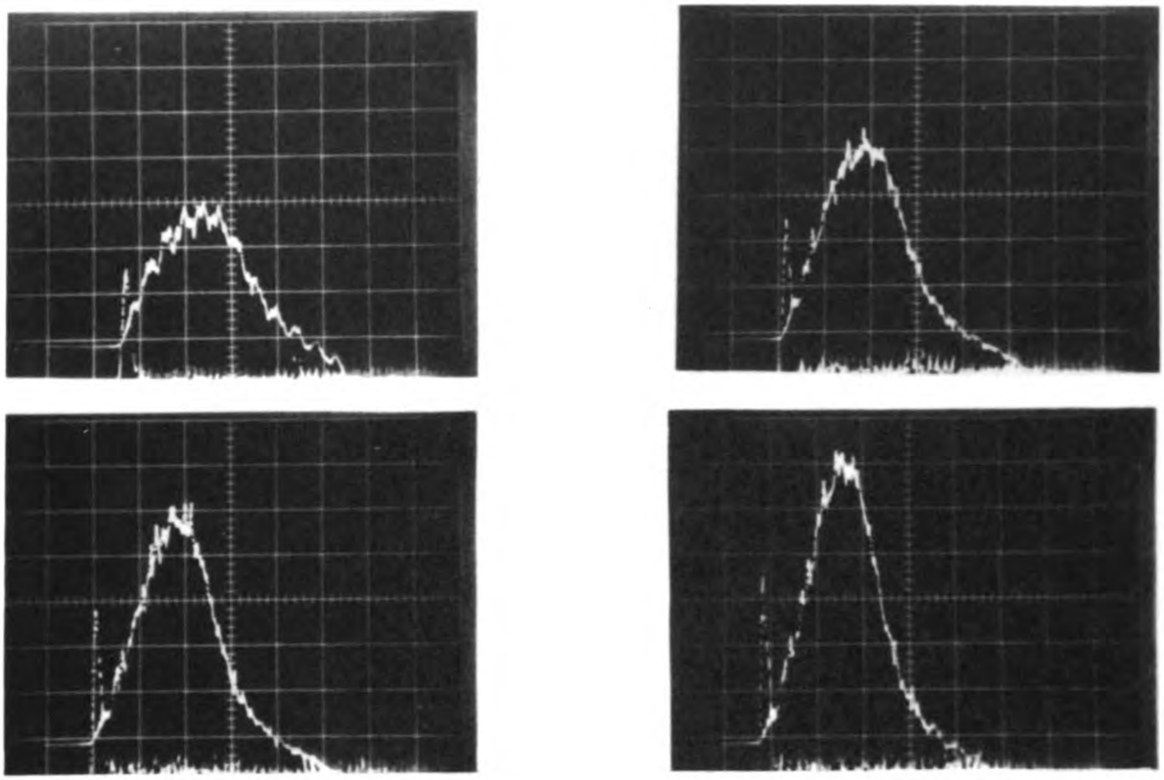

FIGURE 35

Loading of the Cushion 0.206 (PSI)

1

a) Drop height 12 inches.

b) Input to shock table 220 g's.

c) Input to test box 25 g's.

d) Duration of shock 23 ms.

2

a) Drop height 24 inches.

b) Input to shock table 310 g's.

c) Input to test box 41 g's.

d) Duration of shock 23 ms.

3

a) Drop height 30 inches.

b) Input to shock table 350 g's.

c) Input to test box 46 g's.

d) Duration of shock 23 ms.

4

a) Drop height 42 inches.

b) Input to shock table 410 g's.

c) Input to test box 58 g's.

d) Duration of shock 22 ms.

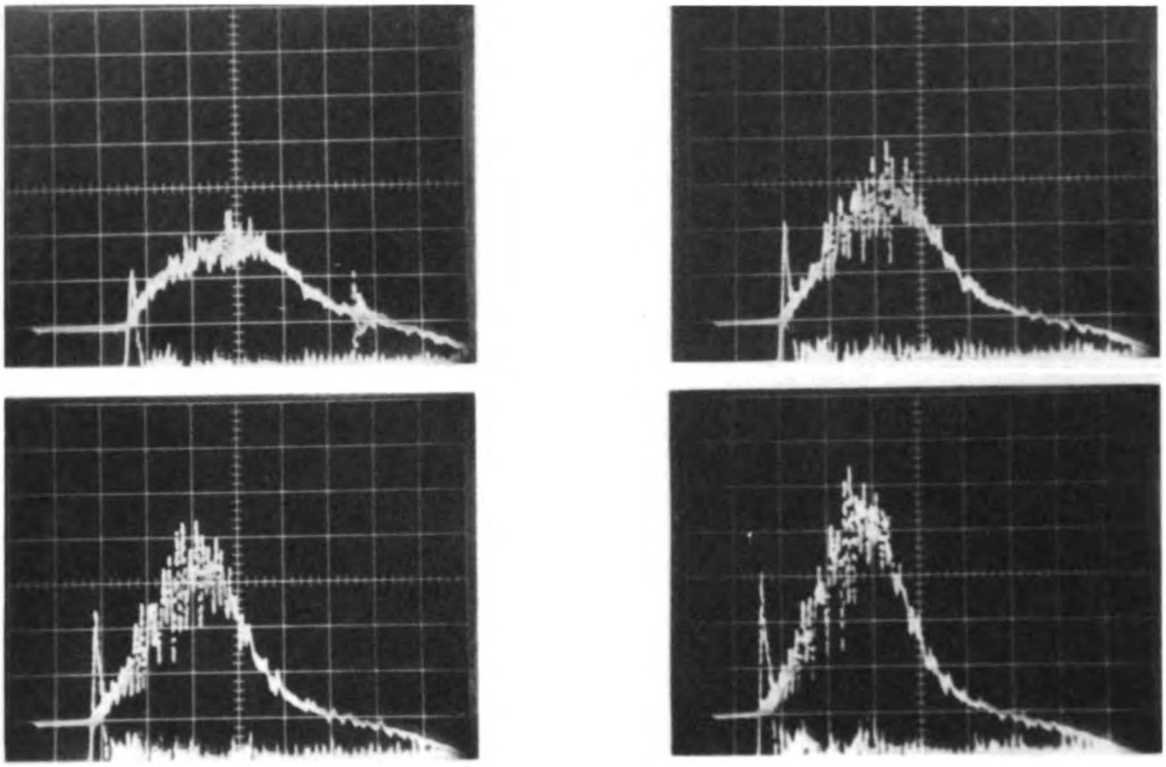

FIGURE 36

Loading of the Cushion 0.328 (PSI)

1

a) Drop height 12 inches.

b) Input to shock table 220 g's.

c) Input to test box 18 g's.

d) Duration of shock 27 ms.

2

a) Drop height 24 inches.

b) Input to shock table 310 g's.

c) Input to test box 28 g's.

d) Duration of shock 27 ms.

3

a) Drop height 30 inches.

b) Input to shock table 340 g's.

c) Input to test box 34 g's.

d) Duration of shock 26 ms.

4

a) Drop height 42 inches.

b) Input to shock table 410 g's.

c) Input to test box 42 g's.

d) Duration of shock 26 ms.

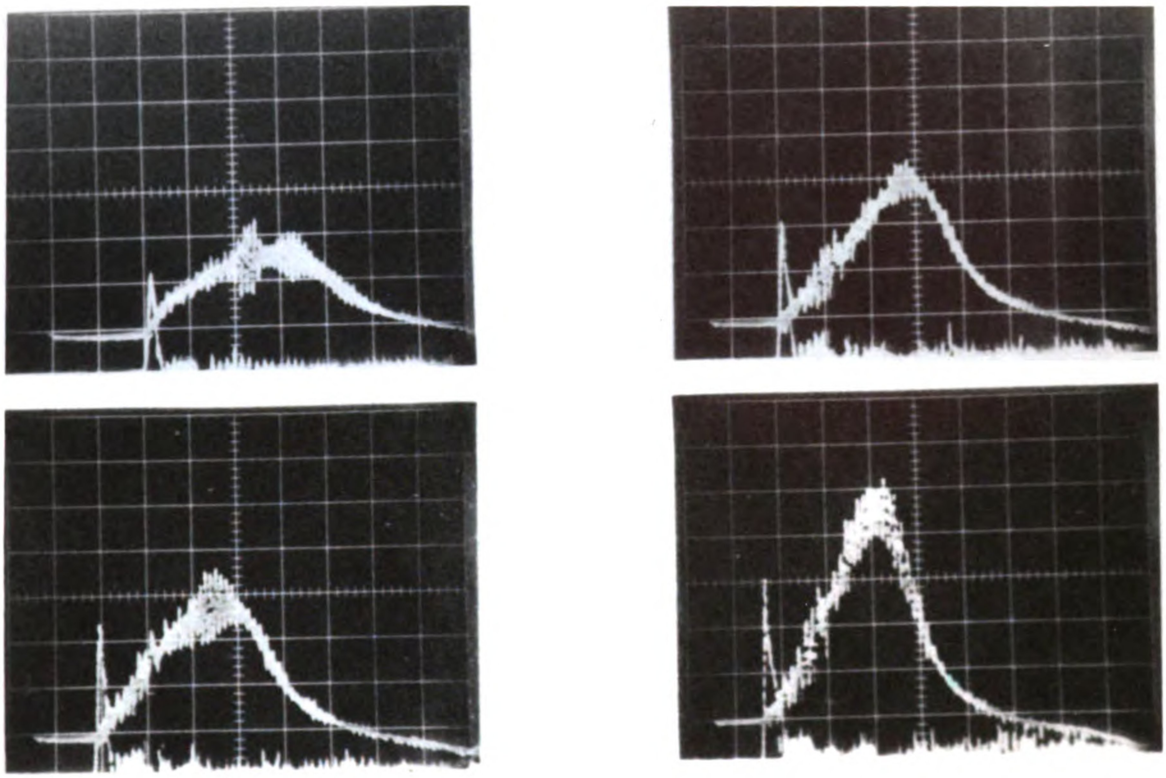

Figure 37

Loading of the Cushion 0.428 (PSI)

1

a) Drop height 12 inches.

b) Input to shock table 220 g's.

c) Input to test box 16 g's.

d) Duration of shock 30 ms.

2

a) Drop height 24 inches.

b) Input to shock table 310 g's.

c) Input to test box 29 g's.

d) Duration of shock 27 ms.

3

a) Drop height 30 inches.

b) Input to shock table 340 g's.

c) Input to test box 29 g's.

d) Duration of shock 27 ms.

4

a) Drop height 42 inches.

b) Input to shock table 410 g's.

c) Input to test box 46 g's.

d) Duration of shock 26 ms.

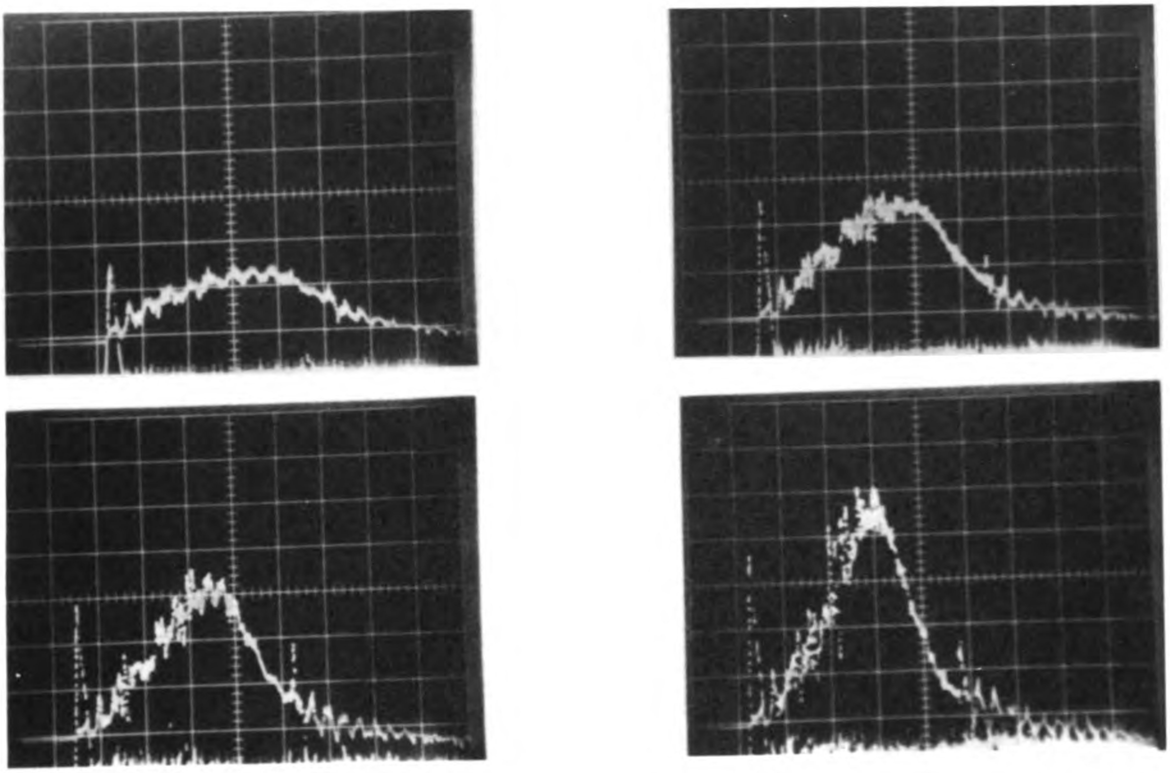

FIGURE 38

Loading of the Cushion 0.595 (PSI)

1

a) Drop height 12 inches.

b) Input to shock table 260 g's.

c) Input to test box 13 g's.

d) Duration of shock 34 ms.

2

a) Drop height 24 inches.

b) Input to shock table 350 g's.

c) Input to test box 24 g's.

d) Duration of shock 32 ms.

3

a) Drop height 30 inches.

b) Input to shock table 390 g's.

c) Input to test box 30 g's.

d) Duration of shock 28 ms.

4

a) Drop height 42 inches.

b) Input to shock table 460 g's.

c) Input to test box 45 g's.

d) Duration of shock 27 ms.

Table 3

Composite Shock Data

Drop Height (IN)	Input to the Shock Table (g's)	Level of Overfill (IN)	Shock Rec'd by Test Box (g's) — Loading of the Cushion (PSI) 0.087	0.156	0.206	0.328	0.428	0.595
12	240	0	32.2	26.0	22.4	15.0	17.8	13.2
24	350	0	51.3	40.7	35.5	22.7	32.3	25.9
30	390	0	58.5	46.8	40.8	25.4	38.7	30.6
42	450	0	73.8	58.8	51.6	32.1	51.4	44.6
12	240	1/2	36.3	27.9	23.3	16.6	17.4	15.6
24	350	1/2	55.0	42.9	37.9	27.0	31.2	29.1
30	390	1/2	62.8	50.3	45.0	31.9	38.0	35.9
42	450	1/2	78.8	62.7	57.4	41.0	49.2	49.1
12	240	1	44.3	30.1	26.7	16.7	18.1	16.2
24	350	1	66.8	45.6	42.7	24.9	32.5	30.7
30	390	1	77.3	54.0	50.3	28.2	38.5	36.7
42	450	1	91.0	66.6	65.4	36.6	48.1	50.1
			Duration of Shock Rec'd by Test Box (ms)					
12	240	0	16.2	24.1	24.5	24.8	32.3	33.6
24	350	0	15.6	23.2	23.1	23.3	27.9	28.6
30	390	0	15.5	23.8	23.0	22.8	26.8	28.5
42	450	0	15.4	22.1	22.1	22.3	24.5	26.4
12	240	1/2	17.8	21.8	22.4	22.5	31.7	33.5
24	350	1/2	17.0	20.8	21.7	22.5	28.4	30.0
30	390	1/2	17.0	20.3	20.9	22.1	27.6	27.3
42	450	1/2	15.9	19.6	20.6	22.3	25.8	26.6
12	240	1	14.5	19.4	20.9	21.6	27.0	32.2
24	350	1	15.1	18.8	19.9	21.6	24.0	28.5
30	390	1	14.8	18.3	19.9	21.2	25.1	27.9
42	450	1	14.5	17.8	19.2	20.9	24.0	26.1

Table 4

Composite Shock Settling of Test Block

Level of Overfill (IN)	Loading of the Cushion (PSI)	Settling of Test Box (IN)
0	0.087	0.490
0	0.156	0.656
0	0.206	0.802
0	0.328	0.969
0	0.428	1.083
0	0.595	1.229
1/2	0.087	0.656
1/2	0.156	0.771
1/2	0.206	0.854
1/2	0.328	0.865
1/2	0.428	1.021
1/2	0.595	1.229
1	0.087	0.740
1	0.156	0.927
1	0.206	0.932
1	0.328	1.021
1	0.428	1.115
1	0.595	1.177

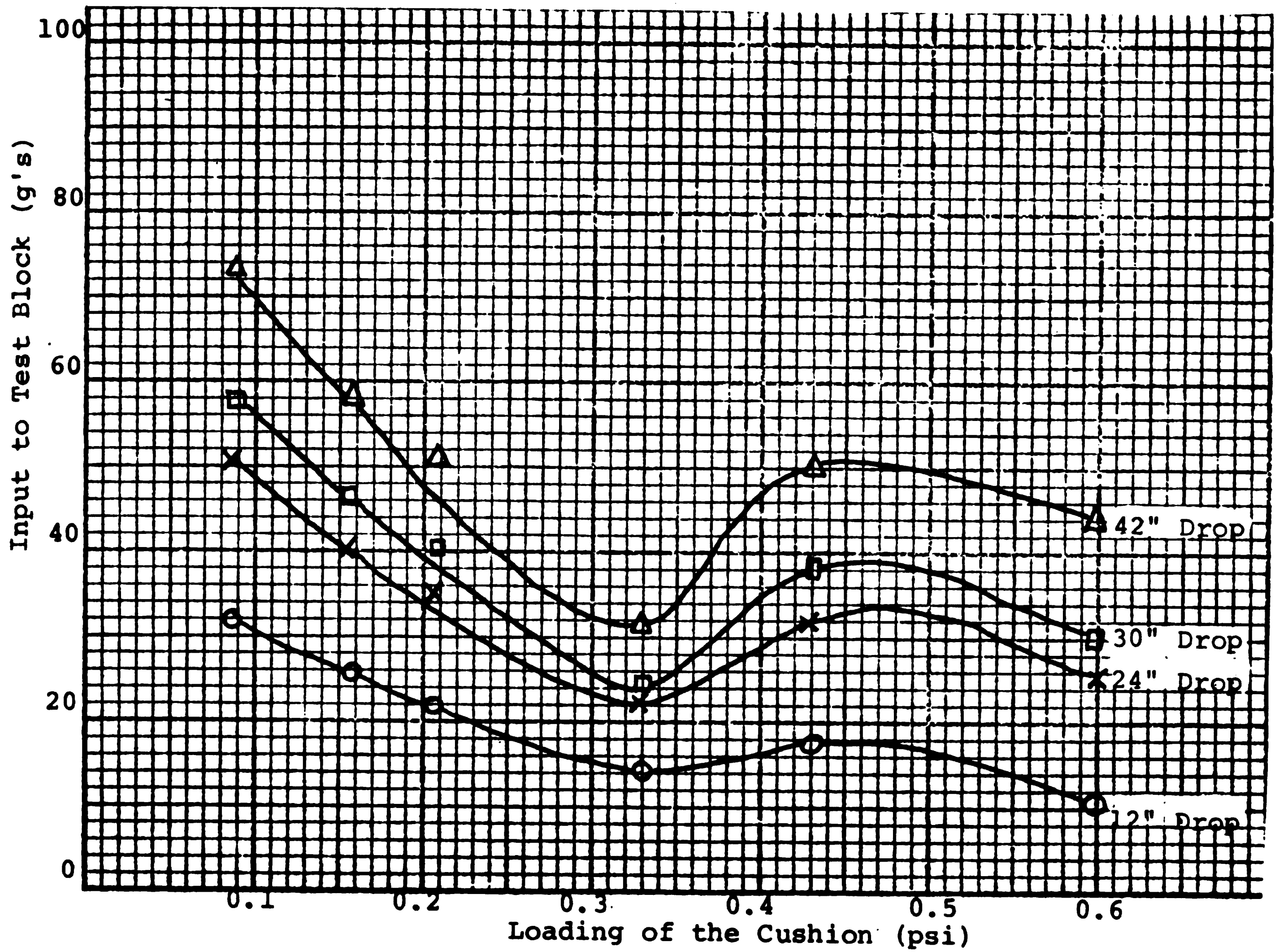

Figure 39

Shock Transmissibility, Composite 0" Overfill

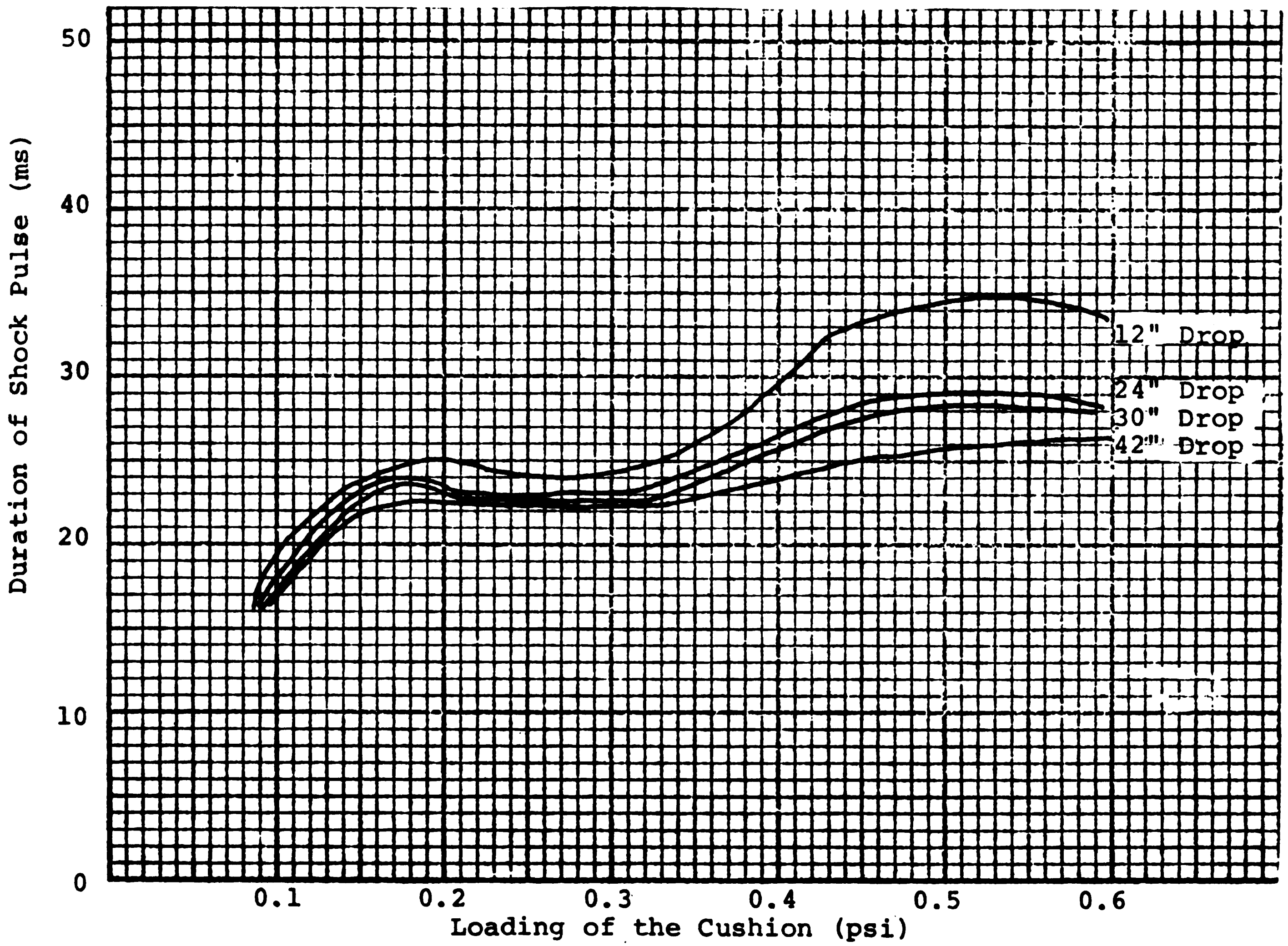

Figure 40

Duration of Shock Pulse Felt by the Test Block 0" Overfill

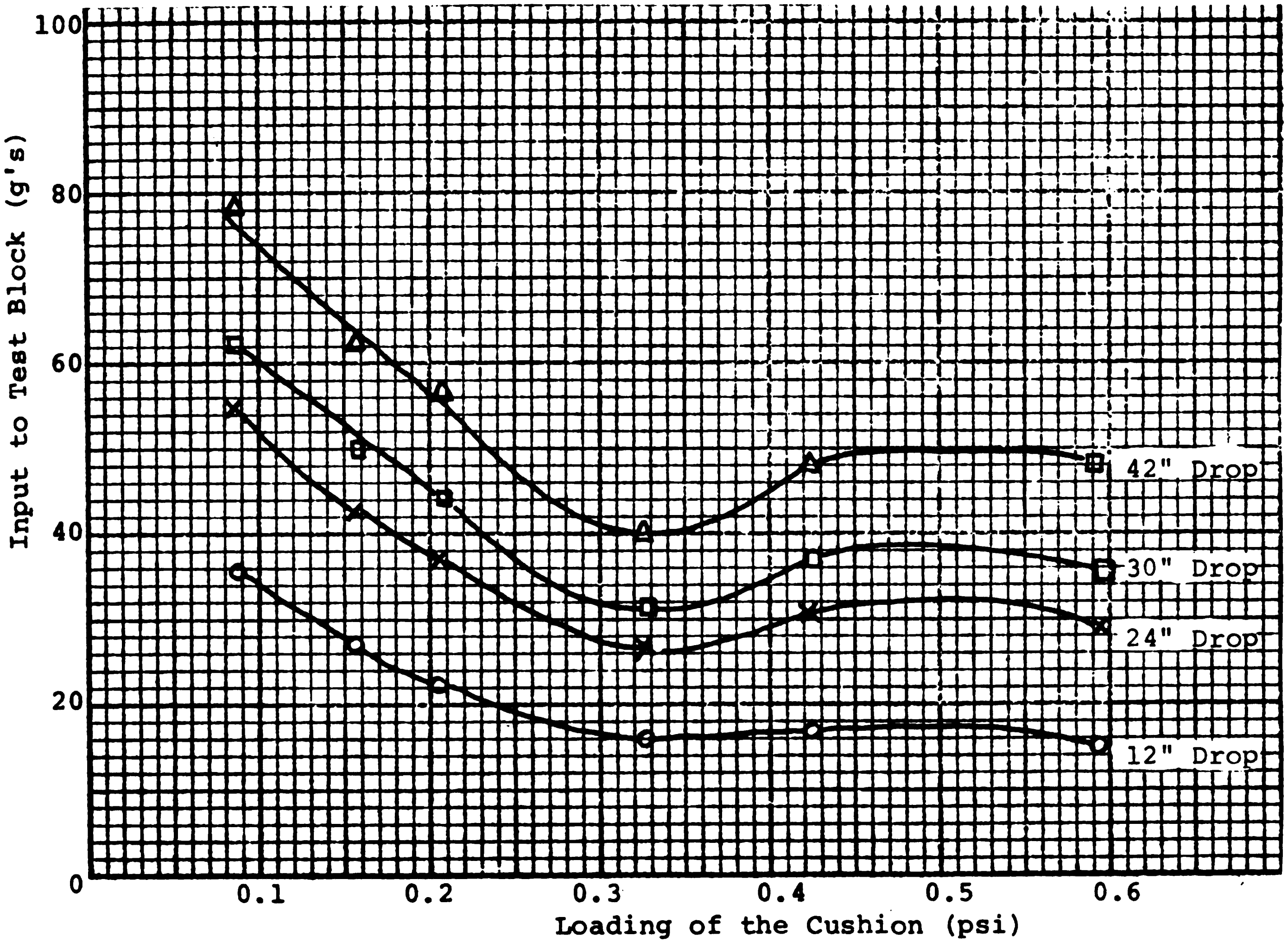

Figure 41

Shock Transmissibility, Composite 1/2" Overfill

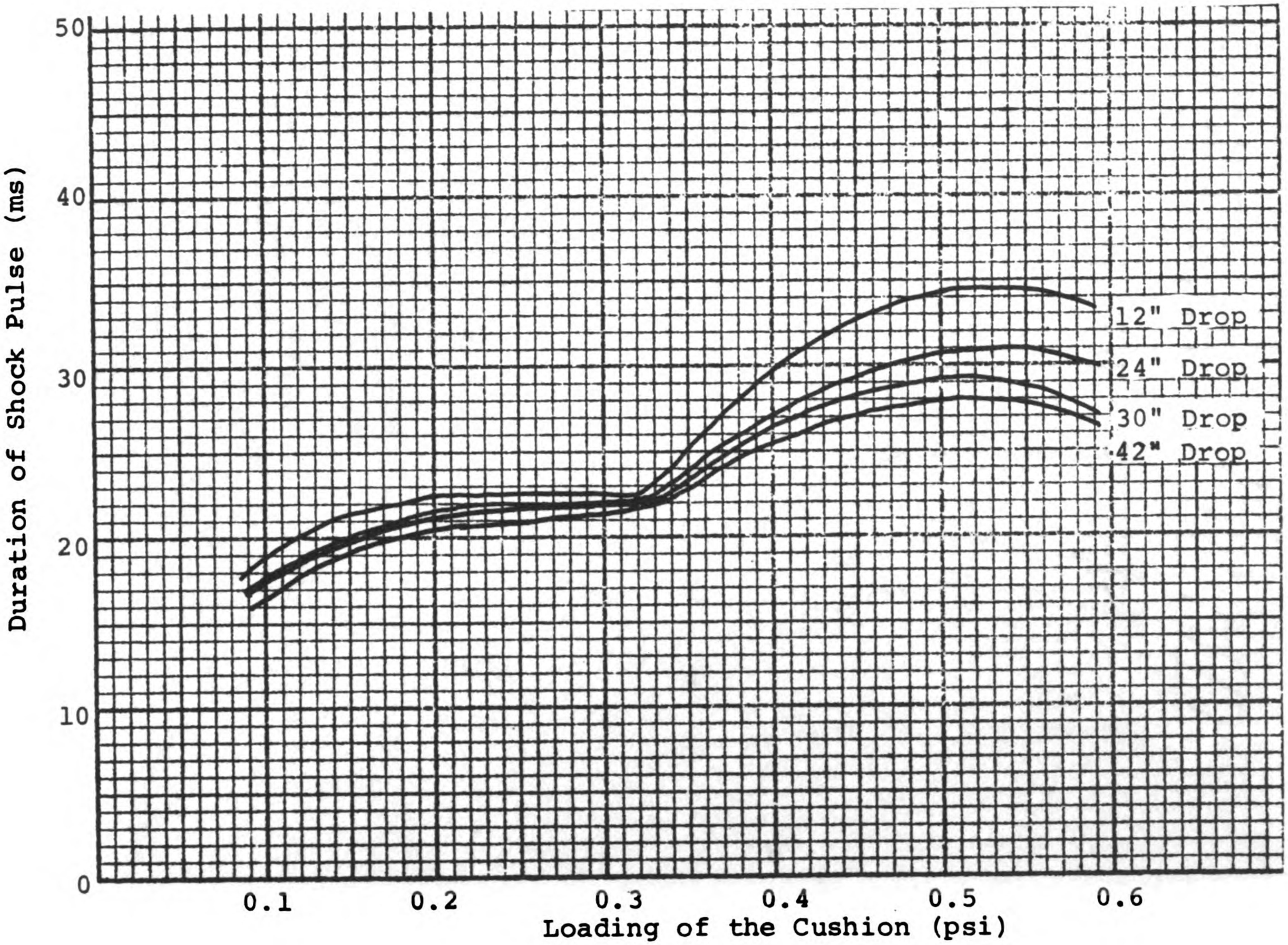

Figure 42

Duration of Shock Pulse Felt by the Test Block 1/2" Overfill

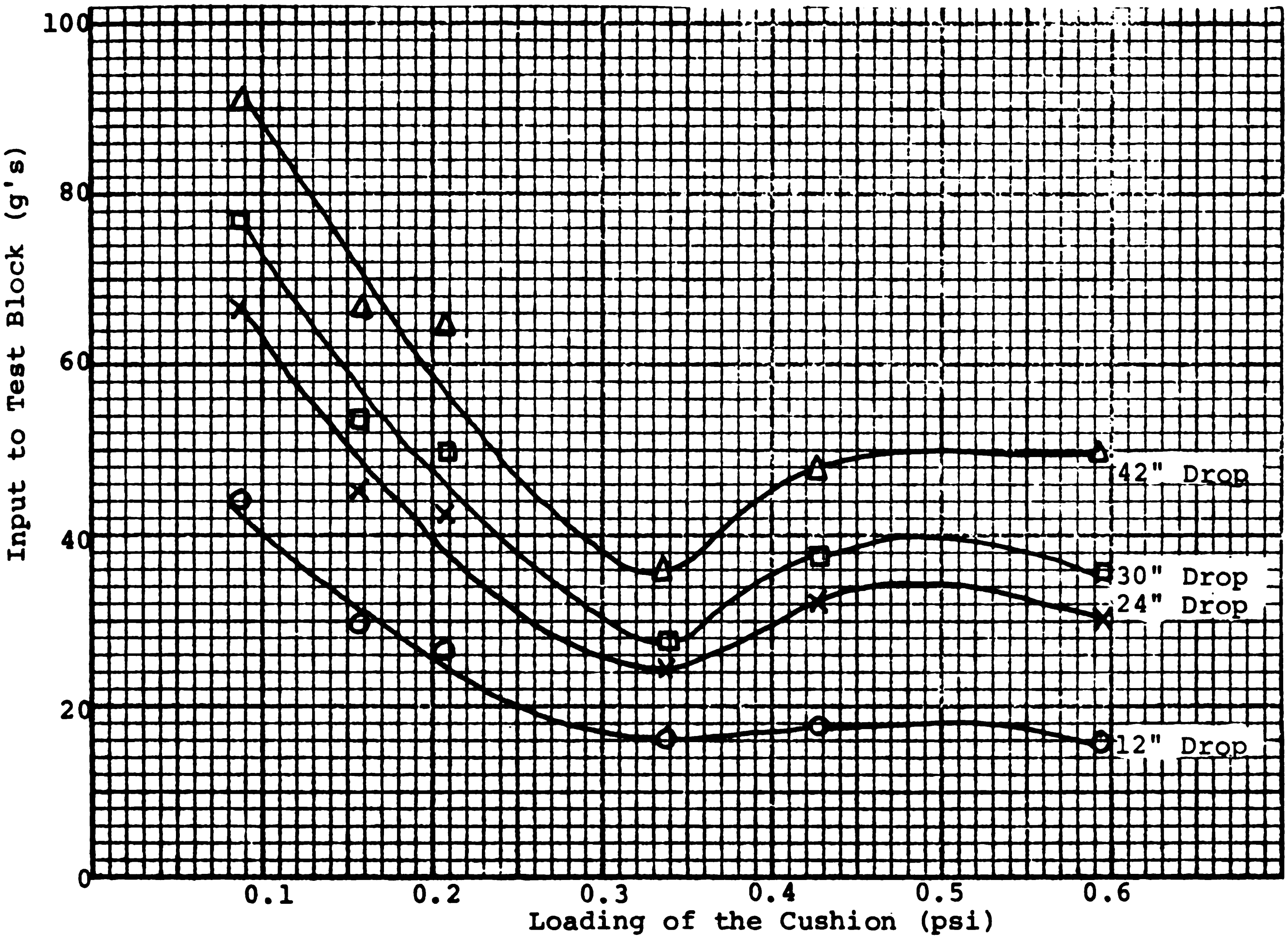

Figure 43

Shock Transmissibility, Composite 1" Overfill

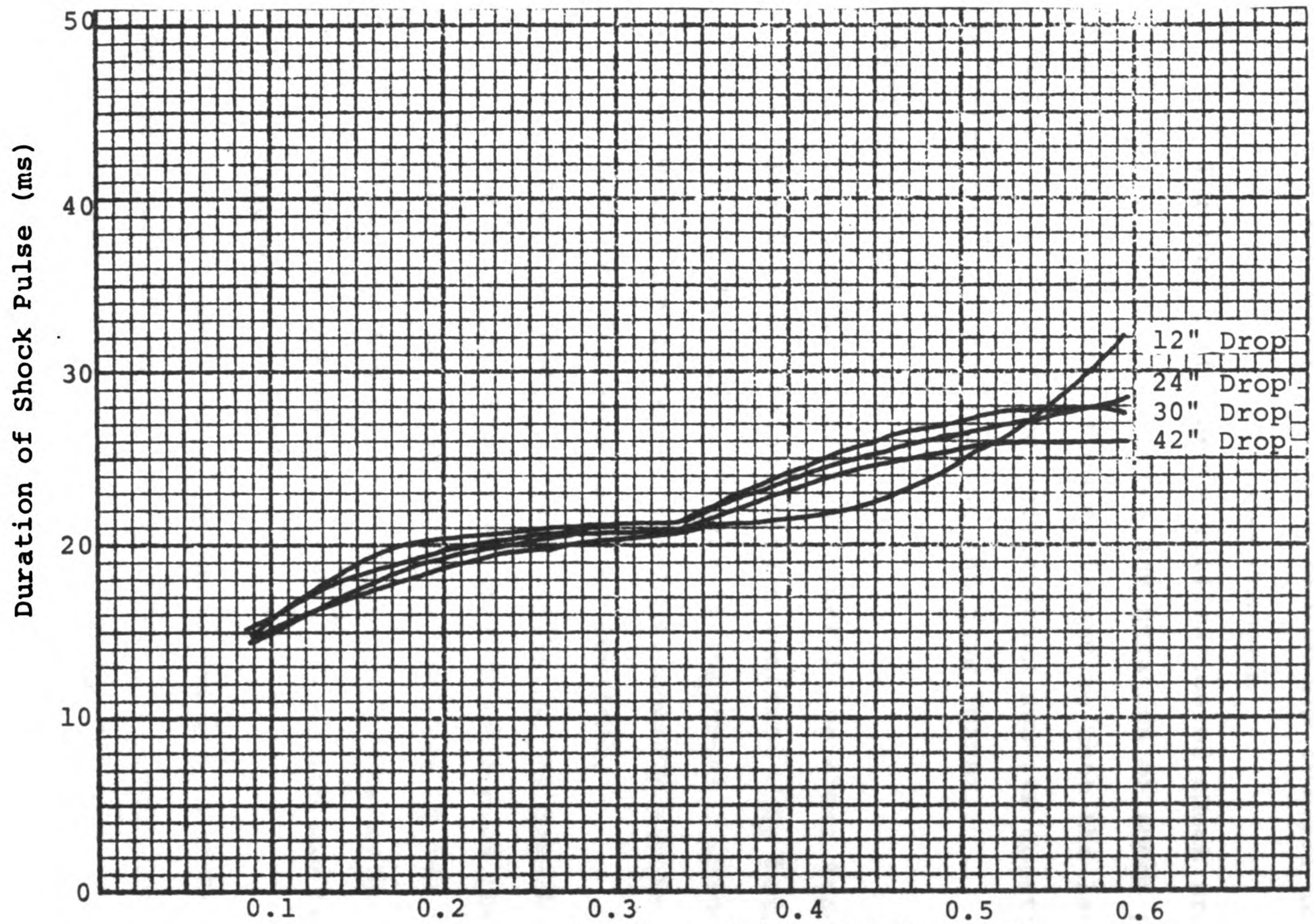

Figure 44

Duration of Shock Pulse Felt by the Test Block 1" Overfill duration of the shock pulse felt by the test block as the loading of the cushion was changed and as the drop height was changed.

Through simultaneous utilization of shock transmissibility composite figures and duration of shock pulse felt by the test block figures (assuming that the level of overfill is the same) the acceleration and its duration can be determined for any loading and drop height.

Effects of Overfill

a. The graphs, effects of overfill on shock transmissibility, maintaining a constant drop height, Figure 45 through Figure 48 represent a situation where the degree of shock attenuation can be compared for each level of overfill.

b. Effect of overfill on settling of the test block due to shock, Figure 49 is a composite of the amount of settling that was incurred by the test block for the entire test series. The effect overfill had on the degree of settling can be observed.

Through analysis of Table 3, Table 4, and Figure 39 through Figure 49 the following information was deciphered.

a. Regardless of drop height as the loading of the cusion increases the acceleration level (g's) decreases with a loading of 0.087 psi, 0.156 psi, 0.206 psi, and 0.328 psi. A loading of 0.328 psi

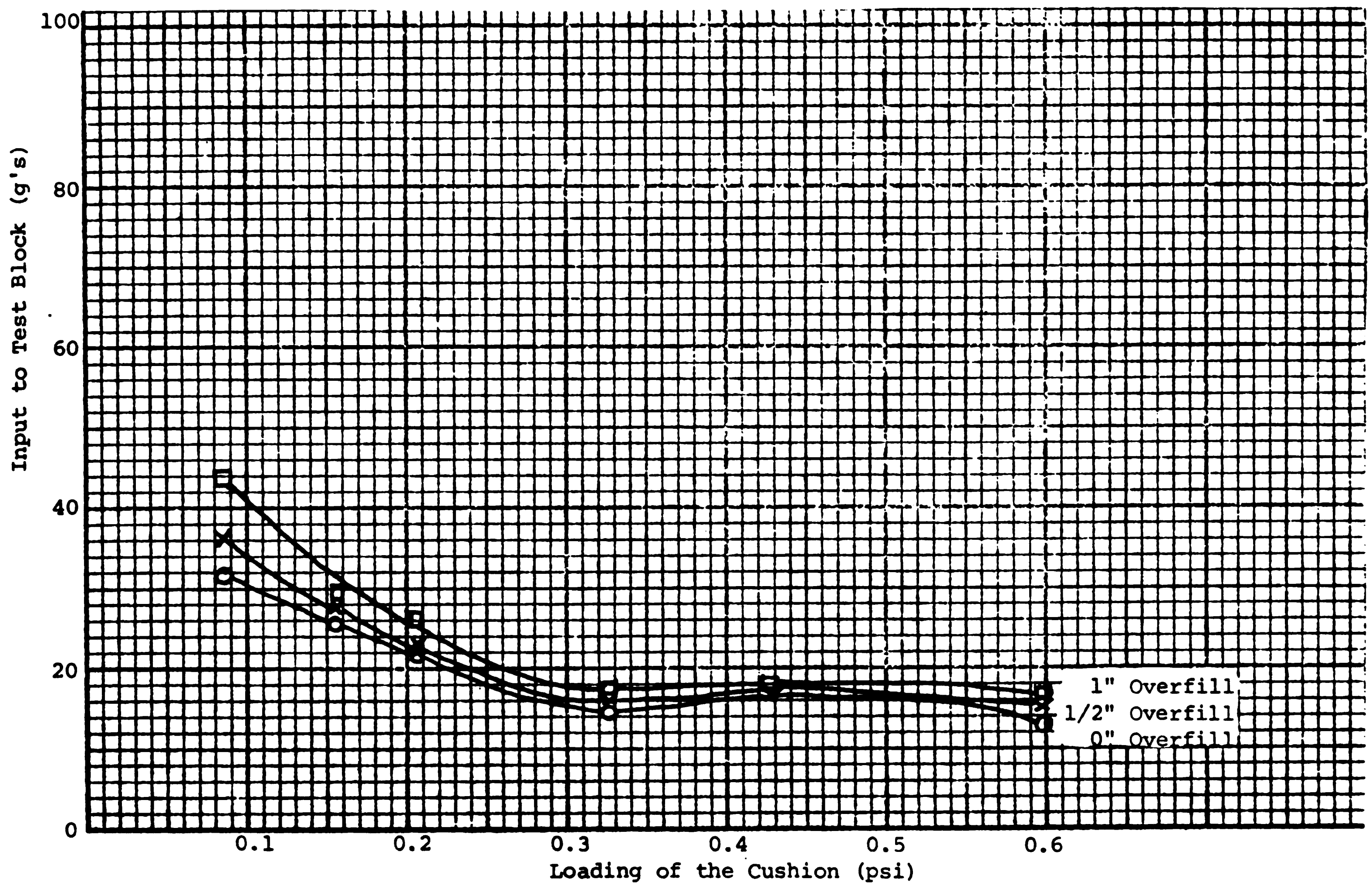

Figure 45

Effects of Overfill on Shock Transmissibility, Maintaining a Constant Drop Height Equivalent to 12" Drop Input to Table 240 g's

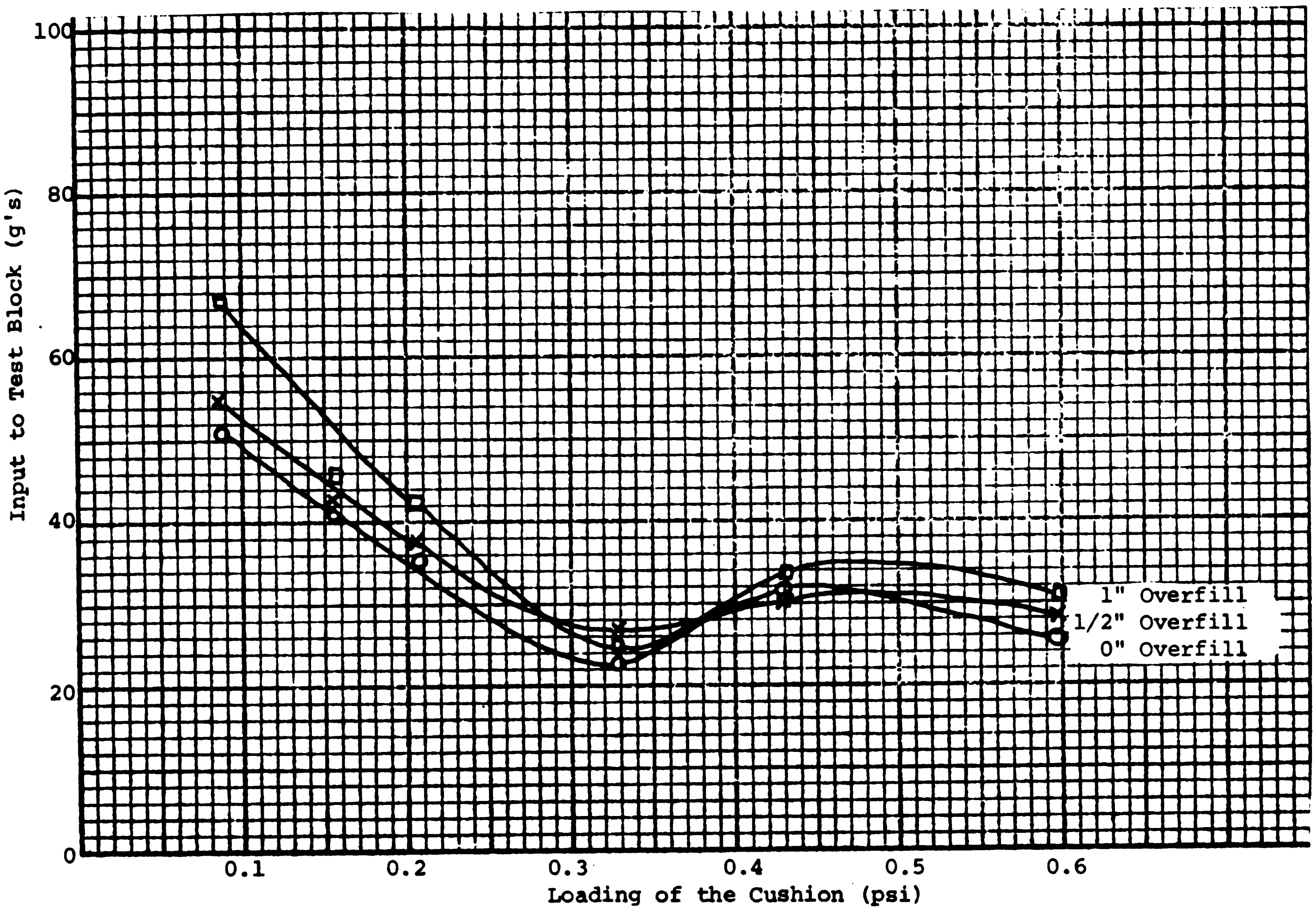

Figure 46

Effects of Overfill on Shock Transmissibility, Maintaining a Constant Drop Height Equivalent to 24" Drop Input to Table 350 g's

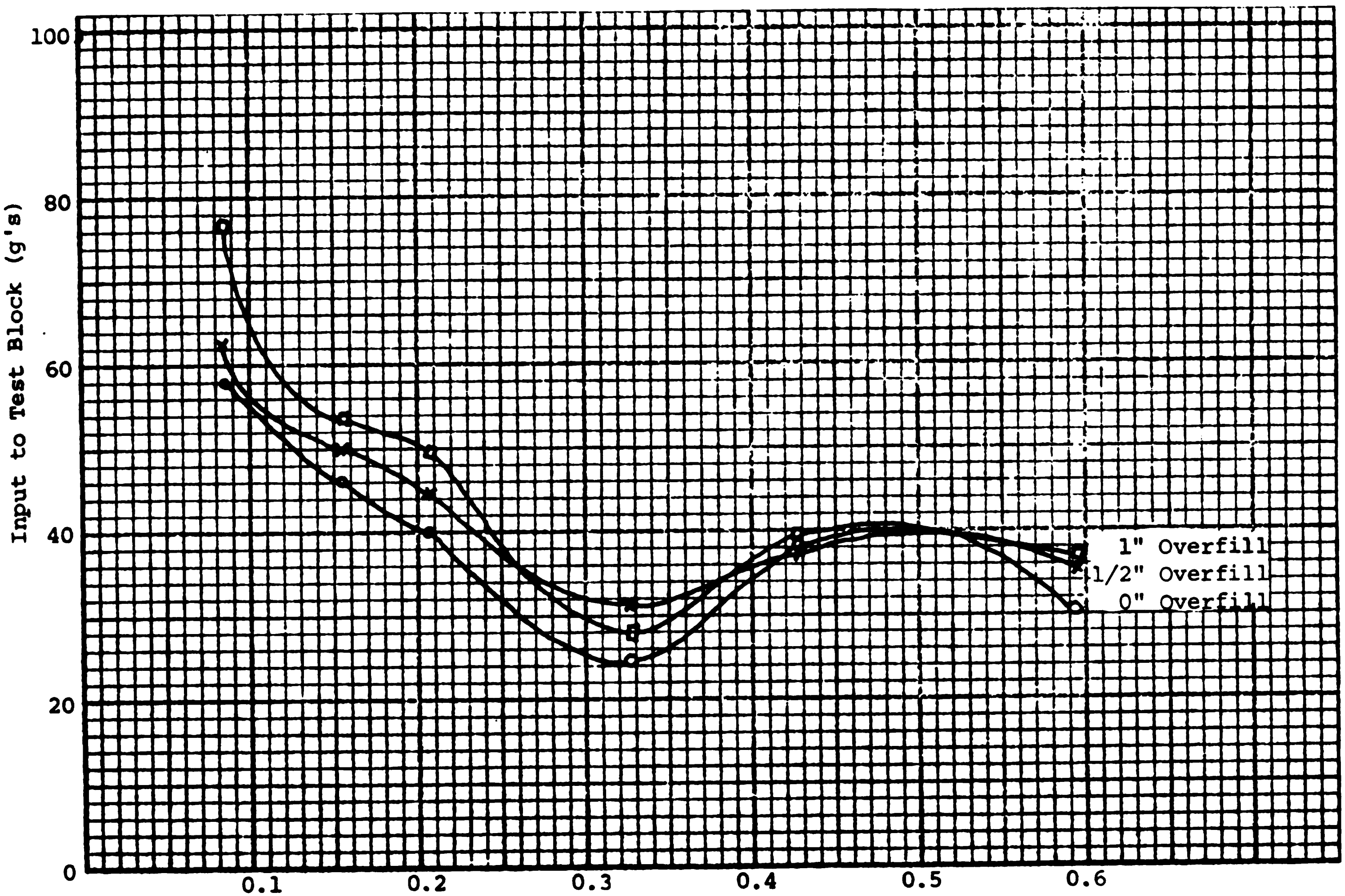

Figure 47

Effects of Overfill on Shock Transmissibility, Maintaining a Constant Drop Height Equivalent to 30" Drop Input to Table 390 g's

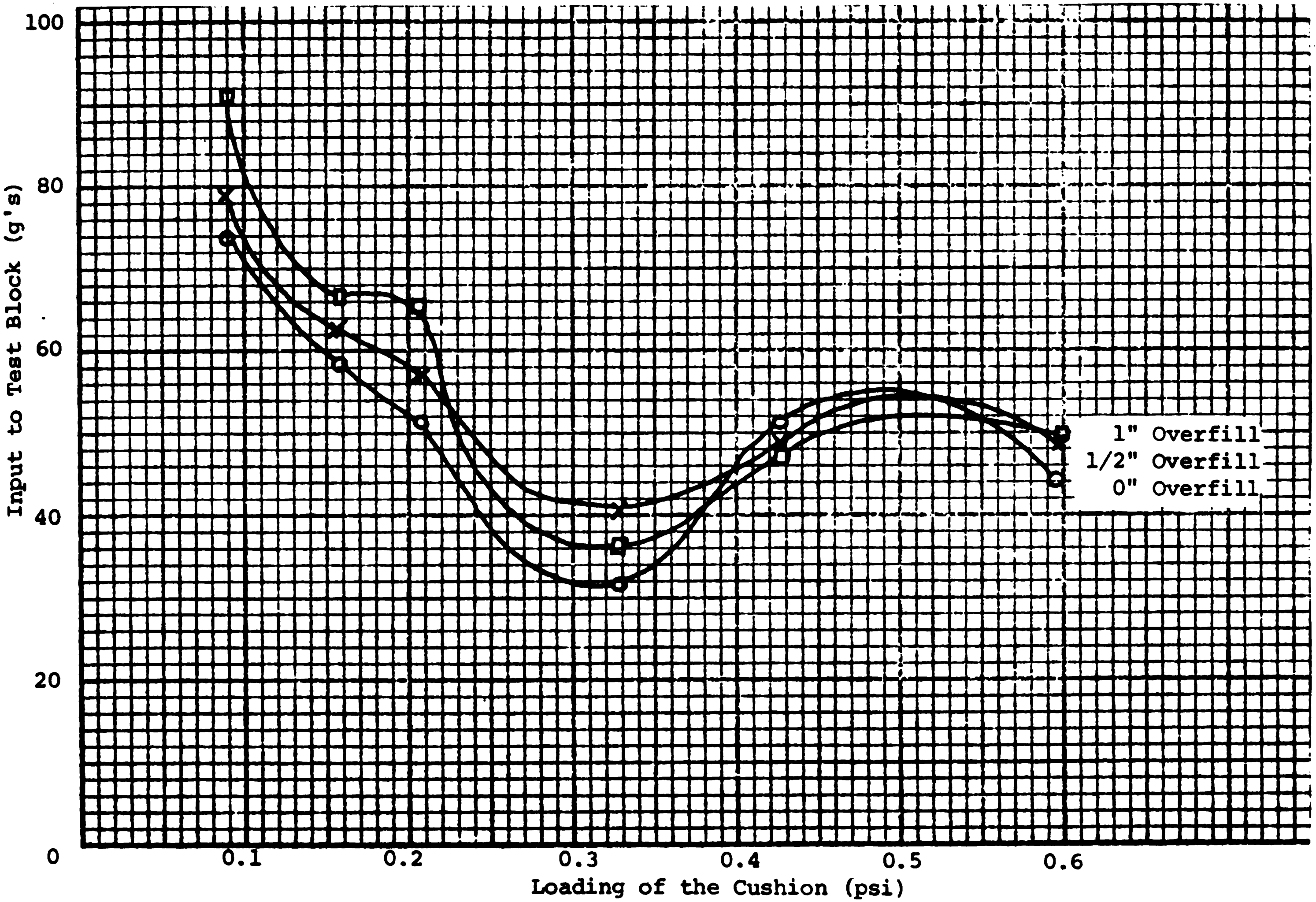

Figure 48

Effects of Overfill on Shock Transmissibility, Maintaining a Constant Drop Height Equivalent to 42" Drop Input to Table 450 g's

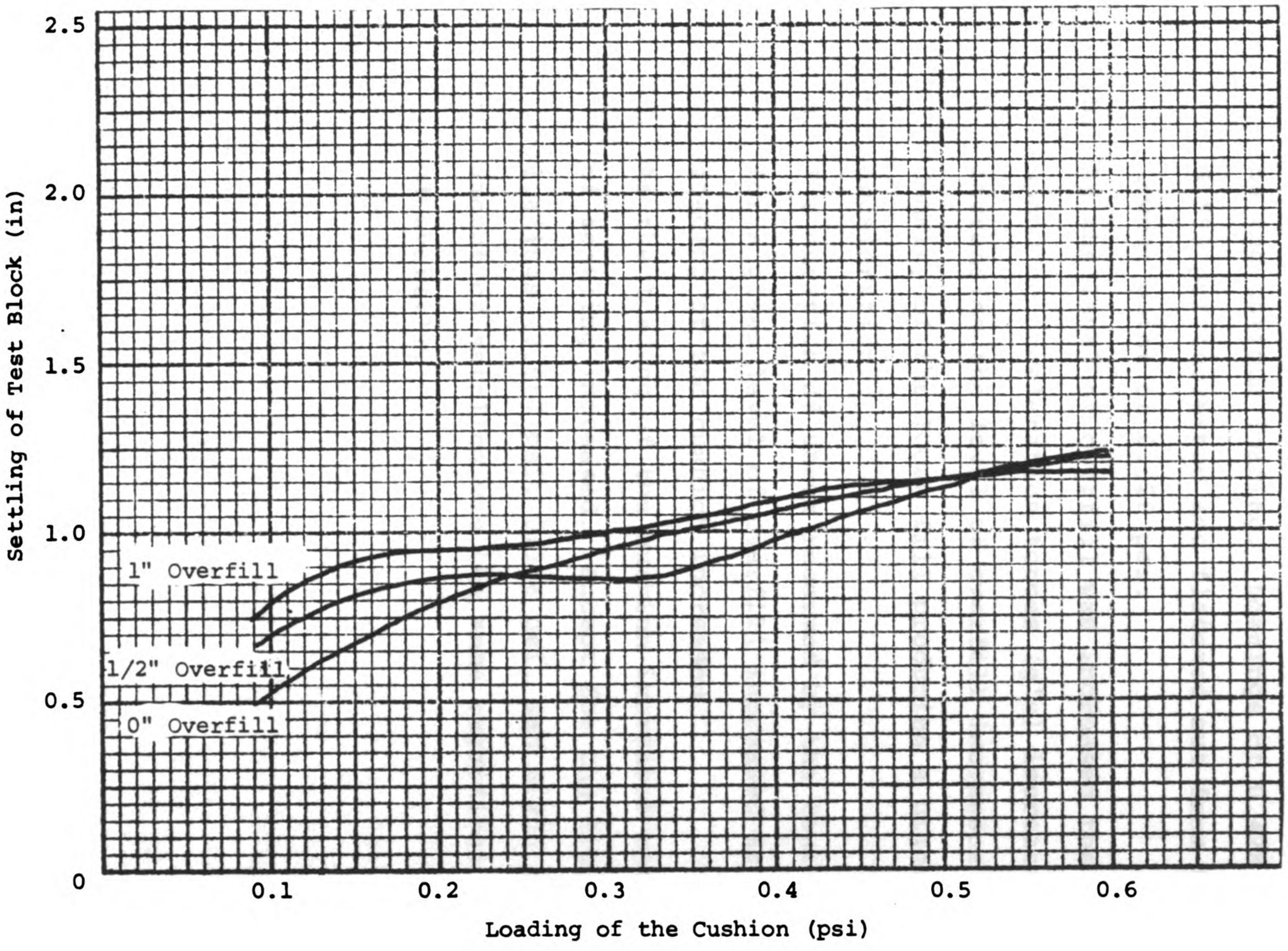

Figure 49

Effect of Overfill on Settling of the Test Block Due to Shock received the lowest shock transmission for all drop heights and levels of overfill. It would seem to be the optimum loading. Loadings of 0.428 psi and 0.595 psi increased and flatened out from the lowest point of 0.328 psi.

b. As the level of overfill was increased the corresponding acceleration forces (g's) increased, increasing the level of overfill increases the density of the loose fill producing a higher acceleration.

c. The duration of shock received by the test block for a given level of overfill increased as the loading of the cushion increased.

d. As the loading of the cushion increased the amount of settling increased. Except for the light loadings (0.087 psi, 0.156 psi, and 0.206 psi) the amount of settling was the same regardless of level of overfill.

CHAPTER V

SUMMARY AND CONCLUSIONS

Chapter V consists of a brief summary of the problem and conclusions.

The problem consisted of developing a method to evaluate the cushioning characteristics of loose fill; to determine the effect loading and the effect of overfill on vibration and shock input transmissibility. In Appendix A a testing method to evaluate the dynamic cushioning characteristics of loose fill is presented. The method produced consistent reproducible results, Table 5.

The developed testing procedure, tests the ability of the loose fill cushioning material to attenuate vibration and shock inputs: a way in which different loose fill cushioning materials can be categorized as to quality of product protection. Utilizing the information derived from testing a product (vibration and shock fragility) it can be packaged in the optimum amount and type of loose fill.

Table 5

Shock Statistical Data

Loading of the Cushion (psi)	Level of Overfill (in)	Drop Height (in)	Mean (in)	Standard Deviation (in)	Standard Error
0.087	0	12	32.2	2.68	0.89
0.087	0	24	51.3	2.69	0.90
0.087	0	30	59.5	5.61	1.98
0.087	0	42	72.3	4.80	1.60
0.087	1/2	12	36.0	2.45	0.87
0.087	1/2	24	55.0	3.39	1.13
0.087	1/2	30	62.8	6.38	2.13
0.087	1/2	42	78.8	2.11	0.70
0.087	1	12	44.3	4.64	1.55
0.087	1	24	66.8	3.83	1.28
0.087	1	30	77.3	8.83	2.94
0.087	1	42	91.0	12.20	4.07
0.156	0	12	26.0	1.22	0.41
0.156	0	24	40.7	2.40	0.80
0.156	0	30	46.8	1.09	0.36
0.156	0	42	58.8	1.86	0.62
0.156	1/2	12	27.9	0.93	0.31
0.156	1/2	24	42.9	2.15	0.72
0.156	1/2	30	50.3	1.94	0.65
0.156	1/2	42	63.1	3.14	1.11
0.156	1	12	29.8	1.28	0.45
0.156	1	24	45.7	2.00	0.67
0.156	1	30	54.0	2.00	0.67
0.156	1	42	66.6	3.71	1.24
0.206	0	12	22.5	1.31	0.46
0.206	0	24	35.9	2.42	0.85
0.206	0	30	41.6	2.13	0.71
0.206	0	42	52.3	2.35	0.78
0.206	1/2	12	23.4	1.92	0.68
0.206	1/2	24	37.9	2.98	0.99
0.206	1/2	30	45.0	2.45	0.82
0.206	1/2	42	57.4	3.00	1.00

Table 5 (Con't.)

Loading of the Cushion (psi)	Level of Overfill (in)	Drop Height (in)	Mean (in)	Standard Deviation (in)	Standard Error
0.206	1	12	26.7	0.87	0.29
0.206	1	24	42.7	3.12	1.04
0.206	1	30	50.3	2.55	0.85
0.206	1	42	65.4	4.90	1.63
0.328	0	12	15.0	1.41	0.47
0.328	0	24	22.7	1.41	0.47
0.328	0	30	25.4	1.74	0.58
0.328	0	42	32.1	1.62	0.54
0.328	1/2	12	16.6	2.74	0.91
0.328	1/2	24	27.0	2.00	0.67
0.328	1/2	30	31.9	2.09	0.70
0.328	1/2	42	41.0	2.12	0.71
0.328	1	12	16.7	0.87	0.29
0.328	1	24	24.9	1.62	0.54
0.328	1	30	28.2	1.48	0.49
0.328	1	42	36.6	2.92	0.97
0.428	0	12	17.8	2.54	0.85
0.428	0	24	32.3	4.36	1.45
0.428	0	30	38.7	3.81	1.27
0.428	0	42	51.4	5.05	1.68
0.428	1/2	12	17.4	1.01	0.34
0.428	1/2	24	31.2	3.23	0.08
0.428	1/2	30	38.0	2.50	0.83
0.428	1/2	42	49.2	2.82	0.94
0.428	1	12	18.1	1.05	0.35
0.428	1	24	32.4	3.28	1.09
0.428	1	30	38.4	2.79	0.93
0.428	1	42	48.1	2.80	0.93
0.595	0	12	13.2	2.68	0.89
0.595	0	24	26.5	5.83	2.06
0.595	0	30	30.6	6.48	2.16
0.595	0	42	44.7	7.11	2.37

Table 5 (Con't.)

Loading of the Cushion (psi)	Level of Overfill (in)	Drop Height (in)	Mean (in)	Standard Deviation (in)	Standard Error
0.595	1/2	12	15.6	2.19	0.73
0.595	1/2	24	29.1	3.92	1.31
0.595	1/2	30	35.9	3.95	1.32
0.595	1/2	42	49.1	4.34	1.45
0.595	1	12	16.2	0.97	0.32
0.595	1	24	30.7	3.67	1.22
0.595	1	30	36.7	2.50	0.83
0.595	1	42	50.1	3.44	1.15

The testing procedure can be incorporated in a manner to test the dynamic cushioning characteristics of all cushioning materials. Thus various materials could be evaluated equally.

APPENDIX A

APPENDIX A

PROPOSED TEST METHOD

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

The following proposal was developed from research conducted and presented in the previous four chapters.

Test Apparatus

Test Block

A test block constructed of 1/2" plywood sides and 3/4" plywood top and bottom should be used, Figure 9. The appropriate accelerometers can be located in either a top or bottom position. Although the utilization of just one position for both vibration and shock testing is recommended.

Sample Box

Through evolution the best sample box to use for vibration and shock testing was the one in Figure 27. It incorporates all improvements and is the most durable.

Fixtures

The mounting fixtures consisted of two 20" 2" x 4" 's, each with a 12" x 1 1/2" section removed and four 22" x 3/8" threaded rods, Figure 28. The 2" x 4" 's were positioned over the cover of the sample box so that the ends rested on the edge of sample box. Wing nuts and washers were used to secured the sample box to the table for testing.

Test Block Orientation Procedure

It is imperative that the test block be position exactly in the center of the sample box. Using the following orientation procedure, placement can be within ± 1/16" of center.

Step 1. An initial layer of approximately 3" is placed in the bottom of sample block. The weight of the test block must be taken into consideration. Regardless of the weight (the greater the weight the greater the compression of loose fill, thus a higher initial layer) the top of the test block must be 6" from the top edge of the sample box. Locating a level board across the edges of the sample box and measuring the depth from the board's edge to each of the test block's corners the test block is vertically centered.

Step 2. Once the test block is vertically centered it can be horizontally centered. Placing a 12" ruler along an edge of the test block it is centered by aligning the perpendicular edges with the 3" and 9" division of the ruler. It is only necessary to perform this procedure on one pair of opposite edges. Now the test block is centered, 3" on all sides.

Step 3. With the test block centered in the sample box the predetermined level of overfill can be added. The loose fill is poured into the sample box until its level coincides with the appropriate horizontal line scored on the inside of the sample box.

Step 4. Regardless of the amount of overfill the volume of the sample box will be one cubic foot after the cover is bolted in place. One corner of the cover is beveled to prevent the accelerometer cable from being pinches.

Test Instrumentation and Test Procedure

Vibration

The sample box is rigidly mounted to a Electro-Hydraulic Vibrator. This machine had a frequency range of 1 H_z to 200 H_z and a variable amplitude. A sinusoidal motion was used as an input.

Piezoresistive accelerometers (Endevco Model 2265-20) were used to monitor the input to the loose fill and the response of the test block. The outputs from the accelerometers were fed into an analog computer for analysis. In the computer the signals were full wave rectified and filtered to get their D. C. equivalents. The D. C. voltages were then fed through a divider circuit to give a ratio of the response acceleration to the input acceleration. This output was a D. C. voltage and was read on a digital voltmeter as a ratio of response to input.

Shock

A drop height sequence of 12", 24", 30", 42", 12", 24", 30", 42", 12", 24", 30", 42" should be used. After each drop height sequence the loose fill should be changed and the test block oriented. At least three separate drop heights sequences should be performed and the results checked for consistency.

Loading of the Cushion

The loadings selected should be such that they represent a cross section of loadings for which the loose fill would be used.