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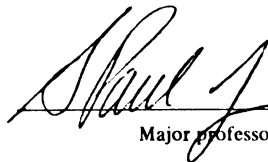
**Comparison of Loose Fill Cushioning Materials for
Shock Absorbing Capabilities and Settling During
Vibration.**

presented by

Constance Maud Zesaguli

has been accepted towards fulfillment
of the requirements for

M.Sc. degree in Packaging


Major professor

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COMPARISON OF LOOSE FILL CUSHIONING MATERIALS FOR SHOCK
ABSORBING CAPABILITIES AND SETTLING DURING VIBRATION

By

Constance Maud Zesaguli

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Submitted to

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1999

ABSTRACT

COMPARISON OF LOOSE FILL CUSHIONING MATERIALS FOR SHOCK ABSORBING CAPABILITIES AND SETTLING DURING VIBRATION

BY

Constance Maud Zesaguli

This study compared two newly patented Expandable Polystyrene loose fill cushioning materials to other commercially available loose fill cushioning materials for shock absorbing capabilities and settling during transportation vibration. Tests for shock absorbing capabilities were conducted according to protocols recommended by ASTM D4168. The transmitted shock levels were presented as cushion curves (transmitted shock levels versus static loading) and environmental cushion curves (transmitted shock levels versus the ratio of required cushion weight or cushion volume to the product weight). The transmitted shock levels for the newly patented expandable polystyrene loose fill cushion materials were much lower compared to the shock levels of the commercially available loose fill cushioning materials. The newly patented expandable polystyrene loose fill cushion showed the best performance in terms of percent weight utilization. Random vibration tests were conducted according to ASTM D4728. The results of the random vibration tests indicated that, of the three different shaped objects used, the flat/rectangular object settled the least, and of the three different shaped loose fill cushioning materials tested, the newly patented EPS loose fill cushioning materials had the best interlocking capabilities.

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This thesis is dedicated to my grand parents, my mother Dr. J.K.P Zesaguli, my two children, Yeukai and Batsirayi, my extended family, and friends for the love and support they have always provided.

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LIST

TABLE OF CONTENTS

LIST OF TABLES.....	vii
LIST OF FIGURES.....	ix
CHAPTER 1 : INTRODUCTION.....	1
1.1 Types of Cushion and Manufacturing Processes.....	3
1.2 Cushion Uses in General.....	6
1.3 Solid Cushion Advantages and Disadvantages.....	8
1.4 Loose Fill Cushion Advantages and Disadvantages.....	12
1.5 Study Objectives.....	17
CHAPTER 2 : MATERIALS, TEST EQUIPMENT AND METHODS	
2.1 Loose Fill Cushioning Materials Evaluated.....	18
2.2 Test Equipment and Instrumented Test Block.....	24
2.3 Outer Shipping Containers.....	28
2.4 Settling Objects used in Vibration Test.....	28
2.5 ASTM Standards - 1996.....	31
2.6 Test Methods for Transmitted Shock Characteristics.....	31
2.7 Test Method to Measure Settling Due to Vibration.....	36
CHAPTER 3 : DATA AND RESULTS	
3.1 Data and Results for Transmitted Shock Tests.....	42
3.2 Data and Results for Random Vibration Tests.....	51
CHAPTER 4 : CONCLUSIONS	
4.1 Conclusions for Transmitted Shock Tests.....	56
4.2 Conclusions for Vibration Tests.....	57
APPENDICES	
APPENDIX A: TRANSMITTED SHOCK DATA.....	58
APPENDIX B: CUSHION CURVES.....	66
APPENDIX C: RANDOM VIBRATION DATA.....	81
APPENDIX D: Average Loose Fill Dimensions and Fragility Levels.....	94
LIST OF REFERENCES.....	95

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A

A

A

A6

A7

A8

B1

B2

B3

B4

B5

LIST OF TABLES

TABLE	PAGE
1	Approximate fragility levels for various classes of products.....94
2	Average Dimensions for High Density and Low Density.....94 EPS Loose fill Cushioning Peanuts
A1	Transmitted Shock Data for Newly Patented HD EPS Loosefill.....58 (Includes Cushion Weight to Product Weight Ratio and Cushion Volume to Product Weight Ratio)
A2	Transmitted Shock Data for Newly Patented HD EPS Loosefill.....59 (Includes Cushion Weight to Product Weight Ratio and Cushion Volume to Product Weight Ratio)
A3	Raw Shock Data for Newly Patented High Density EPS Loose Fill Cushion.....60 24 inches drop height (includes Peak Duration)
A4	Raw Shock Data for Newly Patented High Density EPS Loose Fill Cushion.....61 30 inches drop height (includes Peak Duration)
A5	Raw Shock Data for Newly Patented High Density EPS Loose Fill Cushion.....62 36 inches drop height (includes Peak Duration)
A6	Raw Shock Data for Newly Patented Low Density EPS Loose Fill Cushion.....63 24 inches drop height (includes Peak Duration)
A7	Raw Shock Data for Newly Patented Low Density EPS Loose Fill Cushion.....64 30 inches drop height (includes Peak Duration)
A8	Raw Shock Data for Newly Patented Low Density EPS Loose Fill Cushion.....65 36 inches drop height (includes Peak Duration)
B1	Distance Controlled Vibration data for Object 1.....81 Spherical Object
B2	Distance Controlled Vibration data for Object 2.....82 Cylindrical Object with One Open End and One Protrusion
B3	Distance Controlled Vibration data for Object 3.....83 Cylindrical Object with No Open end and No Protrusion
B4	Distance Controlled Vibration data for Object 4.....84 Rectangular/Flat Object
B5	Distance Controlled Vibration data for Object 5.....85 Cylindrical Object with One Open end and No Protrusion

TABLE	PAGE
C1 Time Controlled Vibration data for Object 1.....	86
Spherical Object	
C2 Time Controlled Vibration data for Object 2.....	87
Cylindrical Object with One Open End and One Protrusion	
C3 Time Controlled Vibration data for Object 3.....	88
Cylindrical Object with No Open end and No Protrusion	
C4 Time Controlled Vibration data for Object 4	89
Rectangular/Flat Object	

LIST OF FIGURES

FIGURE	PAGE
1a	Picture of Newly Patented EPS Loose Fill in Block Form.....22
1b	Picture of Newly Patented EPS Loose Fill in Ruffled Form.....22
2	Picture of Conventional “Small s-shaped” EPS Loose Fill.....23
3	Picture of Conventional “shell shaped” EPS Loose Fill.....23
4	Instrumented Test Block.....27
5	Encapsulated Test Block.....27
6	Drop Tester.....32
7	Vibration Table.....38
B1	Cushion Curve for 3 inch thick Newly Patented Low Density EPS.....66 24 inch Drop Height
B2	Cushion Curve for 3 inch thick Newly Patented High Density EPS.....67 24 inch Drop Height
B3	Cushion Curve for 3 inch thick Newly Patented Low Density EPS.....68 30 inch Drop Height
B4	Cushion Curve for 3 inch thick Newly Patented High Density EPS.....69 30 inch Drop Height
B5	Cushion Curve for 3 inch thick Newly Patented Low Density EPS.....70 36 inch Drop Height
B6	Cushion Curve for 3 inch thick Newly Patented High Density EPS.....71 36 inch Drop Height
D1	Low Density Cushion Weight to Product Weight Ratio vs. Deceleration, 24 inch Drop Height, First Impact.....72
D2	High Density Cushion Weight to Product Weight Ratio vs. Deceleration, 24 inch Drop Height, First Impact.....73
D3	Low Density Cushion Weight to Product Weight Ratio vs. Deceleration, 30 inch Drop Height, First Impact.....74

D4	High Density Cushion Weight to Product Weight Ratio vs. Deceleration, 30 inch Drop Height, First Impact.....	75
D5	Low Density Cushion Weight to Product Weight Ratio vs. Deceleration, 36 inch Drop Height, First Impact.....	76
D6	High Density Cushion Weight to Product Weight Ratio vs. Deceleration, 36 inch Drop Height, First Impact.....	77
E1	Cushion Volume to Product Weight Ratio (cu. in./lb.) vs. G's,..... 24 inch drop height., First Impact.	78
E2	Cushion Volume to Product Weight Ratio (cu. in./lb.) vs. G's,..... 30 inch drop height., First Impact.	79
E3	Cushion Volume to Product Weight Ratio (cu. in./lb.) vs. G's,..... 36 inch drop height., First Impact.	80
F1	Migration distance - Rectangula/Flat Object.....	90
F2	Migration distance - Spherical Object.....	91
F3	Migration distance - Cylindrical Object (No open and no protrusions).....	92
F4	Migration distance - Cylindrical Object (One open and one protrusion).....	93

CHAPTER 1: INTRODUCTION

In the distribution channel, packaged products are exposed to physical and climatic environments, all of which have a variety of forces that potentially damage products or the shipping containers. "It is very important to understand what the term 'damage' means and how it differs depending on the nature of the product. In general, it is said to be diminished goodness, soundness, or value of a product" (Singh, 1983). Damage can be anything from scuffing of the outer containers to loss of product functionality.

In the human environment, the damaging forces range from theft to liability. The damaging forces present in the atmosphere include extreme temperatures, water, gases, light and microbes. In the physical environment, packages are exposed to compressive forces, electric and electromagnetic charges, shock, vibration, and altitude changes. These forces cause crushing and distortion and occur during warehousing, handling, and transportation.

This study focused on shock and vibration effects on cushioning materials. Shock is experienced mostly when packages are dropped and vibration forces are experienced during transportation. Vibration induced by uneven road surfaces can damage a packaged product unless it is well fabricated and properly cushioned in its container.

Protection methods against shock and vibration include ruggedizing the product, unitizing, cushioning, blocking, or changing suspension systems on trucks and cars.

In this study, three different shaped Expandable Polystyrene (EPS) loose fill cushioning materials were compared for protection of three different shaped products against the hazards due to shock and settling of the products in loose fill due to vibration. Expandable Polystyrene is most commonly, although incorrectly, known as Styrofoam. Styrofoam is a trademark name (Dow Chemical Company) for a specific polystyrene insulation application. The proper terms include EPS transport packaging; EPS foam packaging, and shape molded EPS packaging.

One of the many challenges encountered by package designers is selection of the best cushioning material that is not expensive (in terms of processing, storing, dispensing, and post use) and that will protect products against damage due to shock and vibration in the distribution environment. As a result of environmental pressures, materials used in cushioning must provide product protection and also meet environmental requirements (Noone, 1995). An unbiased study of cushion manufacturing processes, uses, advantages and disadvantages of both solid and loose fill cushioning materials is recommended before a particular type of cushion is chosen to package any product. It should

be noted that "not all properties of an ideal cushion are satisfied in a single cushioning material" (Liu, 1995).

1.1 TYPES OF CUSHIONS AND MANUFACTURING PROCESSES

The types of cushions that are commercially available are: extruded planks, foam-in-place, fabricated foams, molded foams, molded paper pulp, loose fill cushion materials, suspension packs, wrapping materials such as bubble wrap, microfoam or sheet stock, and air cell systems. Examples of loose fill cushion materials are cellulose-based (curled wood shavings, popcorn), paper-based (shredded Kraft paper, honeycomb, rumpled paper, shredded corrugated board), plastic type (expanded polystyrene (EPS), polyurethane, polyethylene), and starch-based.

Rapid fill^(R) air-filled bags, manufactured by Sealed Air Corporation, utilize air to fill various size voids instead of bulky traditional fillers. An inflator nozzle is inserted into a Rapid fill^(R) bag and the bag is placed on top of products that are in a shipping container. Three of the shipping container's flaps are closed leaving one flap open to allow insertion of air into the air bag. The Inflator automatically shuts off once void in the shipping container is filled.

Eco-foam^(R), made of 95% cornstarch and a small amount of synthetic additive, is a trademark of the National Starch

and Chemical Company. To reduce Eco-foam^(R)'s susceptibility to attack by rodents and insects, flavor and aroma components of cornstarch used in Eco-foam^(R) are removed by the manufacturing process (Chonhenchob, 1994).

Naturpack^(R), made of 100% plant derivative (wheat, starch), is a trademark of the Zur Natur Zuruck Company in Germany, Canada, and using extrusion processes (Chonhenchob, 1994).

The source of corrugated loose fill cushion is high volume scrap of corrugated side trim. Corrugated loose fill is continuously manufactured on the corrugator as the material is slit and is rolled on a die that develops the unique shapes. The corrugate board that is most commonly used is C-flute with burst strength of 200 psi.

Fiberflow^(R), a paper based loose fill made of 100 % recycled paper fiber material is a trademark of FiberCel Corporation and is manufactured from 100 % post consumer recycled newsprint from the waste stream (Chonhenchob, 1994). The manufacturing process of Fiberflow^(R) involves repulping the paper fibers using water and does not require any harmful chemicals. The material is then formed into peanut half shell shaped pieces approximately 1.5 inches long and 0.75 inches in diameter (Chonhenchob, 1994).

The fabricated/molded foam shapes are generally made from four different kinds of foam: expandable polystyrene (EPS),

resilient moldable beads (PE/PS copolymers, expandable Polyethylene, expandable polypropylene, and their combinations), polyurethane (PU) and extruded polyethylene (PE).

In 1995, Modern Plastics published the major markets for Polystyrene (PS) and the approximate pounds consumed by the major markets. Loose-fill cushion consumed 90 million pounds of the total 749 million pounds of expandable-bead polystyrene, rigid EPS cushion materials consumed 108 million pounds of the total 2054 million pounds of molding (solid) PS and sheet stock cushion consumed 305 million pounds out of a total 2502 million pounds extrusion (solid) PS (Modern Plastics, 1995).

Most EPS used in packaging industry is molded into custom shapes from beads. PU foam shapes are fabricated from large blocks of foam. The producers combine two chemical components to form urethane plastic foam. Polyethylene shapes are fabricated from plank or sheet stock (Packaging, 1998).

Foam-in-place urethane is a method of producing polyurethane foam when it is required in a product package system, using a 3-step process. First, the foam is sprayed into the shipping container, and a layer of release film is placed over the rising foam. The product is then placed in the shipping container, with a sheet of film over the

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product. Lastly, more foam is sprayed into the shipping container after which the flaps are closed and secured. Through this process, a PU foam cushion is produced molded to the shape of the product and the shipping container. In some cases, the foam may be sprayed into a mold, producing a pre-molded cushion for later package assembly (Packaging, Aug. 1998).

Various formulations are available from a number of suppliers, with densities ranging from fairly soft to stiff. The majority of foam-in-place used in packaging applications is of the low-density, semi-rigid variety (Plastics Encyclopedia, 1997).

Instaflex, a semi-rigid CFC free Foam-in-place developed by Sealed Air Corporation is produced on site by pumping Polyurethane resin and Polymeric Isocyanate through the heated line to the dispenser at which the two chemicals are mixed to the proper ratio. As the liquid mixture is dispensed out, it quickly expands and solidifies to form a custom fit cushioning foam. Water vapor and carbon dioxide are emitted during the raising period that might cause concern to the operator (Charnarong, 1991).

1.2 CUSHION USES IN GENERAL.

Cushions are used in product package systems to protect the product from damage due to shock and vibration that the

product experiences in the distribution environment. For expensive products, like electronics, foam cushion are the best cushion materials. Loose fill cushions are used extensively in mail order shipments and this accounts for 65% percent of all loose fill used in U.S (Menasha Co., 1993). Mail order shipments, inexpensive products and products easy to dispense can be packaged in loose fill cushion materials (Chonhenchob, 1994). In most product package systems, loose fill is used together with the solid foam cushion material as a void filler and not for major protection of the product from the hazards of the distribution channel. In most cases, loose fill cushioning material is the best choice since it is not largely shape dependent like the solid type of cushion material which most often go through a lot of designing so as to minimize cushion material costs while at the same time protecting the product(s).

Foam shapes are widely used as a protective packaging material in a number of industries for shipping many different kinds of products. Deciding which foam to use in each application is an important design consideration. High-volume, lightweight, durable goods are often packaged in custom-molded EPS. EPS provides good single-impact protection for relatively durable items such as kitchen appliances and telephones. PU foam is used to package

fragile, extremely lightweight products without regard to volume. Resilient moldable beads combine many of the advantages of EPS foams as well as resiliency or multiple drop protection. PE is used to cushion lower-volume, heavier (10 pounds or more) and more fragile products whose fragility level is between 20 to 100 G's (Packaging, 1988).

Polyurethane sheet stock materials can be reused in loose fill form for protection of lightweight (low static stress) items (Brown, 1996).

Bubble wrap cushioning material is used to protect against damage because it has great tear strength and puncture resistance and low material and labor costs. Sealed Air Corporation (1998) claims that bubble wrap cushioning material has reduced material costs of 30% compared to polypropylene foams, and reduced 21% total costs than polyethylene loose fill cushioning material, and reduced inner packaging of 22% compared to newsprint.

1.3 SOLID CUSHION TYPES

Overall, expanded polystyrene has been the material used for applications in packaging/protection, thermal insulation, flotation, and the market has been always growing (Schneider, 1998).

U.S. production of expandable polystyrene bead stock for 1997 showed an increase of 10.5% over 1996 and was running

at the maximum production capacity of 990 million lb.
(Schneider, 1998).

EPS foam shapes have a clean, custom-designed appearance and a lower material cost than many other foam shapes. (Packaging, 1988). A disadvantage of EPS foam cushioning material is the great capital costs of molding equipment and tooling. There are long lead times required for design development, tooling and delivery of molded parts (Dow Chemical USA, 1998). Another disadvantage of EPS foam is that EPS is not resilient. Once EPS foam is crushed, much of EPS foam cushioning ability is lost (Packaging, 1988).

Resilient moldable beads have higher raw material costs, tooling costs, and capital requirements than those of EPS. The compressive creep for expandable Polyethylene (EPE is greater than that for fabricated PE or EPS (Packaging, 1988). Because the foam parts are individually molded, there may be variability in control of the process, which can result in variance in the physical properties of the foam shape (Packaging, August 1988).

PU is less expensive because of its low cost per-board-foot and multiple-impact protection. The disadvantages of PU foams are that PU foams have a low load-bearing capacity, i.e. a large volume of material is required to support a given load and insure good cushioning performance. Material variations inherent to the manufacturing process of PU

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result in inconsistencies from PU bun to bun and even within a single bun (Packaging 1988). Cushioning design data that relates to a specific supplier's product is not readily available and too much fabrication is required to protect PU from being too static or to provide flame retardance (Packaging, 1988).

PE foam shapes offer lightweight protection, and are more resilient and flexible than EPS shapes. They typically provide cushioning at higher static loads than softer materials like polyurethane foams, thus PE foam designs will usually require much less material than will designs in softer materials. PE foam is unaffected by most chemicals. It's easily fabricated, which allows for design flexibility and is available with anti-static and fire-retardant additives. Some of the disadvantages of PE are that it is more expensive than most other common cushioning materials on a per-cubic-foot basis. It is slightly abrasive for some highly polished or very sensitive painted surfaces (Chonhenchob, 1994). It requires fabrication and storage of fabricated parts. It is perceived as not handling vibration as well as softer materials (Packaging, August 1988).

The advantages of foam-in-place are that it is less expensive to use than a variety of custom-designed foam shapes when low sales volumes are predicted or when packaging products in a wide variety of shapes and sizes.

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Foam-in-place is produced when needed and minimal space is required for storage of foam parts since the chemicals used are stored in liquid form. A sophisticated design process is not usually involved when using foam-in-place (Packaging, 1988). Foam-in-place "provides an increased flexibility to pack a wide variety of product shapes, sizes and weights (Charnarong, 1991).

The disadvantages of using PU foam-in-place are that the formulations produced are not resilient. Protection of packaged products deteriorates significantly after the first impact. In this case, cushion thickness must often be increased to compensate for crushing. Foam-in-place is a messy product and application is labor intensive. Foam-in-place automation requires a substantial capital investment (Packaging, 1988). Extra precaution is required when handling, storing, and dispensing the chemicals since water vapor and carbon dioxide are emitted during the rising phase of the foam (Charnarong, 1991). Aesthetically, it is not an attractive package to look at (Packaging, 1988).

Sealed Air Corporation (1998) claims that the advantages of bubble wrap as a protection against shock and vibration hazards are: reduced material costs, labor savings, smaller outer shipping containers are used, lower shipping costs, reusable, recyclable, disposable and an effective void filler.

1.4 LOOSE FILL CUSHION TYPES

Generally, the problem with loose-fill cushion materials is that they migrate from bottom of the package product system to the top. They take up the space previously occupied by a product that settles, from top to bottom, during distribution of the product package system. Loose fill cushion materials break up easily, that is, they disintegrate/crumble after exposure to multiple drops and because of this, they have questionable shock transmission values. Most loose fill brands settle during transit due to vibration (Chonhenchob, 1994). Some loose fill can be very messy especially when they cling to packaged products, clothes, hands, and working surfaces. Loose fill cushion materials are not designed to protect heavy objects.

Another problem with loose fill cushion materials is that most of them do not have adequate interlocking capabilities. Some loose fill cushions take a long time before the peanuts interlock sufficiently during vibration. The problem is that products find their way to the bottom of the package before interlocking takes place. This implies that the product is no longer protected from the hazards of shock and vibration if the product settles and the loose fill migrates to fill the voids created by the settling product.

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Plastic loose fill cushioning materials are the best choice when used to protect products for single drops in the distribution channel. They do not disintegrate on exposure to moisture but they are recyclable thus reducing waste.

Expanded polystyrene (EPS) loose fill cushioning is widely used compared to the other loose fill cushioning materials. According to Menasha, EPS loose fill cushioning materials account for 81% of the domestic U.S share (Menasha Co., 1993). In U.K the use of expandable polystyrene (EPS) since 1992 has grown by 6-7% per year, and forecasts show that recycling of EPS will continue to grow, reaching 35-40% by the year 2010 (Anon, 1997). The EPS industry has grown on the back of the automotive and the electronic industries, which need cost effective cushion packaging materials.

Compared to other loose fill cushioning materials, EPS weighs far less than other loose fill cushion materials, it costs less on a volume basis, and it is more convenient to use (Chonhenchob, 1994). EPS loose fill is generally considered a stable cushion due to better control in the manufacturing process. The problem with EPS is that it is electrostatic sensitive especially at low humidities, causing it to cling to products or customers' clothes making it messy during unpacking (Chonhenchob, 1994). EPS loose fill peanuts are recyclable thus there is reduction in waste when these loose fill cushioning materials are used. EPS

does not degrade and so it should be recycled rather than landfilled.

EPS loose fill dispensing systems are easily installed overhead, where they don't take up valuable floor space. The loose fill material is quickly dispensed by gravity, resulting in fast packaging rates and reduced labor costs.

Starch-based loose fill cushioning materials are hydrophilic and thus less favorable for use in high humidity and high temperature regions in which the starch biodegrades when exposed to moisture. For the environmentally conscious, the biodegradability nature of starch based loose fill makes it the most favored cushion material. The problem with starch-based loose fill is that the protection capabilities of the loose fill during distribution are dependent on the amount of moisture absorbed by the starch based loose fill. Since starch-based loose fill shrinks in humid environments, its use as a void filler becomes limited for the product package system (Chonhenchob, 1994).

When starch-based loose fill becomes moist, a paste is formed and this ugly mess sticks to products and dries off on the product. This is another form of damage since the product loses aesthetic value when it reaches its destination.

If starch-based loose fill is used in dry environments, it is the best choice for cushioning because the loose fill

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can be disposed of very cheaply. Starch based loose fill can be dumped in sewers, flushed down the toilet or simply left out in the rain, leaving no residue (Larson, 1992). No energy is consumed when loose fill is disposed. The only drawback is that in humid environments, the storage period for packaged products is very short (Larson, 1992).

In 1996, Mosler Company adopted a new moldable water-degradable loose fill cushioning system called Enviromold, produced using corn or potato starch for shipping its pneumatic transfer equipment. Mosler claimed that the switch to the new cushioning system saved them \$27,000 per year in material and labor savings.

When the environmental movement took hold in the late 1980's, foam cushioning went virtually overnight from acceptance to condemnation. What had been a normal part of the American consumer experience became a symbol of waste and environmental heedlessness (Packaging (Boston Mass.)), 1993.

In London, Green Light Products company launched a wheat-based loose fill called Greenfill that it claimed to be " a low-cost biodegradable alternative to EPS loose fill protective packaging". The length of each of the wheat-based loose fill cushion material was 2 inches long. Green Light Products company claimed cost savings of 10% over EPS loose fill (Package Weekly, 1994).

In 1992, paperbased alternatives to plastic loose fill continued to be introduced. Many of the new products were made from recycled Kraft or corrugated that was crimped, cut into small pieces or otherwise prepared for manual or automatic dispensing into cases (Larson, 1992). Paper-based loose fill can be disposed by composting, a low cost and low energy disposal method. Due to this disposal method, paperbased loose fill cushioning materials are a favorite choice among other types of loose fill cushioning materials. Paperbased loose fill cushioning materials are used as void fillers and for limiting migration of product in the package during vibration (Packaging, 1998).

Cellulose-based wood shavings can be composted but the only problem is that they are too rough thus they can scratch products or puncture the primary packages that are not puncture or tear resistant. Cellulose based loose fill cushion material is limited to rigid primary packages which don't get scratched, punctured or torn by the rough wood chips.

Unlike loose-fill, solid cushions have transmissibility curves and cushion curves. There are no ASTM standards on loose-fill. ASTM 4168 is widely used for evaluating transmitted shock characteristics of loose fill cushioning materials.

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A newly patented EPS loose fill cushioning material called Isopak^(R) has great interlocking features and was compared in this study to two conventional EPS loose fill cushioning materials.

1.5 STUDY OBJECTIVES

Two different densities of a newly patented EPS loose fill cushioning material, high density and low density, were studied. These materials were compared to two other types of EPS loose fill commonly available.

Specifically, the objectives of this study were:

- 1.5.1 To compare the dynamic shock absorbing capabilities of two newly patented EPS loose fill cushioning materials at different drop heights and static loadings to the shock absorbing capabilities of previously available loose fill materials.
- 1.5.2 To develop a test method to compare settling of different shaped products in three different types of EPS loose fill cushioning materials.

CHAPTER 2: MATERIALS, TEST EQUIPMENT AND METHODS

2.1 MATERIALS

Three different shapes of EPS loose fill cushioning materials were studied. None of the EPS loose fill contained chlorofluorocarbons (CFC's) and they were made from recyclable EPS material.

All cushion materials were preconditioned according to ASTM D 4332 - 94 for a minimum of twenty-four hours at 73°F and 50% Relative Humidity.

2.1.1 EPS - Newly Patented High Density and Low Density ISOPACK^(R)

In this study, two densities of the newly patented EPS loose fill were subjected to drop tests in accordance with ASTM 4168 to compare their shock absorbing capabilities. ISOPACK is the trade name for the patented HD and LD EPS loose fill cushion material. Each peanut for both HD and LD EPS has a large S-shape configuration. PANELES AISLANTES, S.A. DE C.V., Morelia, Mich. Mexico provided both newly patented EPS for this study. Telephone no.: 011-52-(43) 23 14 87.

Blocks of EPS are cut by a patented process in a way that leaves the ends of the S-shape peanut, having a sharper curve compared to the original s-shape configuration that

has smooth ends. The newly patented EPS is shown in Figure 1. The sharper curved ends aid in interlocking of loose fill in such a way that the peanuts remain interlocked at all stages of the distribution environment, especially during a drop or vibration in the product package system.

The average dimensions for the newly patented loose fill cushion material are 0.4 inches thick, 3.1 inches long and 2.1 inches wide. These dimensions can be easily adjusted.

Unlike conventional EPS loose fill cushioning material that is poured randomly into bags, the newly patented HD and LD EPS is distributed in block form that is untangled/unruffled. The entire block of pre-cut foam is contained in a plastic bag as shown in Figure 1 a. Once discharged it expands and increases the packing volume as shown in Figure 1 b. The rectangular shape of the bag ensures about two-thirds less in transportation volume and much reduced storage costs. The block is about one-third in volume as the equivalent unruffled form.

HD ISOPACK is stiffer than LD ISOPACK is. Density for HD ISOPACK is 1.67 pounds per cubic foot (pcf) and that for LD ISOPACK is 0.74 pcf as calculated using the blocks of loose fill.

2.1.1.2 EPS - conventional "small "s" peanuts".

This loose fill was bought at Packaging Store, Frandor Shopping Center, East Lansing, MI. The cost per pound was between \$2.29-\$2.42.

Each peanut had a small s-shape configuration. The ends of the s-shape were rounded unlike those for ISOPACK that were sharp. These peanuts had some capability of interlocking but not as much as ISOPACK. The reason for this lack of excellent interlocking was the lack of sharp curved ends that help with providing interlock of peanuts for a long time during distribution.

Each peanut had the average dimensions of 0.4 inches thick, 1.3 inches long, and 0.7 inches wide. The raw data for calculations of the average thickness, length, and width of the loose fill peanuts is in Table 3. The edges of the peanut are smooth as shown in Figure 2.

Unlike ISOPACK, this regular green colored EPS loose fill is randomly poured into the bag without any particular order of the peanuts. The bag of this loose fill does not have a regular shape and so when stored on the floor, more empty/void spaces are left between stacked bags. During storage, the bags need to be restricted from toppling over since they do not stand upright, thus transportation costs for this loose fill is more than that for ISOPACK. This

conventional green s-shape peanut is cheaper than ISOPACK since overhead bags are used to dispense the material.

2.1.3 EPS - conventional "shell shaped peanuts".

This loose fill was bought at Staples, Frandor Shopping Center, East Lansing, MI. The cost of the "shell shaped peanuts" was between \$2.39-\$2.42 per pound.

As shown in Figure 3, the configuration of the peanuts is a shell. The raw data for the average dimensions of the shell peanuts used in this study are in Table 3. The average long diameter of the shell shaped loose fill is 1.1 inches and the average thickness of the shells is 0.1 inches. The density of the shell shaped loose fill used in this study was 0.3 pounds per cubic foot.

The green color additive is used to signify that the loose fill cushion is environmentally friendly compared to the virgin EPS loose fill (Chonhenchob, 1994, P. 21) but the white HD and LD ISOPACK are also environmentally friendly although they are not green in color.

The shell shaped EPS loose fill cushioning materials do not interlock like the other loose fill materials in this study. The shape of each shell allows the other shells to fit in the hollow areas of the shell thus forming a mat of impenetrable loose fill cushion.

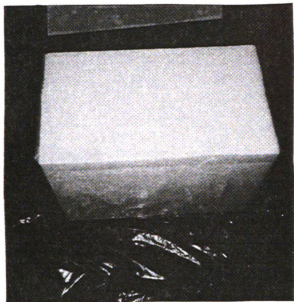


Figure 1a: Pre-cut Newly Patented EPS in Block Form

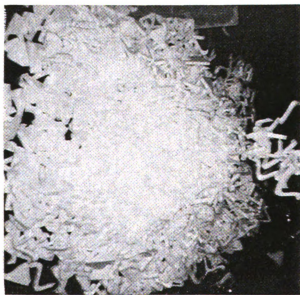


Figure 1b: Pre-cut Newly Patented EPS in Ruffled Form



Figure 2: Conventional "Small s-Shape" EPS Loose Fill

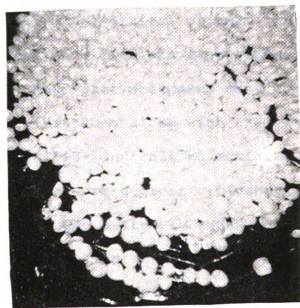


Figure 3: Conventional "Shell-Shape" EPS Loose Fill

2.2 Test Equipment

2.2.1. Vibration Test Machine

Manufacturer : Lansmont Corporation, Monterey, CA

Model No. : 10 000-10

Table size : 60 inches x 60 inches

An electrohydraulic Vibration Table was used in the vibration test. The vibration table is pushed up by high-pressure hydraulic fluid and pulled down by pistons and cylinders. The fluid is set in motion by a servo-valve, which is controlled by an electric signal. The valve releases the fluid in step with the electric signal.

The ASTM vibration tests using the electrohydraulic vibration table are very expensive due to the very high cost of the equipment. The vibration table produces vibration movement restricted in the vertical orientation since accelerations in the vertical orientation are the highest compared to the accelerations experienced in the other orientations. Real life shipments have both lateral and longitudinal vibrations along with the vertical vibrations (Pichyangkura, 1993) and rolling motions.

The three or more degrees of freedom electrohydraulic vibration tables are extremely expensive.

The transportation environment produces vibration levels over a wide range of frequencies at relatively low intensity levels. The electrohydraulic vibration system

allows a closer laboratory simulation of the actual shipping environment as compared to the mechanical vibration systems because they can be operated at fixed acceleration levels versus fixed displacement levels over a frequency range (Pichyangkura, 1993).

2.2.2 Lansmont Precision Drop Tester (PDT)

In this study, the Lansmont Precision Drop Tester was used to evaluate the shock absorbing capabilities of ISOPACK loose fill cushioning materials. The advantages of using a drop tester instead of manually dropping the packaged product is that the drop tester produces a near perfect flat drop, corner drop or edge drop. In this study, the Drop Tester was used to produce a near perfect flat drop at different drop heights.

The Lansmont Precision drop tester consists of a horizontal platform attached to a swing arm, which can be mechanically pulled down and away from the test specimen by means of a pneumatic actuator. The height of the platform is easily adjusted but the length of the swing arm restricts the minimum drop height. The arm had enough clearance beneath it to avoid hitting the ground. Accelerometers, signal conditioners and data storage apparatus were used as required in ASTM D 5276.

2.2.3 Instrumented Test Block

An 8 inch x 8 inch x 8 inch test block shown in Figure 4 was designed and constructed to be as rigid as possible and to minimize motion of the various components. The inside of the block had provisions for firmly mounting ballast weights that were adjusted to get the desired total weight of the test block. Ballast weights were added or removed to achieve the desired static loading on the cushioning material. The accelerometer was considered as a portion of the ballast weight. An accelerometer mounting attachment was placed near the center of gravity of the block. The weight of the outer shipping container was distributed as evenly as possible about the center of the bottom face of the test block (ASTM D4168 - 95).

ASTM D4168 - 95 is recommended as a shock transmission test standard for loose fill. Care must be taken when placing the instrumented test block on the loose fill cushioning material. The test block should be flat before impact to avoid loss of the vertical component of transmitted shock.

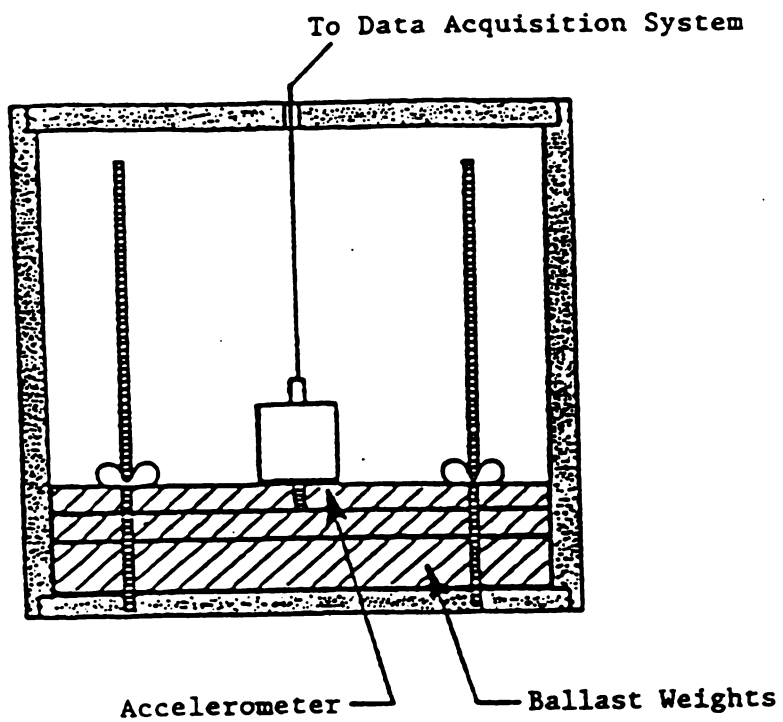


Figure 4: Instrumented Test Block

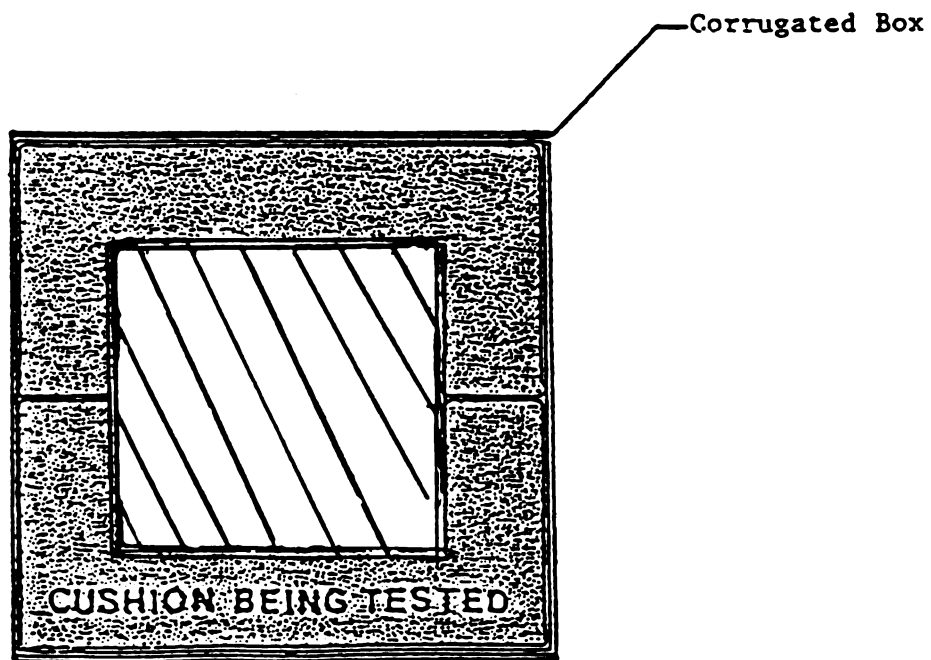


Figure 5: Encapsulated Test Block in
14 inch x 14 inch x 14 inch RSC Ready for Drop Test

2.3 Outer Shipping Containers

The type and quality of materials used in container construction form the basis for package performance. Testing of components can play a significant role in selecting those materials that will provide the greatest product protection for the lowest possible cost.

A 14 inch x 14 inch x 14 inch Regular Slotted Container (RSC) was used in the drop test study to evaluate shock absorbing capabilities of a 3 inch thick newly patented EPS loose fill cushioning material as shown in Figure 5. This allowed the 8-inch x 8 inch x 8-inch test block to be completely encapsulated inside the shipping container.

For the vibration experiment, a 12'' x 12'' x 12'' RSC was used.

2.4 Settling Objects used in Vibration Test

In the vibration section of this study, three different shaped objects were studied to evaluate the effect of shape on settling of objects in EPS loose fill cushioning materials. The objects studied were not extremely heavy. Very heavy objects were not used in this study because EPS loose fill cushion materials are used to package light weight objects.

2.4.1 Object 1 - Spherical Object

The spherical object used was a billiard ball with a smooth outer surface. The weight of the billiard ball was 147.89 grams and the diameter was 2.1 inches.

2.4.2 Cylindrical Objects

Three cylindrical objects were studied to compare the settling behavior of closed objects with no protrusions to open objects with protrusions. All three cylindrical objects had smooth outer surfaces because the roughness of the outer surface could have an effect on the settling of the objects in loose fill cushion materials.

2.4.2.1. Object 2 - Cylindrical Object with One Open End and a Protrusion.

A coffee mug was used for this part of the study. The weight, height and diameter of the coffee mug were 352.92 grams, 4.7 inches and 3.2 inches respectively.

2.4.2.2 Object 3 - Cylindrical Object with No Open End and No Protrusions

A soup can bought at a local grocery store was studied. The weight, height and diameter of the soup can were 469.28 grams, 4.4 inches and 2.9 inches respectively. During

vibration the soup can had its original contents but the paper label was removed.

2.4.2.3 Object 5 - Cylindrical Object with one open end and no protrusion

A drinking glass was studied during the pilot vibration test where distance was controlled and the settling time of each object was recorded. The drinking glass was discarded from the vibration test after raw data was collected as shown in Table B4. Before the vibration test, it was difficult to lay the drinking glass uniformly on top of the 9 inches of loose fill in the RSC. The base of the drinking glass was too heavy compared to the rest of the drinking glass such that, during vibration, the base sunk faster and deeper into the loose fill compared to the rest of the drinking glass. The other three objects had more uniform weight distribution and so they uniformly settled into the EPS loose fill cushioning materials.

2.4.3 Object 4 - Rectangular/Flat Object

The last shape investigated was a rectangular/flat object. A picture frame was the choice because the glass surface on the picture frame was as smooth as the surfaces of the other objects in the study. The weight of the picture frame and the length, width and thickness of the glass face of the

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picture frame were 239.65 grams , 8 inches, 6 inches and 0.5 inches respectively.

2.5 ASTM Standards -1996 Volume 15.09

A number of organizations have worked on developing packaging test standards in the United States. The oldest and largest is the American Society for Testing and Materials (ASTM), Committee D-10 on Packaging. Operating as a balanced consensus group the ASTM D-10 Committee has generated over a hundred packaging standards since its inception in 1914.

Drop tests were conducted in full compliance with ASTM D 4168 and ASTM D5276. ASTM D 4332 was adopted for conditioning of EPS loose fill and regular slotted containers and ASTM D 4168 was adopted for the set up of the package product system in preparation for the drop test.

2.6 Test Setup and Method for Transmitted Shock Characteristics.

The method/procedure described in ASTM D 4168 was used to determine the shock absorbing qualities of ISOPACK loose fill. The test was done in the Shock and Vibration Lab at School of Packaging, East Lansing, Michigan. The impact surface under the drop tester shown in Figure 6 was flat and was of concrete/steel as required by ASTM D5276.

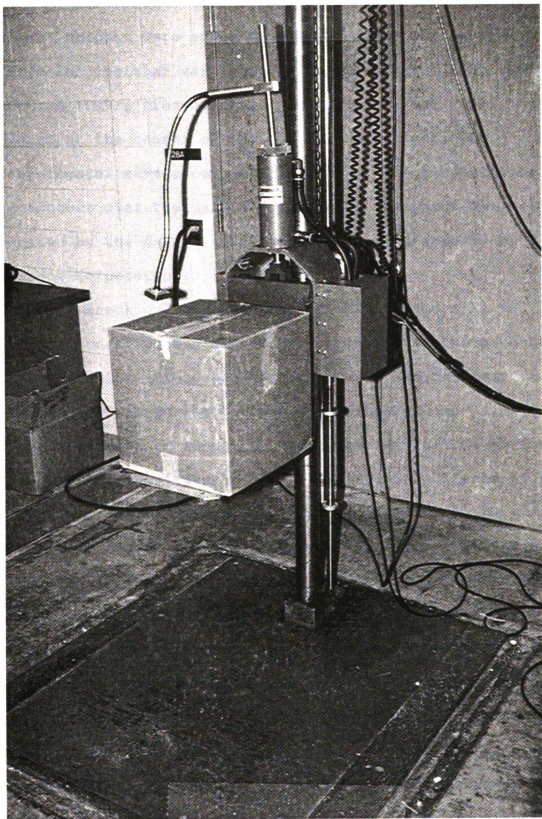


Figure 6: Drop Tester

An instrumented test block was used for this study. Ballast weights were added or removed depending on the static loading that was required to measure the transmitted shock. A 10mV/g piezoelectric accelerometer was firmly mounted at the center of the top ballast weight. The accelerometer gave a complete picture of the deceleration of the product over the entire duration of the shock as acquired by the data acquisition system manufactured by Lansmont Corporation.

This shock pulse was a plot of instantaneous acceleration at every instant during impact of the product and the cushion. Since the test equipment and the test specimen vibrate during the test, the shock pulse obtained by the test partner needs to be cleaned out for the peak G to be determined without much difficulty. This cleaning out of unwanted frequencies is called filtering. The filter frequency used in this study was past 156 Hz. This means that components whose frequency was more than 156 Hz were discarded. This is just right because if we filter at higher frequencies, we include some of the noise created by the vibrations of the ballast weights or instrumentation noise. Lower filter frequencies produce smoother shock pulses but most of the properties of the pulse are lost.

To reduce the noise and obtain a smoother shock pulse, caution was exercised to insure that the cable was straight

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and that the accelerometer remained firmly attached to the top ballast weight after the drops. An opening was made in the center of the cover of the test block for the accelerometer cable to pass through.

For both HD and LD EPS loose fill cushioning material, three inches of loose fill was poured into a 14 inch x 14 inch x 14 inch RSC. The dummy product, with the cable hanging out of its top cover, was placed in the center on a 3-inch layer of HD EPS loose fill cushion. More loose fill was then added to encapsulate the dummy product with 3 inches of the EPS loose fill cushioning material. The accelerometer cable was pulled out of the loose fill and directed out of the RSC through a small hole made at the corner of the RSC to the data acquisition system. The release mechanism was set at the desired drop heights. The product package system was manually placed on the release mechanism in such a way that the center of gravity of the product package system was in the center of the release mechanism and in a way that insured a flat face drop. There were no lifting devices to place the RSC on the release mechanism. Care was taken to insure that the cable did not interfere with the drop test in any way and that the test block was sitting perfectly flat before impact. The RSC was securely closed with tape since tape is used when shipping packages, which contain EPS loose, fill cushion materials.

Failure criteria was established before the drop test was carried on. Severity of the shock was judged according to the degree of crushing of loose fill under the test block. The outer container was checked for damage after the first drop as well as after the fifth drop.

Five consecutive drops were done for each of the five static loads and at each of the three-drop heights for both HD and LD EPS loose fill. The static loads used were 0.2, 0.35, 0.5, 0.65, and 0.8 pounds per square inch (psi). The drop heights were 24, 30, and 36 inches. There were one-minute intervals between drops. This allowed the EPS loose fill cushion material to recover.

Peak acceleration, in G's, and peak duration, in milliseconds, were recorded. G is the ratio of deceleration to the acceleration resulting from gravity.

The raw data from the drop tests is in Table A-1 and Table A-2 (Transmitted Shock Data for 3-inch thick high density and low-density ISOPACK EPS loose fill cushion material). After dropping at each static loading, each loose fill cushioning material was replaced and a new RSC was used for each of the five static loadings.

2.7 Test to Evaluate Settling during Transportation

Vibration.

Vibration testing can be used to evaluate the packaging and to reveal unknown weaknesses in the product itself, such as inadequate welds, bolts without lock washers, or loose self-taping screws.

In this study, vibration tests were done to study the settling behavior of "shell shaped", "small s-shape" and the newly patented EPS loose fill cushioning materials. Three shapes of objects that were subjected to the random vibration test were spherical, cylindrical, and rectangular. The spherical object was a billiard ball. Cylindrical objects were a soup can, a drinking glass and a coffee mug, and the flat/rectangular object was a picture frame. With the three cylindrical objects, the aim was to study the effect of the number of protrusions and the number of open ends on the settling of the objects in loose fill cushioning materials. The soup can represented a closed cylinder with no protrusions, the drinking glass represented cylindrical objects with one open end and no protrusions and the coffee cup represented cylindrical objects with one open end and one protrusion and the coffee cup represented the open cylinder.

A 12-inch x 12 inch x 12 inch RSC was placed near the edge of the vibration table. Flat restraints were screwed

5mm from the base of the RSC so as to restrict its horizontal movement on the table during vibration. The RSC was not strapped down because the objective was to simulate less than truckload (LTL) conditions and to get vertical motions that are the most severe during vibration. The top flaps of the RSC were erected using tape so as to keep them upright during vibration. A separate piece of corrugated board was placed on top of the erected flaps and taped to the erected flaps as shown in Figure 6. A small hole, big enough to allow the measuring tape through without restricting it, was made in the center of the top piece of corrugated board. This helped to keep the measuring tape straight when getting the readings instead of slanting the measuring tape and getting false measurements at an angle.

9 inches of loose fill cushion material was poured into the RSC. Before the objects were placed on the 9-inch layer of loose fill cushion material, a non-calibrated tape was tied to the objects.

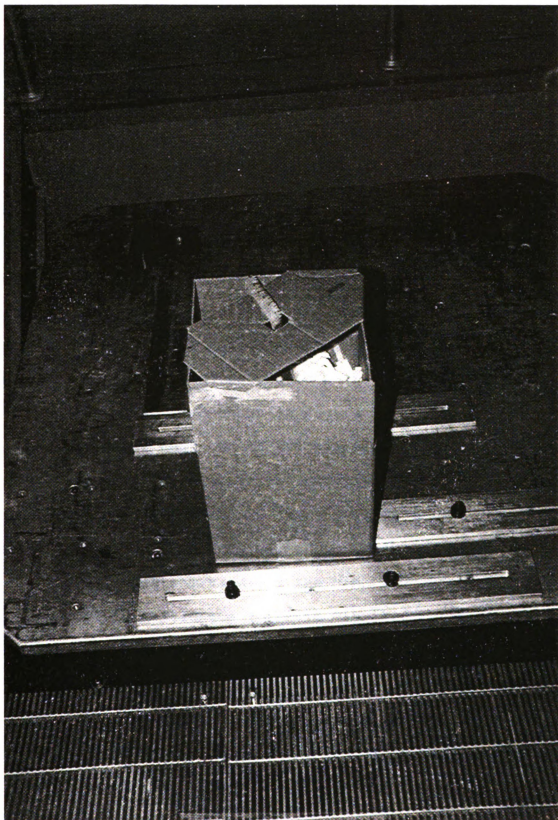


Figure 7: Vibration Test Setup

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The objects were carefully lowered and lightly placed on top of the 9 inches of loose fill material. The flexible uncalibrated tape tied to the objects was directed through the hole and the ZERO point was marked on the tape using a sharp grease pencil. The zero mark was made to coincide with the top corrugated board.

The masking tape was calibrated using a ruler whose smallest increment was 1/16 inches and a sharp permanent marker. The numbers on the masking tape were from 0 inches to 9 inches since 9 inch layer of cushion was poured into the 12 inch x 12 inch x 12 inch RSC. The marks on each masking tape were large enough to be read from the side of the vibration table as shown in Figure 7. At the beginning of the exercise, each object was placed on top of the 9-inch loose fill cushion. A different masking tape was used for each object and for each EPS loose fill material since a different zero mark had to be set for each experiment.

The PSD spectrum used for the vibration tests were the random air/truck 1.15 gms for both vibration tests.

2.7.1 Vibration tests: distance controlled

In the first pilot study settling distance was controlled. The time (in seconds) that it took the objects to settle 3 inches, 6 inches and 9 inches into the loose fill cushion materials was measured.

Before the vibration test, an uncalibrated tape was tied to the objects used in the test. The calibrations were done in increments of 1/16 inches prior to the vibration test. The zero point coincided with the top corrugated board. After this, the random vibration test was run for 3 hours non-stop per trial. The time it took the objects to sink 3, 6 and 9 inches into the loose fill was recorded. New loose fill cushion material and a new RSC was used for each 3-hour vibration trial to ensure that results are valid . During this time flow properties of each EPS loose fill was observed during the vibration test. The raw data collected was recorded in Table B1 - B5.

Data collected did not show differences in material performance so another procedure was followed where time instead of distance was controlled.

2.7.2 Vibration tests: time controlled

The second way of evaluating the settling of objects in EPS loose fill cushioning material during transportation vibration was to control time. We investigated how far the objects settled in loose fill at particular time intervals, which were every 15 seconds.

The vibration test set up was the same as the set up in the distance controlled random vibration. The random vibration test was run and every 15 seconds the settling distance was

recorded. The duration of each trial was 15 minutes. A newly constructed RSC and unused loose fill cushioning material were used for each trial. Flow properties of the three different shaped EPS loose fill cushioning materials were observed. Raw data collected was recorded in Tables C1 - C4.

The data from this procedure satisfactorily showed the differences in the settling of objects in loose fill cushioning materials during transportation vibration.

Chapter 3: DATA AND RESULTS

3.1 DATA AND RESULTS FOR TRANSMITTED SHOCK.

This study investigated the shock absorbing capabilities of the newly patented EPS loose fill cushioning materials. Tables A-1 and A-2 contain the data collected in the laboratory to evaluate transmitted shock data for high density (HD) and low density (LD) EPS ISOPACK loose fill cushioning materials. Also included in Tables A-1 and A-2 are the calculated values for cushion weight to product weight ratio and cushion volume to product weight ratio. Tables A-3 to A-8 have the raw data of peak acceleration and shock duration obtained from the shock pulses for both high and low density EPS loose fill cushioning materials.

The first drop data of HD and LD EPS loose fill cushioning materials is presented in the form of cushion curves. Cushion curves show the relationship between peak deceleration experienced by the product during the drops versus static loading, where static loading is the ratio of product weight to cushion area (the area of the cushion that is in direct contact with the product). Peak deceleration, in G's, was plotted on the vertical axis and static stress, in pounds per square inch, was plotted on the horizontal axis. The accelerometer attached to the product generated a shock pulse that was first filtered to get rid of noise from

the equipment. After filtering, peak accelerations in G's and the shock duration in milliseconds were read from the data produced by the shock pulse. The five different static loadings were obtained by dividing the different product weights by the contact area between the instrumented test block and the loose fill cushioning material.

In this study, calculated static loading was less than the actual static loading since the calculated contact area between the instrumented test block and the loose fill cushioning materials was greater than the actual contact area. It was also observed that the instrumented test block did not stay perfectly flat before impact due to migration of loose fill on impact with the test block. Some vertical component of transmitted shock was lost.

The characteristic shape of cushion curves for the resilient cushioning materials is that they slope downward at low static loadings, level off, and slope upward at higher static loadings. The cushion curves for low density and high density EPS loose fill cushioning materials for Figures B1 to B6 can be drawn in to resemble the characteristic cushion curves. Loose fill flowed in and out from underneath the product during the drops and produced peak accelerations that fluctuated from low to high and back to low unpredictably between the five static loadings for each drop height.

Resilient materials have cushion curves generated using first impact as well as the average of the 2nd to 5th impact data from the drop tests. If it is known that a package will most likely experience only one severe drop during the distribution cycle then the 1st impact published cushion curves may be used to design the cushion. If a product package system is likely to be dropped more than once, then the 2nd to 5th impact published cushion curves may be referred to when designing the cushion. Conservatively, it is safer to use the average of the 2nd to 5th impact data since the transmitted shock levels experienced after multiple impacts is always higher than the peak G for the first impact. For this study, only 1st impact cushion curves were drawn because most of the products packaged in loose fill are expected to be dropped only once severely during the distribution cycle.

After multiple drops, both High and Low Density ISOPACK cushioning material crushed under the product but high density ISOPACK crushed more than Low Density ISOPACK. The crushed loose fill caused greater shock transmittance.

From the published foam cushion curves, information about how much cushioning material to use underneath the product and how to distribute the cushioning material underneath the product is obtained. With loose fill cushioning materials, there is little need to decide how to

distribute the cushion underneath the product; a layer of loose fill will be underneath the product and so a cushion designer only needs to find out the amount or thickness of loose fill to spread underneath the product.

In order to use the cushion curves produced in this study to determine the amount of loose fill cushioning needed to provide protection, the shock fragility of products must be known. Fragility is the critical acceleration that is obtained from a Damage Boundary Curve. A Damage Boundary Curve shows the critical acceleration and critical velocity change values that cause damage to a product (ASTM D3332). Exact fragility levels for products must be obtained by testing. The approximate fragility levels for various classes of products are shown in Table 2.

After obtaining a product's fragility level, a horizontal line is drawn through the loose fill cushion curves that intersect the transmitted shock axis at the fragility level found from the Damage Boundary Curve. Only those points on the graphs that lie below the horizontal line must be used to determine the amount and type of loose fill cushioning material to encapsulate the product. Points above the horizontal line are ruled out because the transmitted shock levels above the line are higher than the fragility of the product.

Next, the static stress is determined. For a fixed product weight and an assumed fixed contact area (loose fill supports the product in parts of the base), the static stress is fixed. So, a vertical line is drawn that intersects the fixed static stress level and the horizontal fragility line. Only the curve which lies below the fragility line at that fixed stress must be used to protect the product from shock. If different cushion thicknesses lie below the horizontal line, then the thinnest layer of loose fill cushion possible must be used.

From the cushion curves shown in Figures B1 to B6, the following is known. If a first impact drop height for a known product is 36 inches, then a 3 inch thick low density EPS loose fill cushioning material can be used to package the product assuming its approximate fragility level is 75 G's. The corresponding weight for the product must be no less than 51 pounds since the safe static loading is 0.8 pounds per square inch for a fixed contact area of 64 square inches. As shown in Table 2, the fragility level of small appliances is 75 G's. The safest weight for the small appliances would be 51 pounds if it is to be packaged in a 3 inch thick low density EPS loose fill cushion material for a 36 inch first impact drop height.

EPS loose fill cushioning materials are widely used to package electronic equipment, books, and various mail order

items. Table 2 shows that the approximate fragility level for electronic equipment is 25 G's. From all the cushion curves in Figures B1 to B6, we deduce that, for a 36 inch drop height, 3 inch thick high density EPS loose fill cushion can not be used to package electronic equipment.

If the predicted drop heights for a product are 24, 30, and 36 inches, 3-inch thick low density EPS loose fill cushion can not be used to safely package products whose fragility levels are approximately 15 G's. For 24, 30, and 36 inch drop heights, the lowest fragility levels must be approximately 30 G's, 35 G's, and 20 G's respectively for any product with these fragility levels to survive the first impact drops for particular calculated product weights. It is shown in Table 2 that the approximate fragility level for precision instruments is 15 G's. Low density EPS loose fill can not be used to package precision instruments at 24, 30, and 36-inch drop heights. If the drop heights for products whose fragility levels is 15 G's are 24 inches and 30 inches, then high density EPS loose fill can be used in the product package system. A 36-inch drop height in high density EPS loose fill will damage the product since the lowest fragility for this height and material is approximately 40 G's.

When making decisions as to how much cushioning to use in a product package system, two parameters can be considered; cushion weight and cushion volume.

The amount of cushioning to be used can be determined using the weight ratio, the ratio of the weight of the cushion supporting the product to the weight of the product. The weight of the product is found by multiplying cushion density, contact area, and cushion thickness. Mathematically,

$$\text{Weight Ratio} = DA t / W = Dt / \sigma \quad (3-1)$$

where

D	=	Cushion Density (lb/in ³)
A	=	Contact Area (in ²)
t	=	Cushion Thickness (in)
W	=	Product Weight (lb.)
σ	=	Static Loading (lb/in ²)

Figures D1 to D6 show weight ratio versus transmitted shock (G's) for high density and low density EPS loose fill cushioning materials.

Another measure for the amount of cushion to be used is the ratio of cushion volume to product weight. Cushion volume is obtained by multiplying cushion area and cushion thickness. Mathematically,

Cushion volume to Product Weight Ratio =

$$At / W = t / \sigma \quad (3-2)$$

Graphs representing cushion volume to product weight ratio versus transmitted shock for both High Density and Low

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Density EPS loose fill cushioning materials are shown in Figures E1 to E3.

In Figures D1 to D6 and Figures E1 to E3, points closest to the origin must be identified since these are the points where the cushion weight to product weight ratio and cushion volume to product weight ratio are lowest. In addition, points closest to the origin have the lowest transmitted shock values. This means that we can use the least amount of material to safely package a product whose fragility level is very small.

Figures D1, D2, and E1 show that very small quantities of high density and low density EPS loose fill cushioning materials can be used to package a product whose fragility level is approximately 30 G's for a 24 inch drop height.

For the 30-inch drop height, high-density EPS loose fill cushion curves were closest to the origin. For this drop height, it is economically feasible to use this loose fill since very little amount of loose fill will be required to protect products whose fragility levels are very low.

For a 36-inch drop height, low-density EPS loose fill cushion curves were closest to the origin in both Figure D5 and Figure E3.

Comparing low and high density ISOPACK environmental cushion curves presented in this study to the environmental cushion curves of other loose fill cushioning materials

(Corrugated, Eco foam, Fiberflow, Naturpak, Popcorn, Curl Pak, and Recycled EPS) in Chonhenchob's study (Chonhenchob, 1994), low and high density ISOPACK show excellent material utilization since the least amount of material is required by weight to safely package products with very low fragility levels.

In Chonhechob's study, 100% Recycled EPS showed "the best performance in terms of percent weight utilization as compared to Corrugated, Eco foam, Fiberflow, Naturpak, Popcorn, and Curl Pak" (Chonhenchob, 1994). This study shows that low and high density ISOPACK are far better than 100% Recycled EPS since the cushion weight to product weight ratios for both high and low density ISOPACK are not more than 0.01 compared to weight ratios of more than 0.05 for 100% Recycled EPS.

High and low density ISOPACK show very little material utilization by volume compared to 100% Recycled EPS since in Figure E1 of this study, high and low density ISOPACK are closer to the origin compared to 100% Recycled EPS in Figure 16 of Chonhenchob's study (Chonhenchob, 1994). Naturpak, Eco-foam, and Fiberflow have approximately the same volume ratios as high and low density ISOPACK.

3.2 DATA AND RESULTS FOR RANDOM VIBRATION TESTS.

Tables B1 to B5 show the data collected for the pilot vibration test where distance was controlled. The distance controlled random vibration tests were run for three hours. Data collected in the pilot study did not show significant differences in cushioning material performances. Therefore a different test protocol was used where time was controlled.

Tables C1 to C4 show data for the time-controlled tests and Figures F1 to F4 show settling distance versus time for the time controlled tests. The drinking glass was discarded from these tests.

The spherical object migrated deepest into the "small s-shaped" EPS loose fill and least in the newly patented low density EPS loose fill as shown in Figure F2. The spherical object migrated downwards with ease because its surface was smooth and the "small s-shaped" loose fill did not lock up well enough to prevent the migration. On average, the spherical object migrated 6 inches downward into the low density EPS loose fill cushioning material at the end of the test.

Figure F1 shows that the rectangular/flat object migrated the least into the ISOPACK low density EPS loose fill cushioning material and the most through the "shell shaped" loose fill cushioning material. It should be noted that after 11.75 minutes

of vibration in the time controlled test, the "shell shaped" EPS loose fill formed a solid looking mat of cushion that prevented the rectangular/flat object from migrating further down whereas during the same time, the rectangular/flat object in the "small s-shaped" loose fill continued to migrate down the loose fill steadily. If the rectangular/flat object was vibrated for a longer period in "shell shaped" loose fill, it would not migrate significantly further because the "shell shaped" loose fill formed a mat underneath the rectangular/flat object that prevented further migration of the rectangular/flat object through the loose fill. If the rectangular/flat object was vibrated longer in the "small s-shaped" loose fill cushioning material, it would have migrated further down the loose fill since the "small s-shaped" loose fill did not have good interlocking capabilities. From this test it was observed that more "small s-shaped" EPS loose fill cushioning material would be required under flat objects than "shell shaped" loose fill cushioning materials.

Therefore, although the rectangular/flat object migrated the most into the "shell shaped" EPS loose fill at the end of fifteen minutes, with increased vibration test time, the rectangular/flat object migrated the most in the "small s-shaped" EPS loose fill cushioning materials as shown in Figure 1.

The cylindrical object with one open end and one protrusion also migrated more through the "small s-shaped" EPS loose fill cushioning material and the least through the newly patented low density EPS loose fill cushioning material as shown in Figure F4. The smooth surface and shape of the cylindrical object with one open end and one protrusion contributed greatly to the loss of interlocking systems of all the three types of EPS loose fill used in this study. All three types of EPS loose fill kept moving around and into the coffee cup during vibration. The "small s-shaped" loose fill cushioning materials and the "shell shaped" loose fill were so small that they found a way into the cylindrical object with one open end and one protrusion thus giving the object more room to migrate downwards. As noted in Table 1, the dimensions of the newly patented low density EPS loose fill were bigger than those of "shell shaped" and "small s-shaped" EPS loose fill cushioning materials. Due to their size and excellent interlocking capabilities, they showed better performance.

The cylindrical object with no open ends and no protrusions also migrated the most down the "shell shaped" EPS loose fill and the least down the low density EPS loose fill cushioning materials as shown in Figure F3. The cylindrical object with no open ends and no protrusions found its way down to the bottom of the box in the "shell

shaped" EPS loose fill cushioning material. Comparing Figure F4 for the cylindrical object with one open end and one protrusion to Figure F3 for the cylindrical object with no open ends and no protrusions, the heavy weight of the cylindrical object with no open ends and no protrusions contributed greatly to its migration all the way to the bottom of the box. After fifteen minutes of vibration the cylindrical object with no open ends and no protrusions easily found its way to the bottom of the box through the "small s-shaped" loose fill cushioning materials.

Another comparison was made on the basis of migration distance of each type of object in each type of loose fill at the end of fifteen minutes.

Using the time controlled results for the newly patented low density EPS loose fill, it was observed that the cylindrical object with no open ends and no protrusions migrated least (approximately 1.6 inches) followed by the rectangular/flat object (approximately 2.4 inches), the spherical object (approximately 6.3 inches), and the cylindrical object with one open end and one protrusion (approximately 6.4 inches) which migrated the most. The heavy weight of the cylindrical object with no open ends and no protrusions helped the newly patented low density EPS loose fill to interlock to each other early in the vibration test. Unlike the cylindrical object with one open end and

one protrusion, no loose fill material flowed into the cylindrical object with no open ends and no protrusions. The lighter objects did not compress the loose fill enough to prevent the loose fill from flowing freely around the lighter objects.

It was observed that migration of objects and settling of loose fill depend on object shape, loose fill peanut shape, object weight, and object dimensions. The bigger objects (greater dimensions) migrated the least through loose fill cushioning materials but loose fill peanuts settled more when objects were bigger and heavier. Tapered loose fill cushioning materials settled the least and the smooth curved "s-shape" loose fill cushioning materials settled the most.

CHAPTER 4: CONCLUSIONS

4.1 Conclusions for Transmitted Shock Tests

Two newly patented EPS loose-fill cushioning materials (ISOPACK) of two densities were studied so as to compare their protective capabilities against shock during drops. The conclusions made based on the data collected and results discussed in the previous chapter were:

1. Both low and high density ISOPACK loose fill cushioning materials migrate upwards after a drop leaving the product unprotected if insufficient loose fill is used.
2. Both low and high density ISOPACK loose fill cushioning materials were crushed under the product after the second impact especially at high static loads, therefore, both low and high density ISOPACK loose fill cushioning materials should be used for products that will experience single impacts and not multiple impacts during the distribution cycle.
3. Both high and low density ISOPACK show excellent material utilization, since the least amount of material is required both by weight and volume to safely package products with very low fragility levels.
4. High Density ISOPACK is best for low drop heights and Low Density ISOPACK is best for high drop heights.

4.2 Conclusion for Vibration Tests

Three different shapes of objects: spherical, cylindrical, and rectangular were studied to see if migration of objects during transportation vibration in three different EPS loose fill material was shape dependent.

Based on the data collected and the results discussed in the previous chapter the following conclusions were made:

1. Low density ISOPACK loose fill cushioning material flowed the least and had the best interlocking capabilities. Low density ISOPACK loose fill prevented migration of all objects in the study to the bottom of the corrugated box.
2. All objects migrated significantly more in the "small s-shaped" loose fill followed by the "shell-shaped" EPS loose fill, and then in the ISOPACK loose fill cushioning materials.
3. The difference between the migration distance of the spherical and cylindrical objects through the "small s-shaped" EPS loose fill was significantly small.
4. The thin layer of loose fill that remains under the product after vibration compounds shock problems.
5. Vibration settling depends on object size and object shape as well as on loose fill peanut size and loose fill peanut shape. Smaller objects migrate deeper into loose fill compared to bigger objects. Bigger and more tapered loose fill peanuts settle the least.

APPENDICES

APPENDIX A

Table A1: High Density ISOPACK Transmitted Shock Data
(includes weight ratio and volume ratio).

Static loading (psi)	Drop Sequence	24" drop height	30" drop height	36" drop height	cushion weight to product weight ratio, Dt/s (lb/lb)	cushion volume to product weight ratio, t/s (cu.in/lb)
		156 Hz	156 Hz	156 Hz		
0.2	1	31.36	33.34	38.54	0.0145	15.00
	2	41.30	46.55	51.83		
	3	47.69	52.15	59.25		
	4	45.72	52.15	61.93		
	5	48.01	56.11	60.16		
average of 2nd to 5th drops		44.66	51.33	56.00		
0.35	1	29.90	27.45	35.07	0.0083	8.57
	2	43.89	48.84	50.95		
	3	49.61	59.80	55.33		
	4	50.95	56.66	64.59		
	5	56.04	63.93	58.40		
average of 2nd to 5th drops		49.97	56.39	54.68		
0.5	1	26.38	25.85	36.29	0.0058	6.00
	2	37.91	46.18	60.36		
	3	44.91	62.31	73.69		
	4	48.63	68.62	78.81		
	5	46.42	72.17	81.93		
average of 2nd to 5th drops		42.17	59.18	71.15		
0.65	1	9.94	7.17	38.35	0.0045	4.62
	2	14.31	15.75	66.36		
	3	13.18	17.93	88.10		
	4	13.18	17.89	89.09		
	5	13.18	17.67	72.35		
average of 2nd to 5th drops		13.75	16.71	69.36		
0.8	1	8.54	17.36	38.93	0.0036	3.75
	2	12.91	18.06	59.45		
	3	15.73	18.37	76.42		
	4	16.06	19.59	89.91		
	5	16.84	23.35	101.24		
average of 2nd to 5th drops		14.88	20.71	80.35		

Table A2: Low Density ISOPACK Transmitted Shock Data
(includes weight ratio and volume ratio).

Static loading (psi)	Drop Sequence	24" drop height	30" drop height	36" drop height	cushion weight to product weight ratio, Dt/s (lb/lb)	cushion volume to product weight ratio, t/s (cu.in/lb)
		156 Hz	156 Hz	156 Hz		
0.2	1	31.36	33.34	38.54	0.0145	15.00
	2	41.30	46.55	51.83		
	3	47.69	52.15	59.25		
	4	45.72	52.15	61.93		
	5	48.01	56.11	60.16		
average of 2nd to 5th drops		44.66	51.33	56.00		
0.35	1	29.90	27.45	35.07	0.0083	8.57
	2	43.89	48.84	50.95		
	3	49.61	59.80	55.33		
	4	50.95	56.66	64.59		
	5	56.04	63.93	58.40		
average of 2nd to 5th drops		49.97	56.39	54.68		
0.5	1	26.38	25.85	36.29	0.0058	6.00
	2	37.91	46.18	60.36		
	3	44.91	62.31	73.69		
	4	48.63	68.62	78.81		
	5	46.42	72.17	81.93		
average of 2nd to 5th drops		42.17	59.18	71.15		
0.65	1	9.94	7.17	38.35	0.0045	4.62
	2	14.31	15.75	66.36		
	3	13.18	17.93	88.10		
	4	13.18	17.89	89.09		
	5	13.18	17.67	72.35		
average of 2nd to 5th drops		13.75	16.71	69.36		
0.8	1	8.54	17.36	38.93	0.0036	3.75
	2	12.91	18.06	59.45		
	3	15.73	18.37	76.42		
	4	16.06	19.59	89.91		
	5	16.84	23.35	101.24		
average of 2nd to 5th drops		14.88	20.71	80.35		

Table A3: 24" drop height, High Density ISOPACK.

Static loading, psi	Drop Sequence	Peak Acceleration, G	Peak duration, ms
0.20	1	31.36	25.10
	2	41.30	21.15
	3	47.69	19.15
	4	45.72	19.80
	5	48.01	17.85
0.35	1	29.90	27.05
	2	43.89	19.90
	3	49.61	18.15
	4	50.95	18.15
	5	56.04	16.70
0.50	1	26.38	24.90
	2	37.91	23.85
	3	44.91	21.60
	4	48.63	22.00
	5	46.42	20.25
0.65	1	9.94	3.10
	2	14.31	17.90
	3	13.18	16.40
	4	13.18	16.40
	5	13.18	15.50
0.80	1	8.54	34.60
	2	12.91	29.55
	3	15.73	17.80
	4	16.06	25.95
	5	16.84	17.90

Table A4: 30" drop height, High Density ISOPACK.

Static loading, psi	Drop Sequence	Peak Acceleration, G	Peak duration, ms
0.20	1	33.34	24.35
	2	46.55	19.05
	3	52.15	18.30
	4	52.15	18.30
	5	56.11	17.85
0.35	1	27.45	21.90
	2	48.84	20.15
	3	59.8	16.95
	4	56.66	18.60
	5	63.93	16.55
0.50	1	25.85	24.90
	2	46.18	21.75
	3	62.31	19.25
	4	68.62	17.75
	5	72.17	18.20
0.65	1	7.17	3.00
	2	15.75	22.70
	3	17.93	13.60
	4	17.89	13.60
	5	17.67	14.05
0.80	1	17.36	29.35
	2	18.06	28.10
	3	18.37	24.00
	4	19.59	26.45
	5	23.35	23.95

Table A5: 36" drop height, High Density ISOPACK.

Static loading, psi	Drop Sequence	Peak Acceleration, G	Peak duration, ms
0.20	1	38.54	22.35
	2	51.83	17.95
	3	59.25	16.55
	4	61.93	16.45
	5	60.16	17.25
0.35	1	35.07	25.20
	2	50.95	18.70
	3	55.33	18.20
	4	64.59	16.65
	5	58.40	17.85
0.50	1	36.29	24.30
	2	60.36	16.30
	3	73.69	14.10
	4	78.81	13.45
	5	81.93	12.90
0.65	1	38.35	19.15
	2	66.36	14.00
	3	88.10	12.90
	4	89.09	11.60
	5	72.35	12.75
0.80	1	38.93	23.15
	2	59.45	17.40
	3	76.42	15.30
	4	89.91	13.75
	5	101.24	13.40

Table A6: 24" drop height, Low Density ISOPACK.

Static loading, psi	Drop Sequence	Peak Acceleration, G	Peak duration, ms
0.20	1	20.34	24.95
	2	34.33	30.70
	3	37.44	28.30
	4	39.89	25.95
	5	40.78	26.30
0.35	1	40.45	25.40
	2	59.06	18.50
	3	64.54	18.20
	4	67.00	17.15
	5	73.42	14.40
0.50	1	25.75	23.80
	2	58.72	17.95
	3	68.32	15.90
	4	75.62	14.60
	5	78.64	14.00
0.65	1	40.10	21.75
	2	50.26	18.90
	3	63.90	16.70
	4	67.95	15.55
	5	73.39	14.50
0.80	1	37.63	23.45
	2	57.05	19.85
	3	71.15	16.80
	4	73.76	15.45
	5	69.41	16.10

Table A7: 30" drop height, Low Density ISOPACK.

Static loading, psi	Drop Sequence	Peak Acceleration, G	Peak duration, ms
0.20	1	38.73	27.05
	2	49.38	22.55
	3	54.12	20.7
	4	55.94	20.55
	5	60.98	19.1
0.35	1	27.98	21.95
	2	54.89	20.35
	3	64.44	17.6
	4	79.20	35.65
	5	80.45	12.65
0.50	1	47.49	20.4
	2	71.72	17.9
	3	81.12	14.75
	4	91.76	13.45
	5	88.43	13.8
0.65	1	28.06	26.55
	2	50.96	18.45
	3	77.49	15.4
	4	88.16	13.05
	5	113.05	9.45
0.80	1	61.52	19.9
	2	111.17	17.65
	3	81.48	14.4
	4	137.39	12.5
	5	123.58	12.05

Table A8: 36" drop height, Low Density ISOPACK.

Static loading, psi	Drop Sequence	Peak Acceleration, G	Peak duration, ms
0.20	1	13.56	20.20
	2	15.32	18.45
	3	16.01	18.40
	4	18.97	15.70
	5	18.99	15.10
0.35	1	17.68	14.75
	2	23.84	14.35
	3	25.32	12.25
	4	27.61	11.85
	5	30.27	10.95
0.50	1	23.42	15.20
	2	26.79	13.70
	3	34.44	11.35
	4	37.95	8.30
	5	35.72	9.50
0.65	1	33.76	10.50
	2	44.85	7.70
	3	50.45	7.20
	4	46.93	7.20
	5	28.69	4.15
0.80	1	85.49	21.80
	2	83.08	22.60
	3	128.62	6.15
	4	153.52	11.00
	5	118.77	20.35

APPENDIX B

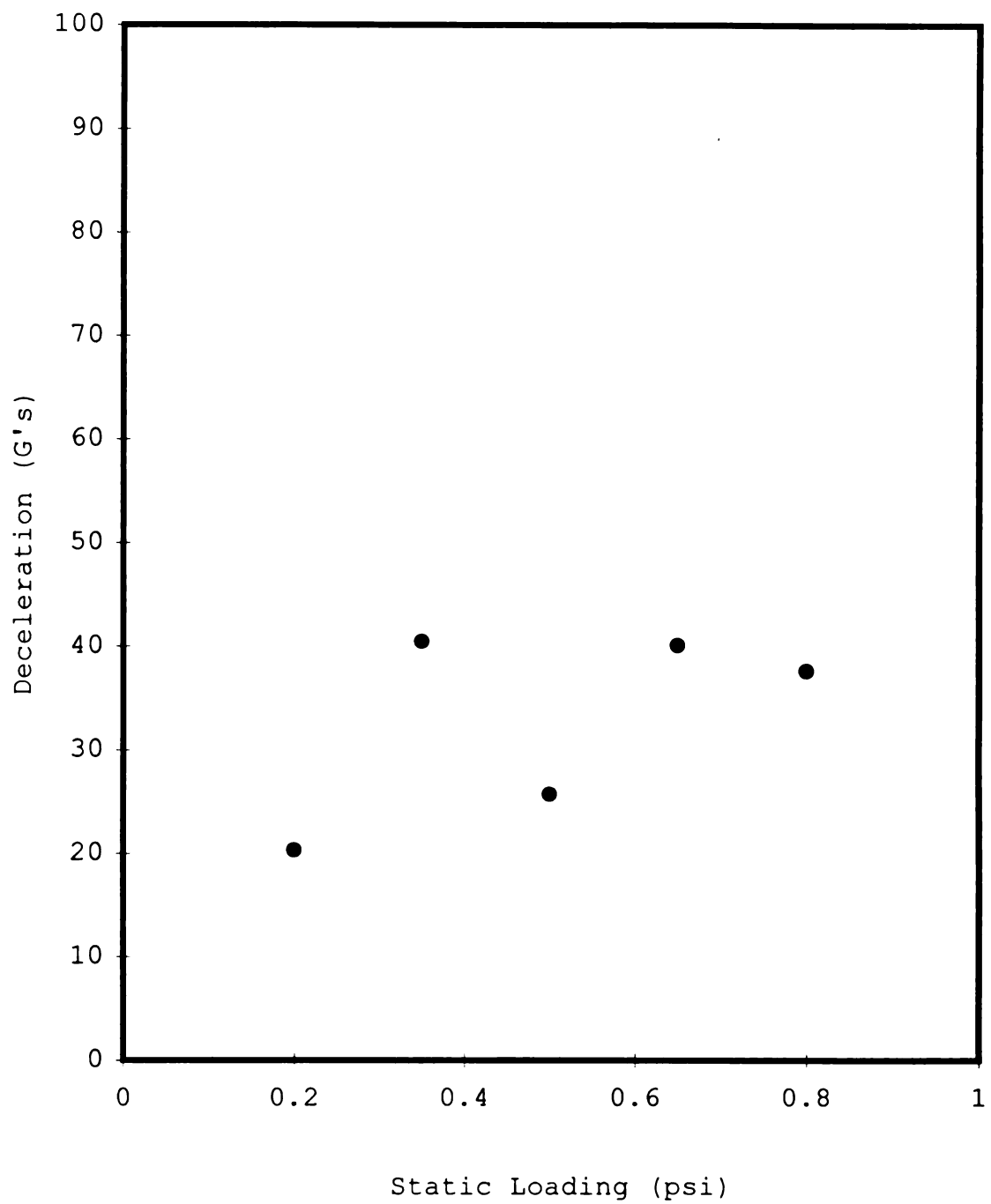


Figure B1: Cushion Curve for 3 inch thick Low Density ISOPACK from 24 inch drop height.

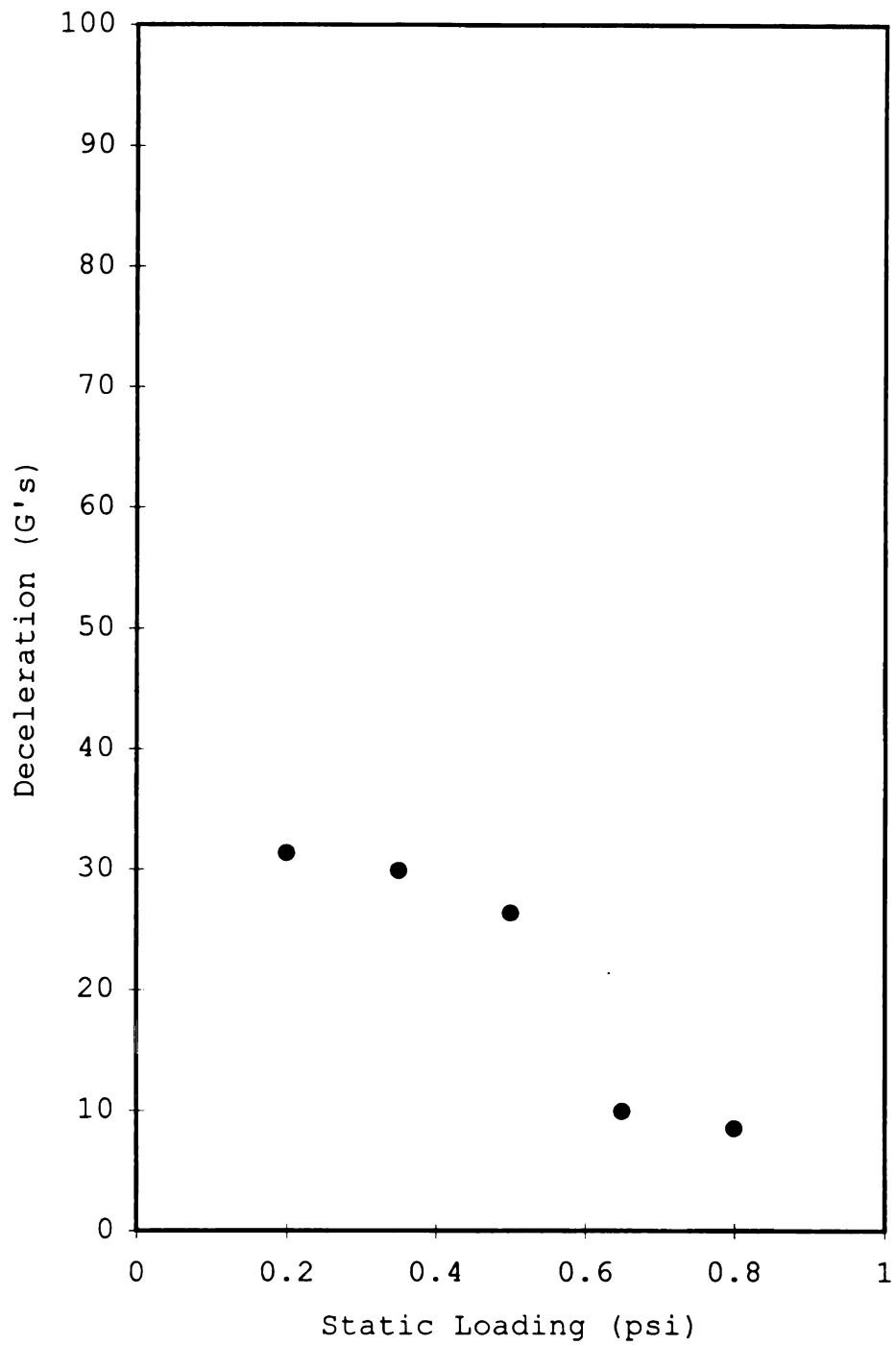


Figure B2: Cushion Curve for 3 inch thick High Density ISOPACK from 24 inch drop height.

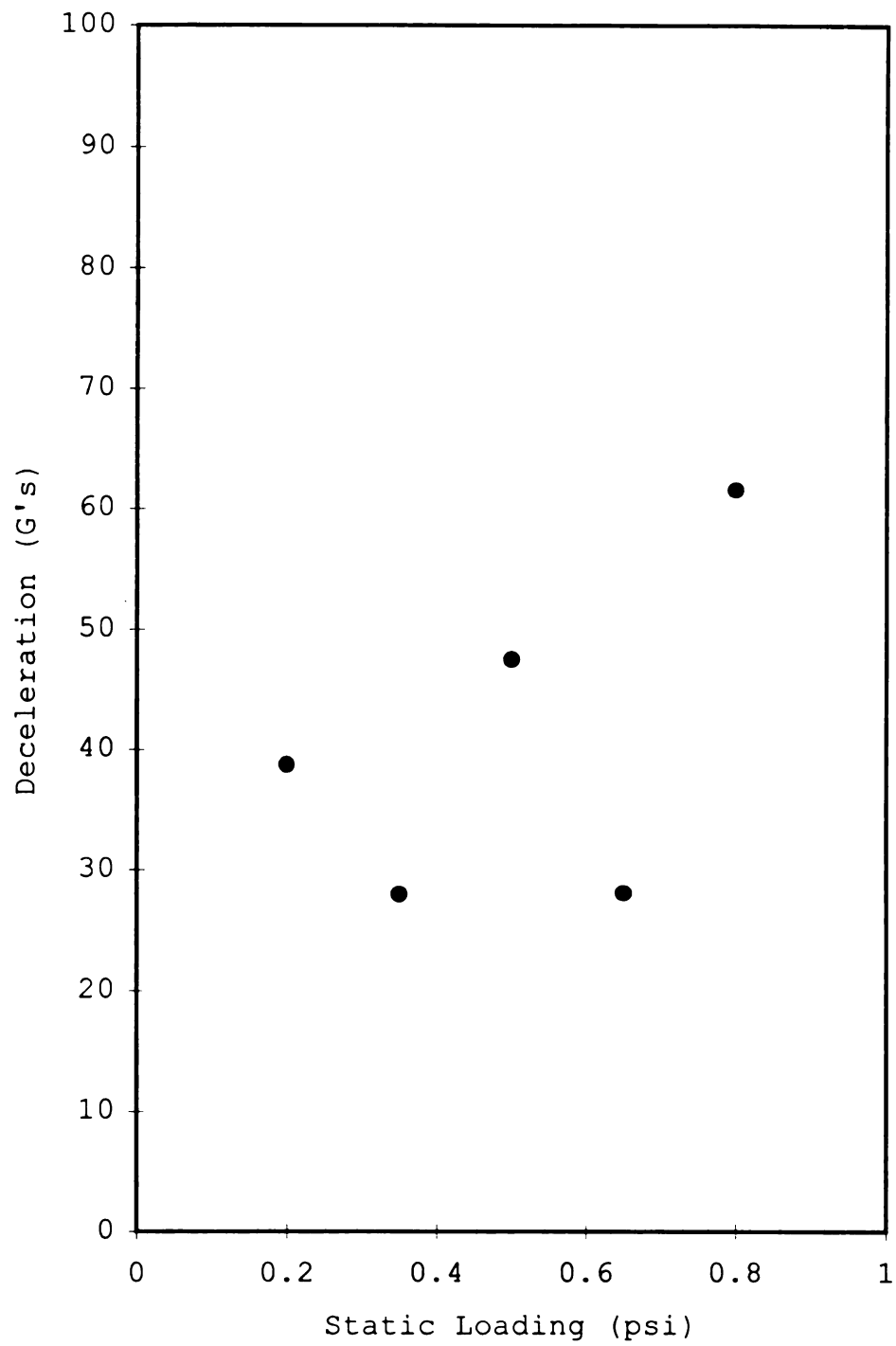


Figure B3: Cushion Curve for 3 inch thick Low Density ISOPACK from 30 inch drop height.

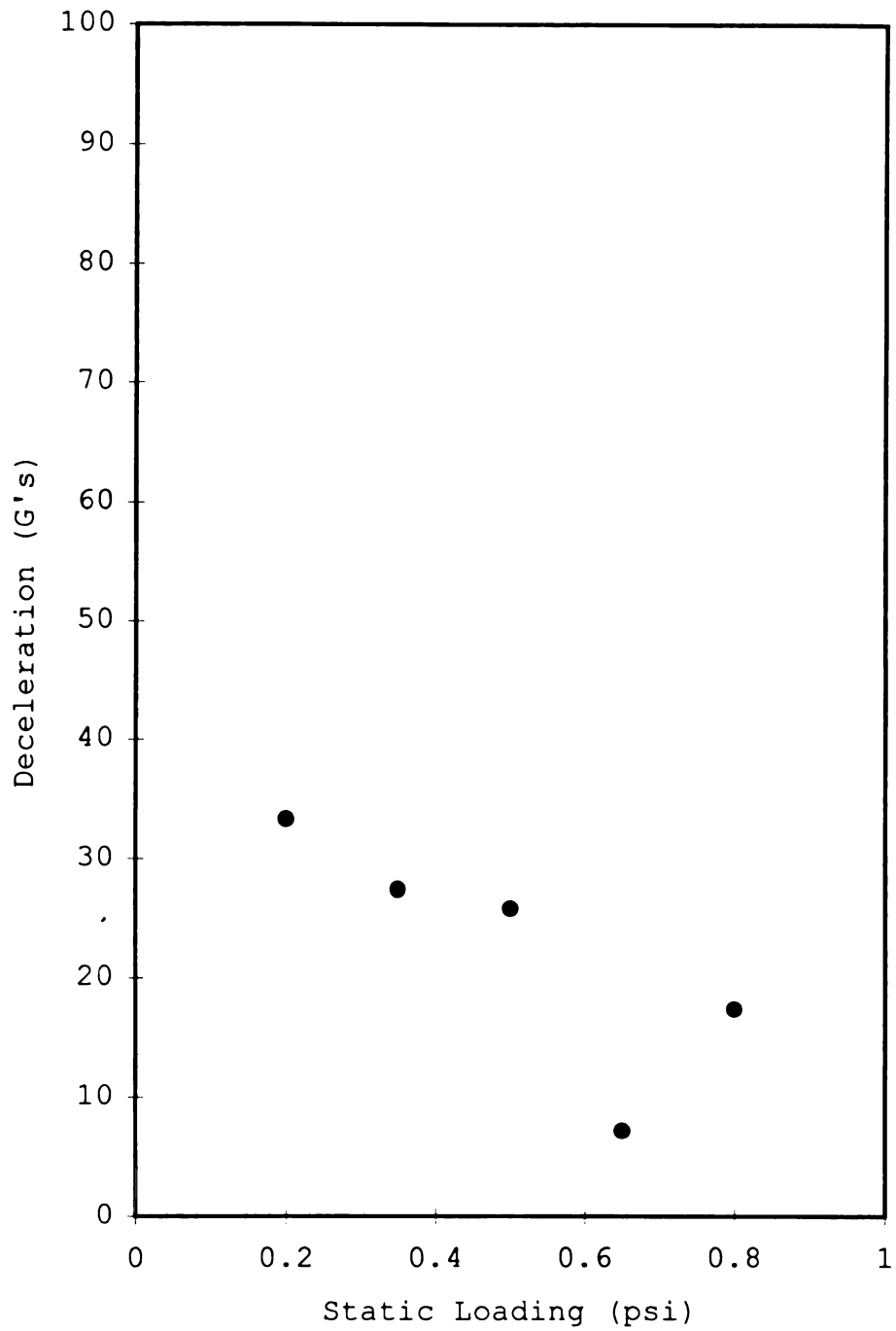


Figure B4: Cushion Curve for 3 inch thick High Density ISOPACK from 30 inch drop height.

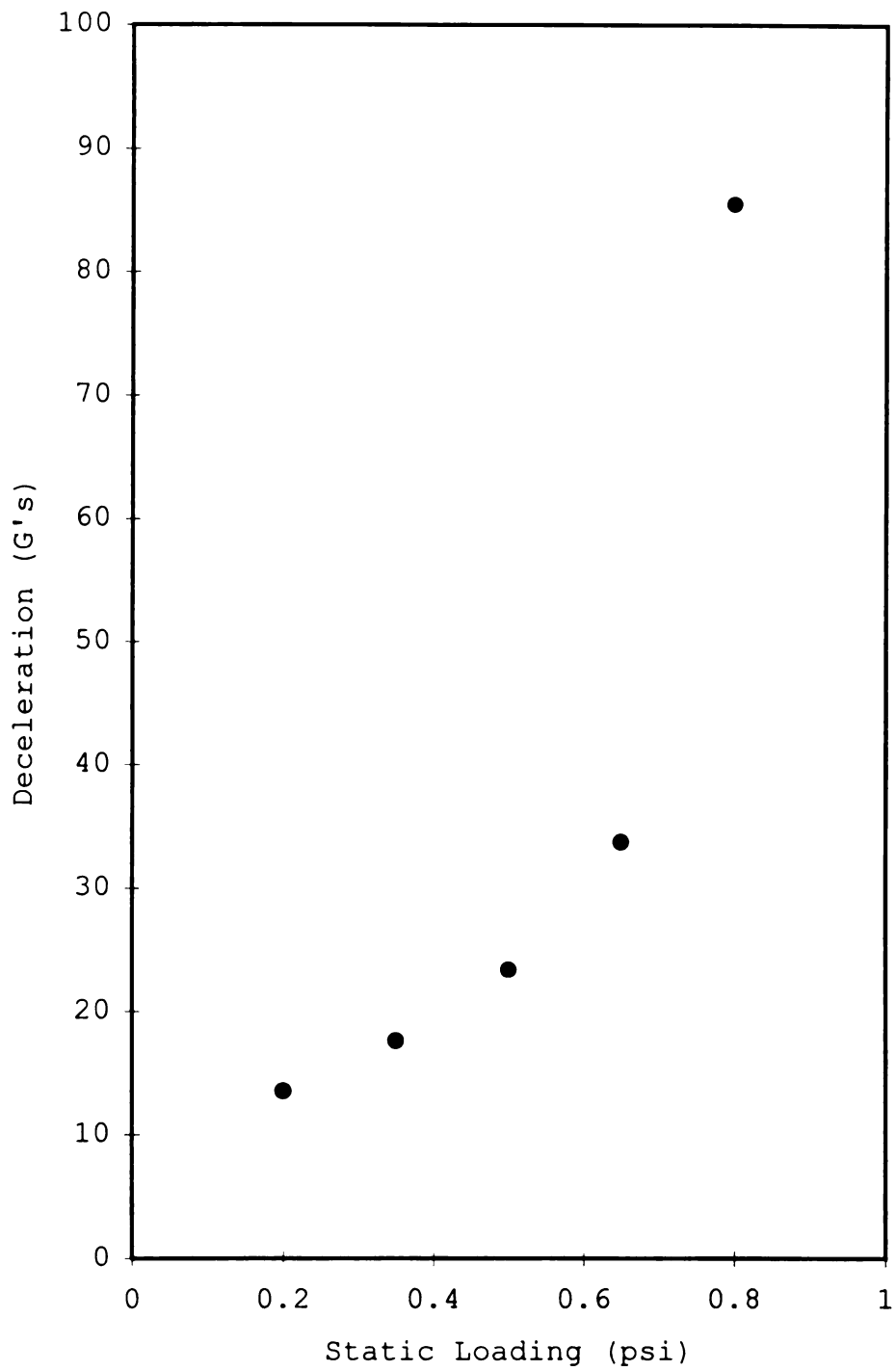


Figure B5: Cushion Curve for 3 inch thick Low Density ISOPACK from 36 inch drop height.

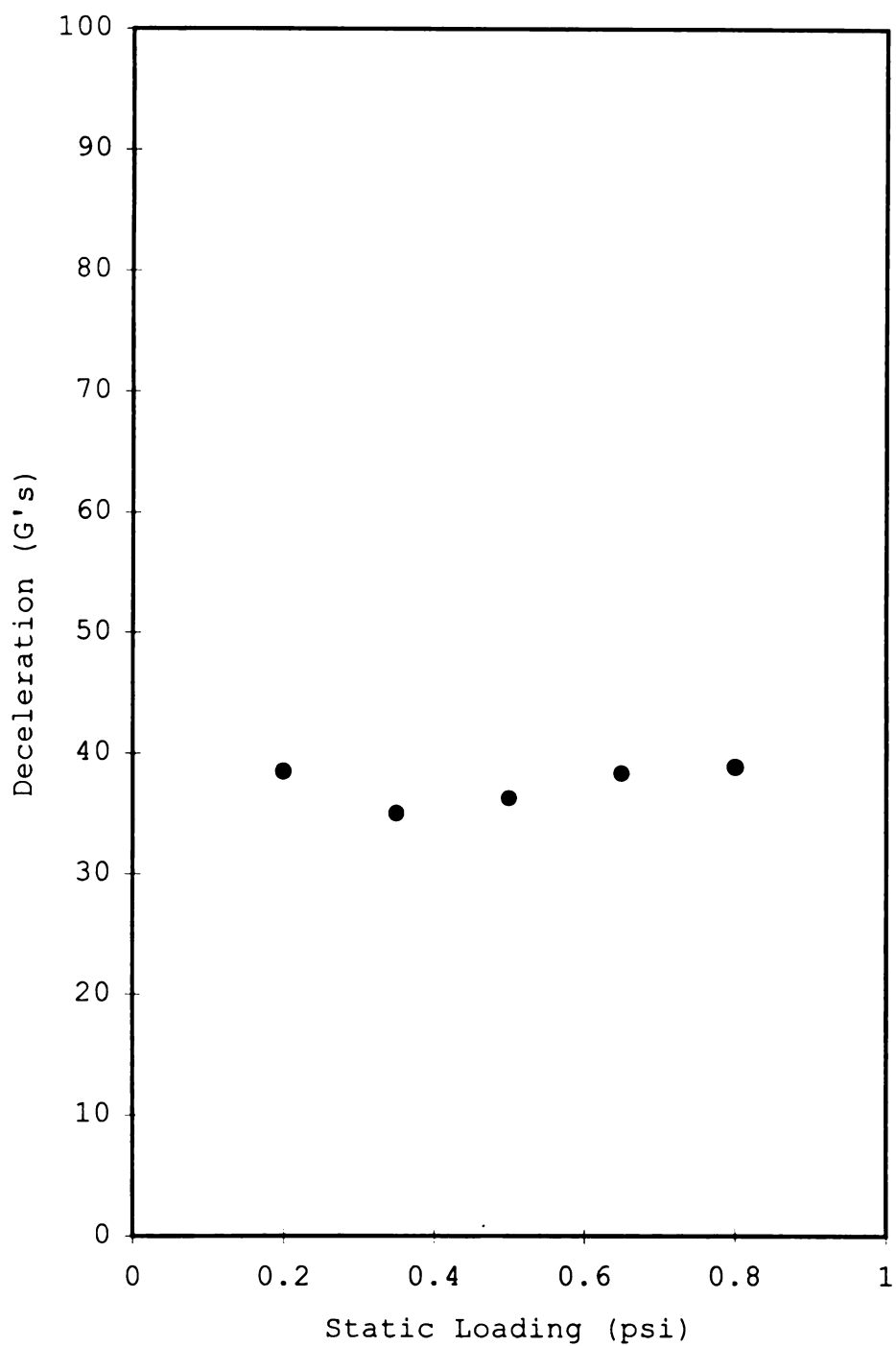


Figure B6: Cushion Curve for 3 inch thick High Density ISOPACK from 36 inch drop height.

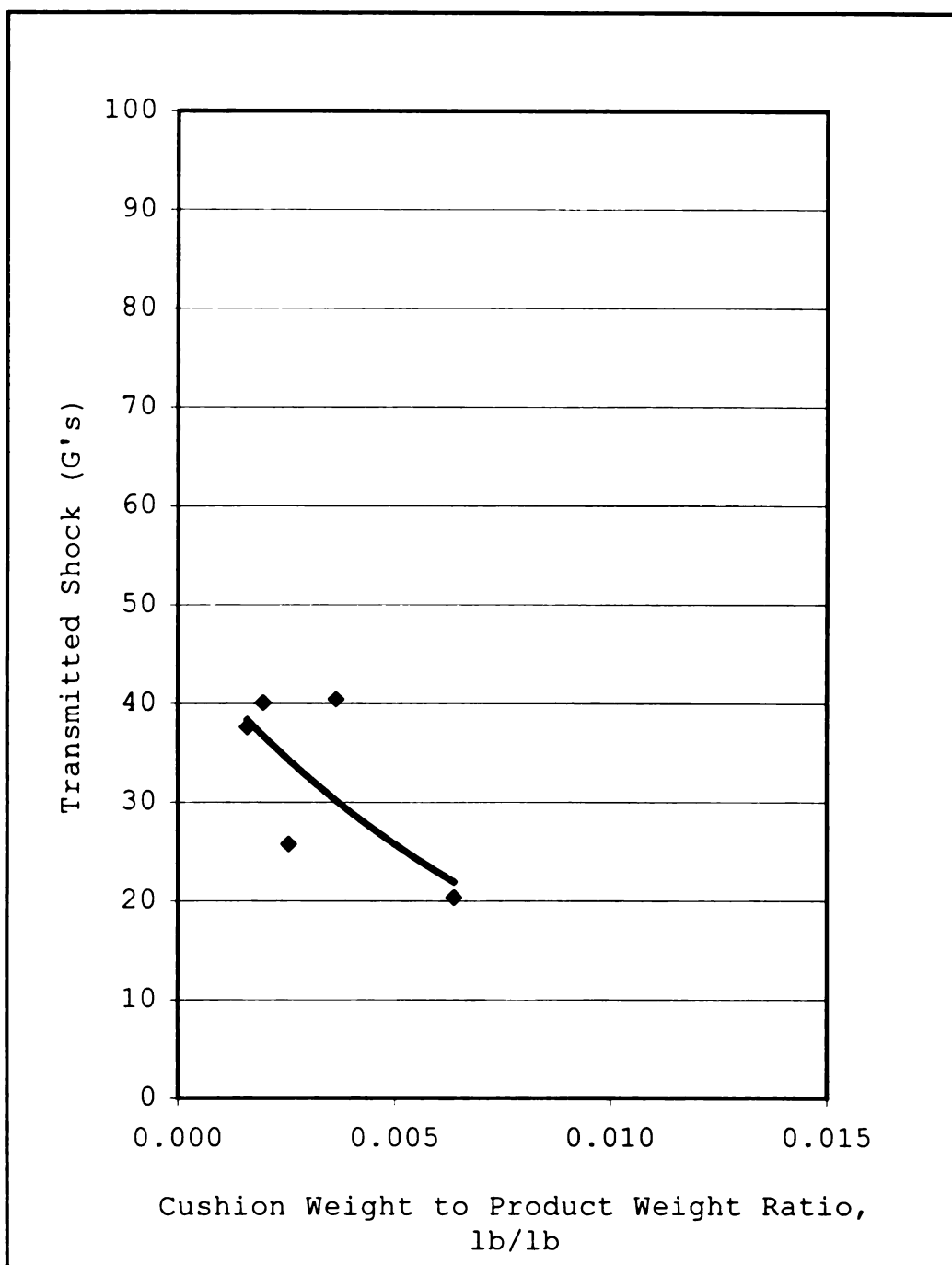


Figure D1: Low Density ISOPACK Transmitted Shock (G's) versus Cushion Weight to Product Weight Ratio, 24-inch drop height, First Impact.

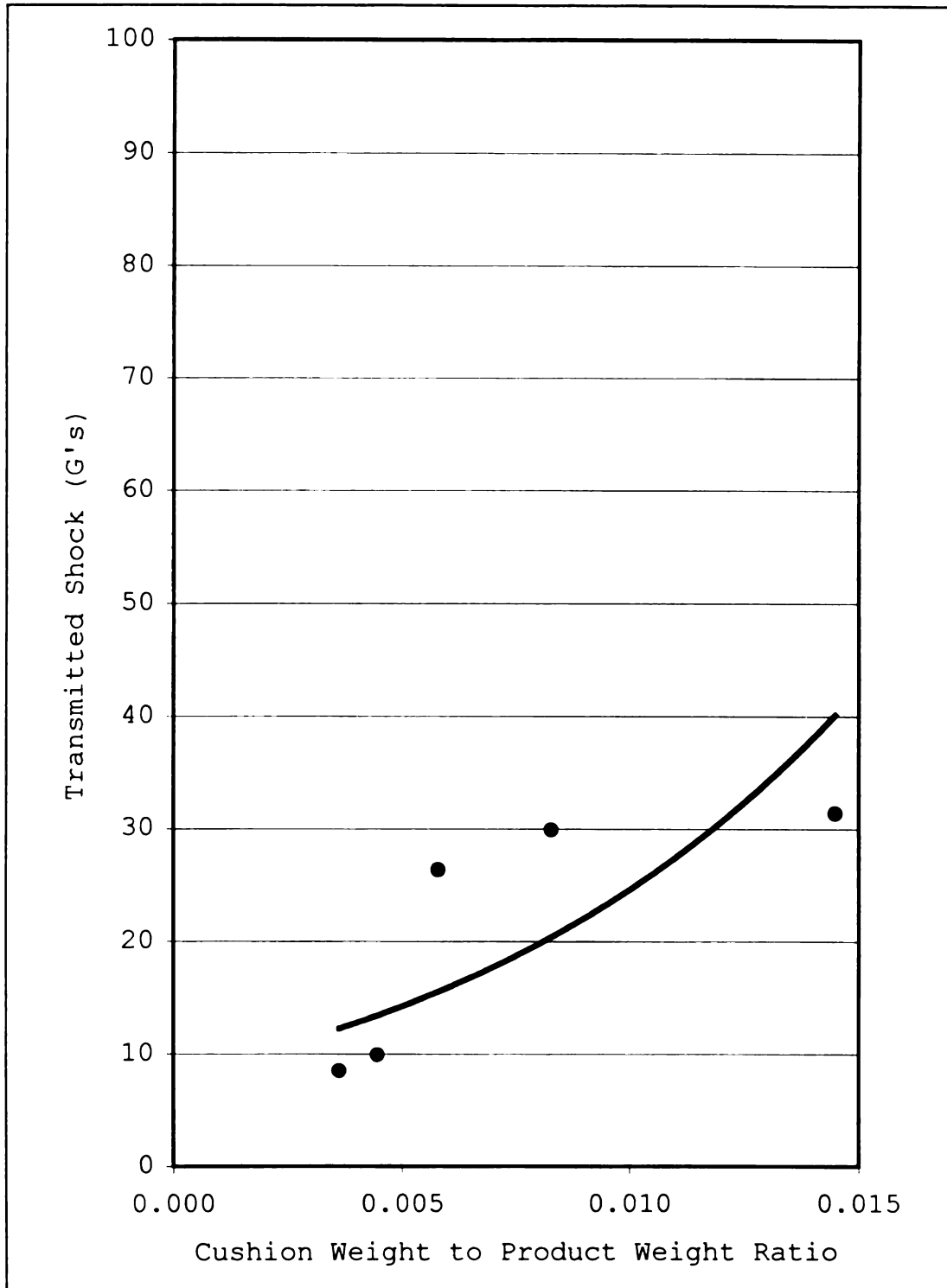


Figure D2: High Density ISOPACK Transmitted Shock (G's) versus Cushion Weight to Product Weight Ratio, 24-inch drop height, First Impact.

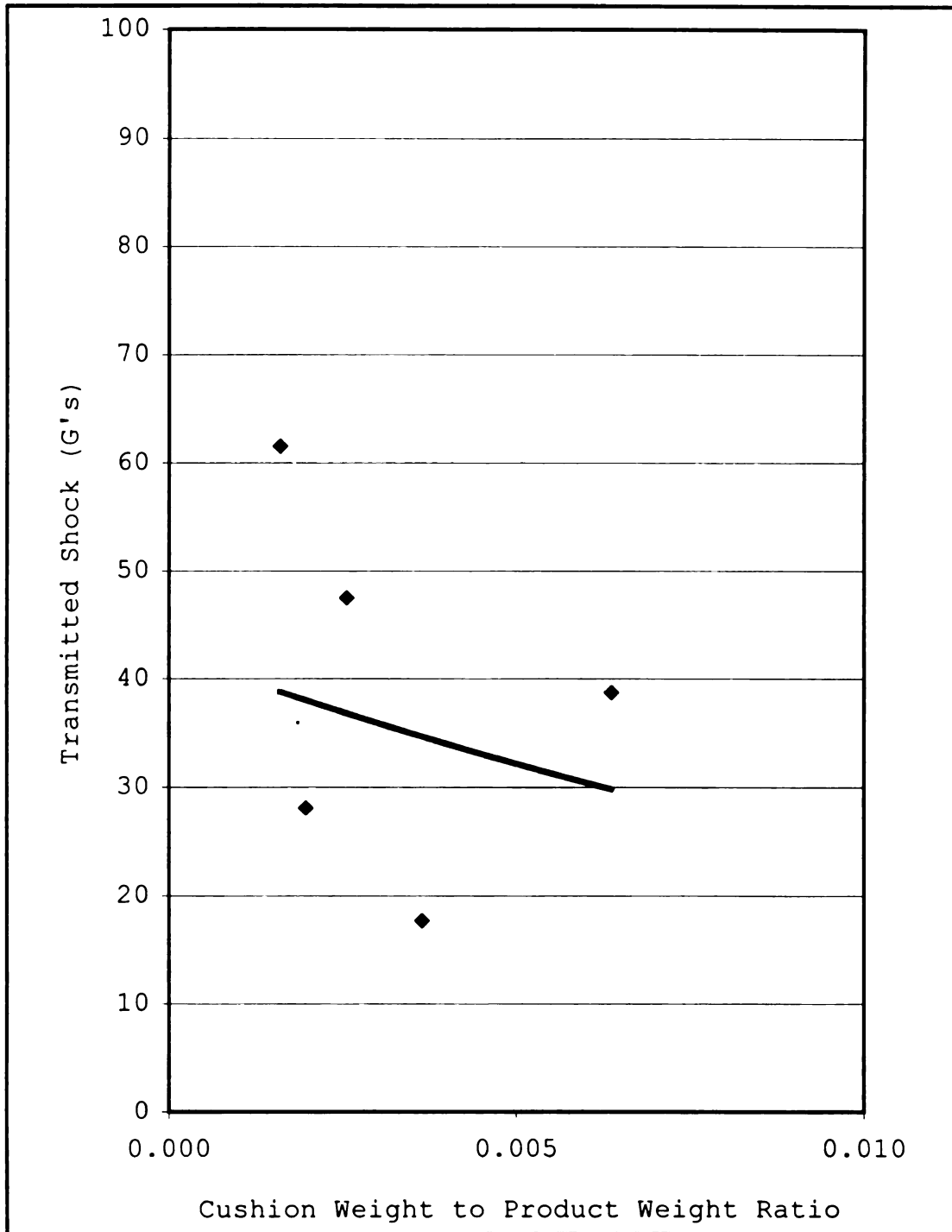


Figure D3: Low Density ISOPACK Transmitted Shock (G's) versus Cushion Weight to Product Weight Ratio, 30-inch drop height, First Impact.

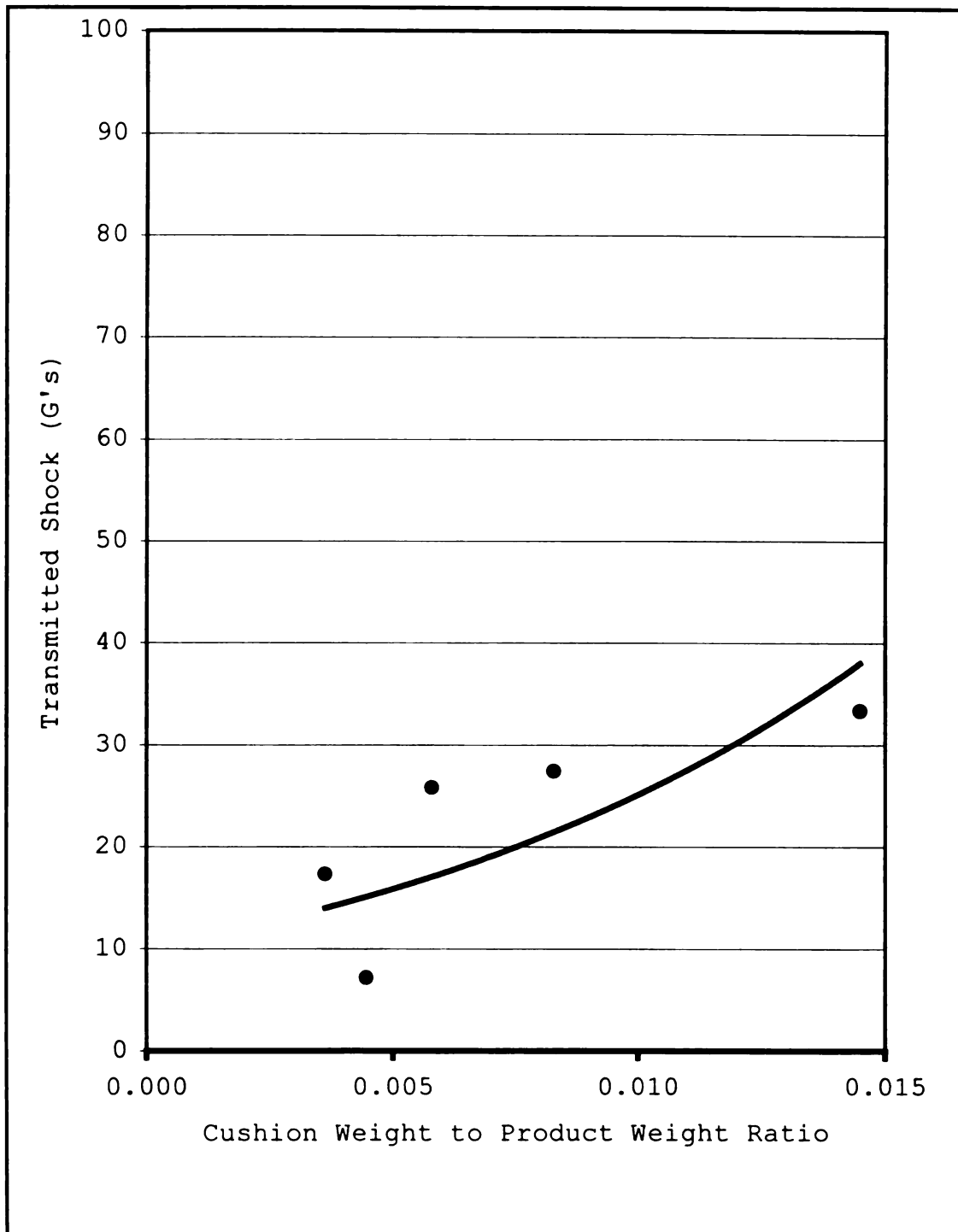


Figure D4: High Density ISOPACK Transmitted Shock (G's) versus Cushion Weight to Product Weight Ratio, 30-inch drop height, First Impact.

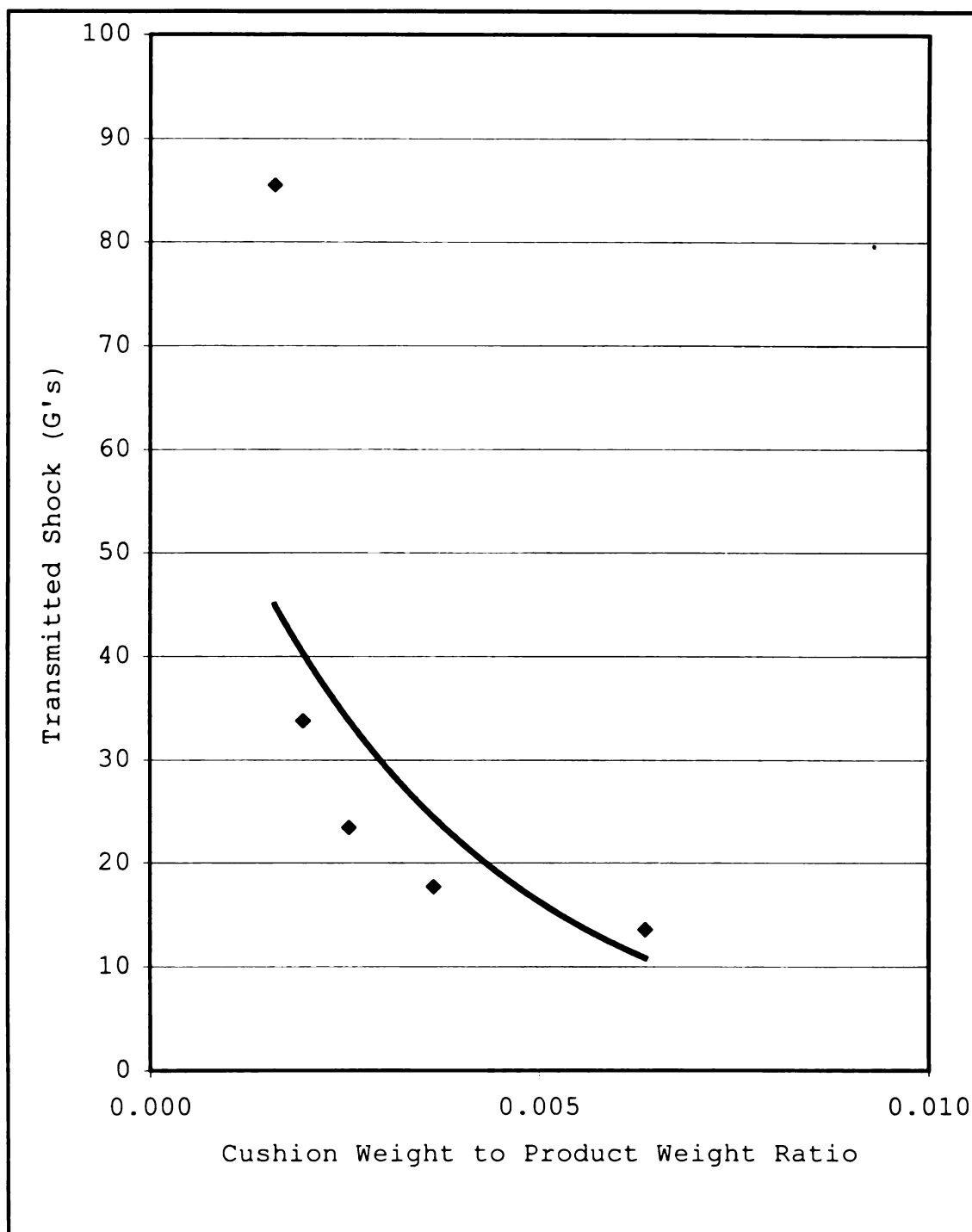


Figure D5: Low Density ISOPACK Transmitted Shock (G's) versus Cushion Weight to Product Weight Ratio, 36-inch drop height, First Impact.

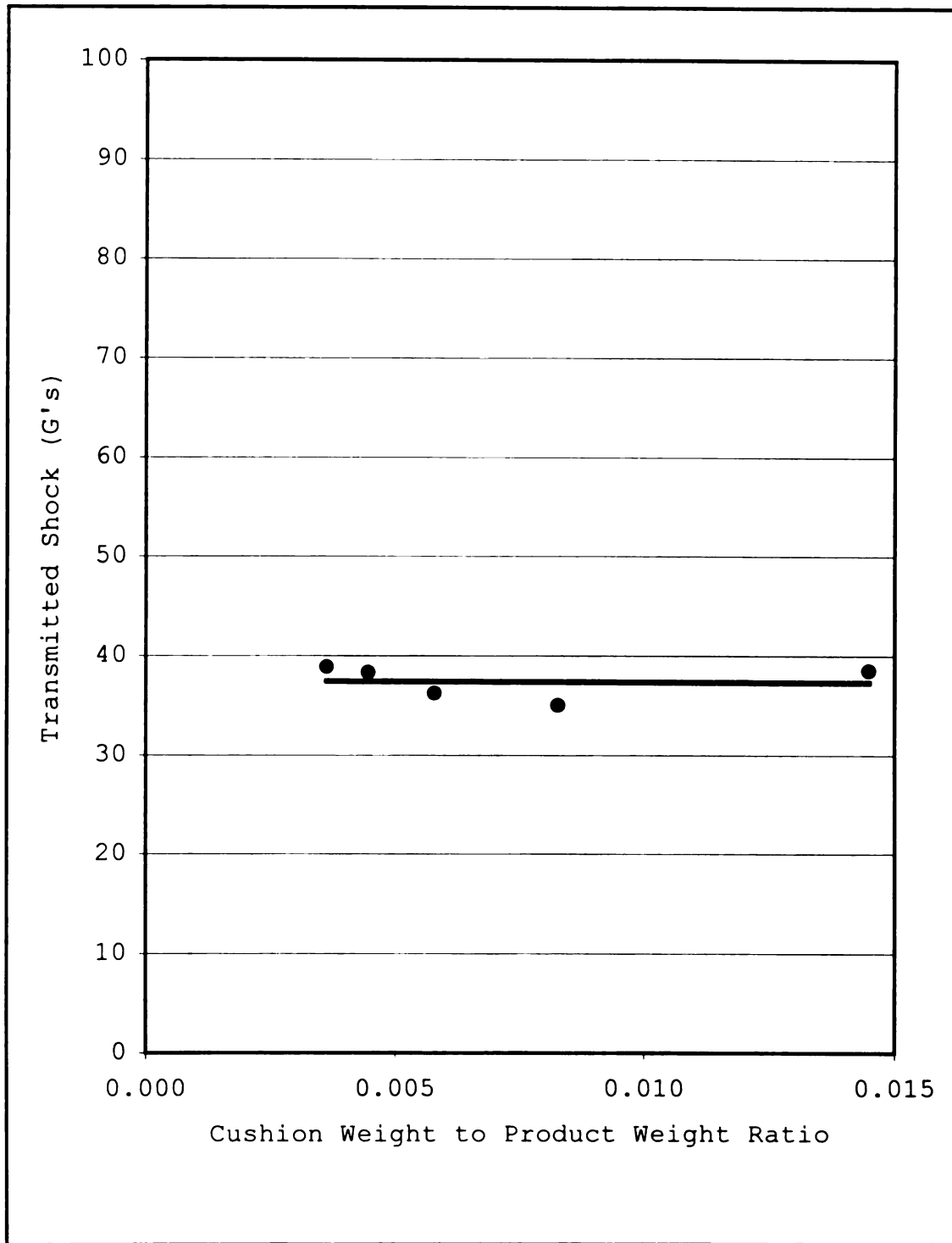


Figure D6: High Density ISOPACK Transmitted Shock (G's) versus Cushion Weight to Product Weight Ratio, 36-inch drop height, First Impact.

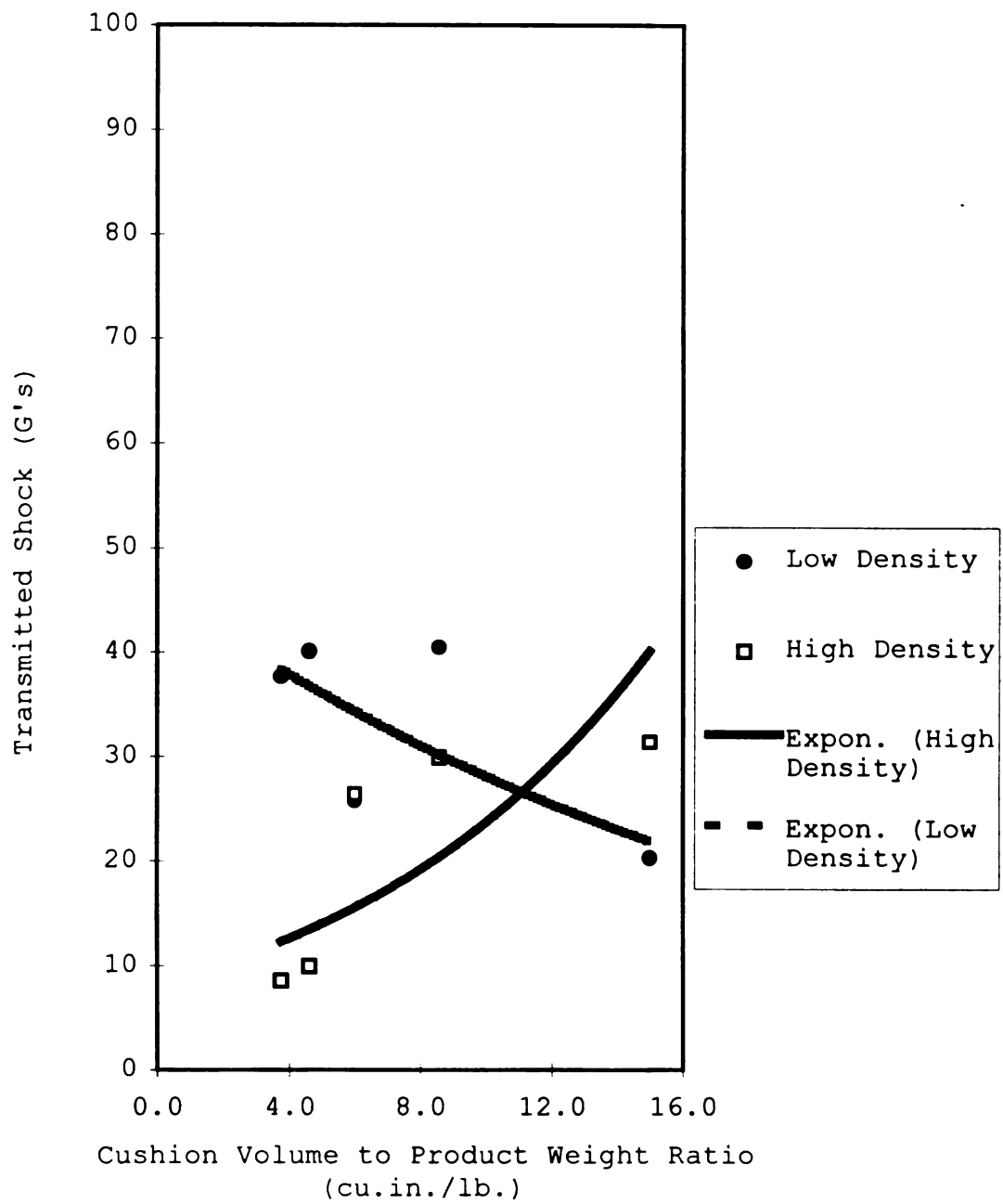


Fig. E1: Cushion Volume to Product Weight Ratio (cu. in./lb.) versus G's, 24 inch drop height., First Impact.

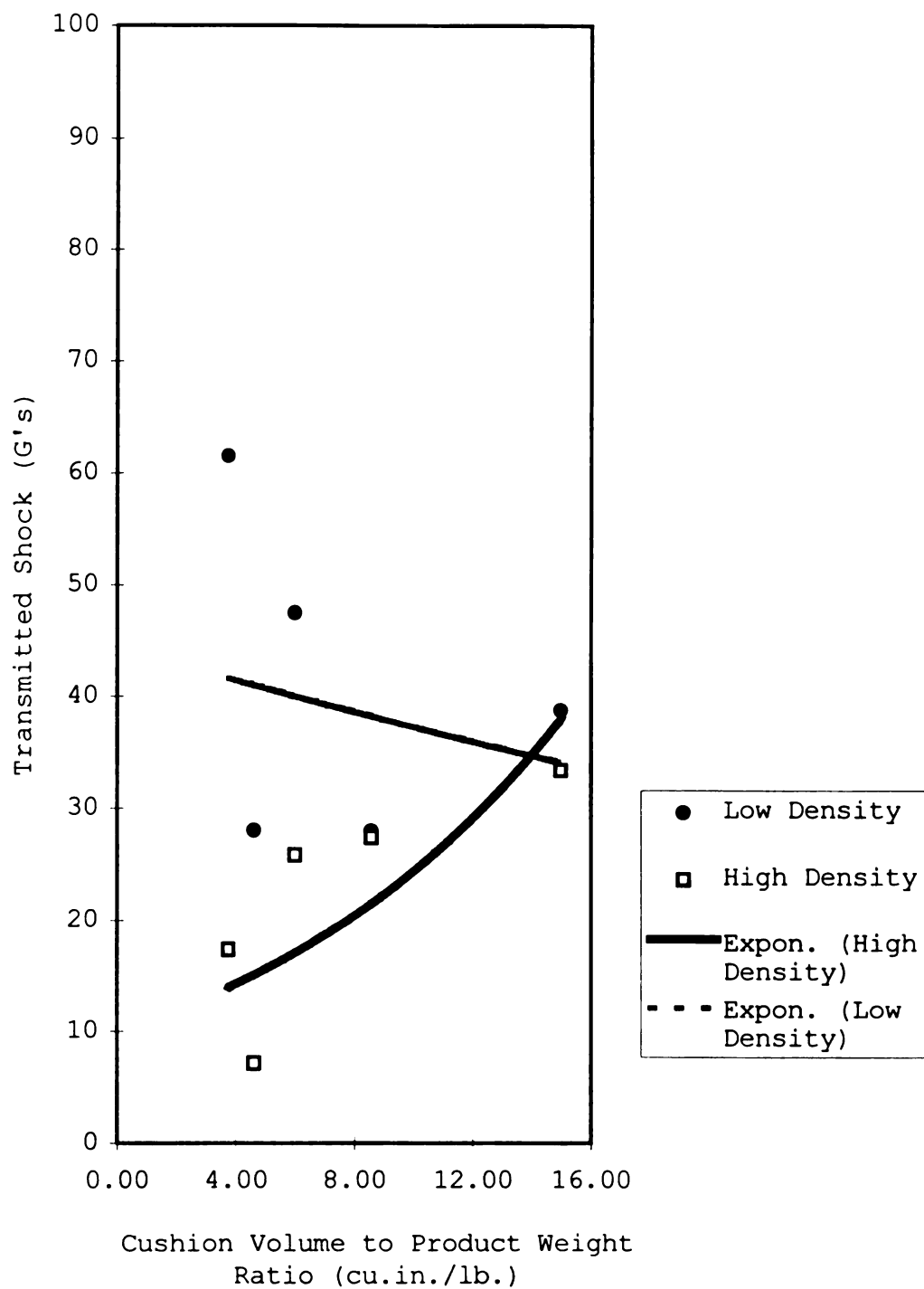


Fig. E2: Cushion Volume to Product Weight Ratio (cu.in./lb.) versus G's, 30 inch drop height., First Impact.

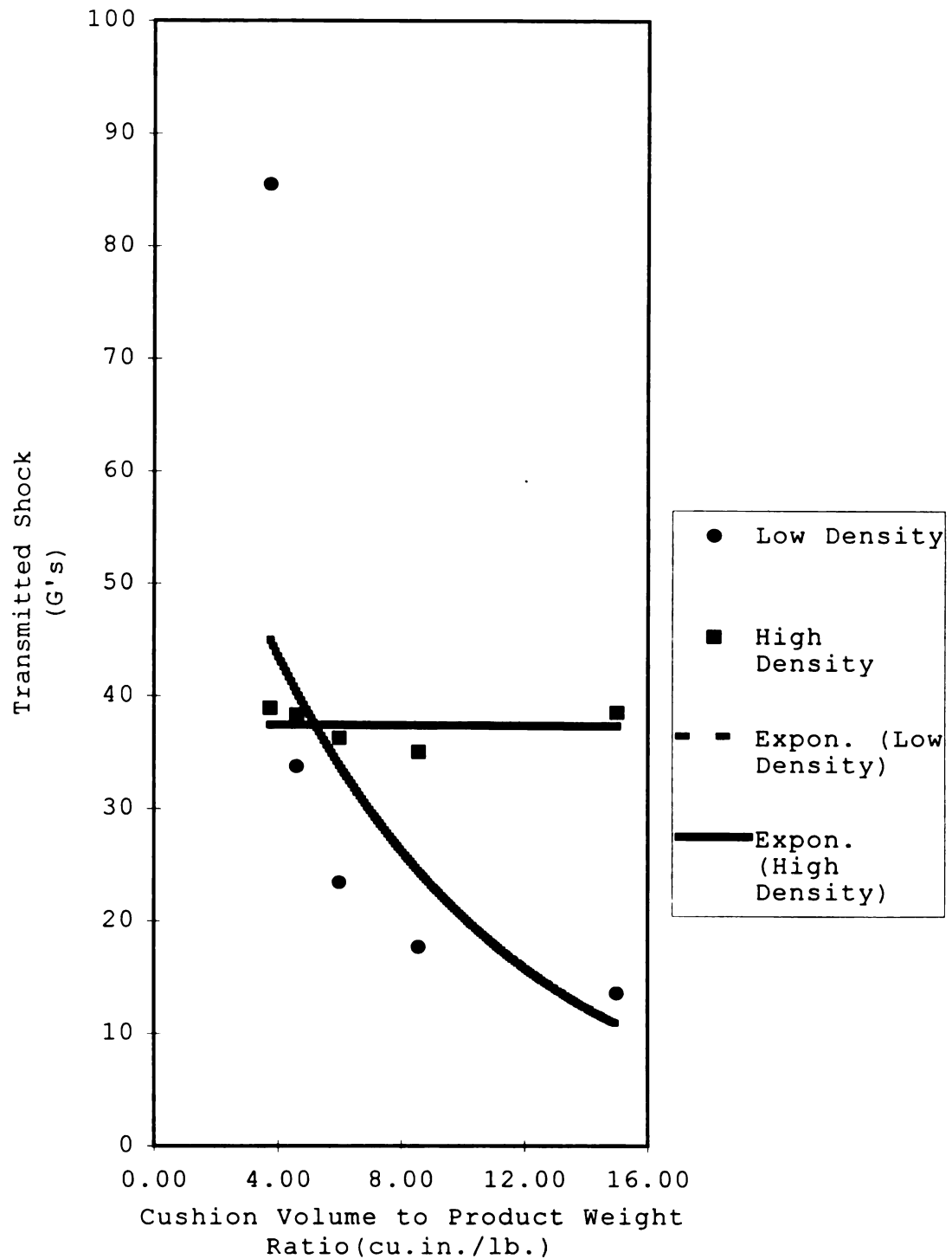


Fig. E3: Cushion Volume to Product Weight Ratio (cu.in./lb.) versus G's, 36 inch drop height., First Impact.

APPENDIX C

Table B1: Distance Controlled Vibration data for Object 1

SPHERICAL OBJECT

"Small s-Shaped" EPS Loose Fill

Trial 1		Trial 2		Trial 3	
distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)
3	0:00:26	3	0:00:14	3	0:00:22
3	0:02:12	3	0:01:10		
6	0:01:02	6	0:00:44	6	0:01:24
6	0:03:12	6	0:01:40	6	0:13:49
7	0:03:18	7	0:04:46	7	0:06:32
8.9	3:00:00	8.9	3:00:00	8.8	3:00:00

Low Density ISOPACK Loose Fill

Trial 1		Trial 2		Trial 3	
distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)
1	0:00:08	1	0:00:22	1	0:00:16
2	0:00:24	2	0:01:14	2	0:01:16
3	0:00:59	3	0:02:48	3	0:01:56
4	0:01:14	4	0:02:58	4	0:02:40
5	0:01:57	5	0:03:12	5	0:03:24
6	0:02:30	5.9	3:00:00	6	0:05:50
6.1	3:00:00			7	0:06:58
				7.1	3:00:00

"Shell-shaped" EPS Loose Fill

Trial 1		Trial 2		Trial 3	
distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)
3	0:00:12	3	0:00:34	3	0:00:12
6	0:04:21	6	0:04:11	6	0:05:15
6.8	3:00:00	6.5	3:00:00	8	3:00:00

Table B2: Distance Controlled Vibration data for Object 2

CYLINDRICAL OBJECT: one open end and one protrusion.

"Shell-shaped" EPS Loose Fill

Trial 1		Trial 2		Trial 3	
distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)
3	0:00:21	3	0:00:28	3	0:00:32
6	0:01:24	6	0:01:22	6	0:01:46
7	0:06:42	7	0:15:48	7	0:10:18
8	1:44:56	8	1:48:11	8	2:40:16
8.1	3:00:00	8.2	3:00:00	8.2	3:00:00

Low Density ISOPACK Loose Fill

Trial 1		Trial 2		Trial 3	
distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)
3	0:01:35	3	0:01:52	3	0:01:46
6	0:27:14	6	0:29:26	6	0:27:34
6.1	3:00:00	6.2	3:00:00	6.1	3:00:00

"Small s-Shaped" EPS Loose Fill

Trial 1		Trial 2		Trial 3	
distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)
3	0:00:30	3	0:00:20	3	0:00:28
6	0:02:56	6	0:02:34	6	0:02:54
9	0:12:54	9	0:15:06	9	0:14:46

Table B3: Distance Controlled Vibration data for Object 3.

CYLINDRICAL OBJECT: No open end and no protrusions.

"Shell-shaped" EPS Loose Fill

Trial 1		Trial 2		Trial 3	
distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)
3	0:00:48	3	0:00:25	3	0:00:32
6	0:02:59	6	0:01:49	6	0:02:12
9	0:05:02	9	0:22:20	9	0:08:54

"Small s-Shaped" EPS Loose Fill

Trial 1		Trial 2		Trial 3	
distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)
3	0:00:38	3	0:00:40	3	0:00:42
6	0:02:30	6	0:09:22	6	0:02:50
9	0:05:06	9	0:29:20	9	0:34:40

Low Density ISOPACK Loose Fill

Trial 1		Trial 2		Trial 3	
distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)
1	0:47:24	1	0:45:40	1	0:06:28
2	1:41:30	2	1:40:55	2	0:08:14
2.9	3:00:00	3	3:00:00	3	3:00:00

Table B4: Distance Controlled Vibration data for Object 4

FLAT OBJECT

"Shell-shaped" EPS Loose Fill

Trial 1		Trial 2		Trial 3	
distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)
1	0:01:46	1	0:01:21	1	0:02:18
2	0:06:42	1.5	3:00:00	1.6	3:00:00
2.2	3:00:00				

Low Density ISOPACK Loose Fill

Trial 1		Trial 2		Trial 3	
distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)
1	0:03:56	1	0:05:14	1	0:09:10
1.1	3:00:00	1	3:00:00	1.3	3:00:00

Small Green s-Shaped EPS Loose Fill

Trial 1		Trial 2		Trial 3	
distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)
1	0:08:49	1	0:09:52	1	0:09:46
1.2	3:00:00	1.7	3:00:00	1.5	1:46:54
				2	3:00:00

Table B5: Distance Controlled Vibration data for Object 5

CYLINDRICAL OBJECT: One open end and No Protrusions

"Shell-shaped" EPS Loose Fill

Trial 1		Trial 2		Trial 3	
distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)
3	0:03:39	3	0:04:10	3	0:04:14
6	0:08:20	6	0:08:10	6	0:09:16
7	0:12:45	7	0:15:12	7	0:14:48
7.3	3:00:00	7.1	3:00:00	7.1	3:00:00

Low Density ISOPACK Loose Fill

Trial 1		Trial 2		Trial 3	
distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)
3	0:06:30	3	0:07:42	3	0:07:12
4	0:10:46	4	0:12:30	4	0:12:10
4.6	3:00:00	5	0:20:14	5	0:18:20
		5.2	3:00:00	5.1	3:00:00

"Small s-Shaped" EPS Loose Fill

Trial 1		Trial 2		Trial 3	
distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)	distance (inches)	time (hr:min:sec)
3	0:02:01	3	0:02:20	3	0:02:16
6	0:07:49	6	0:07:40	6	0:08:12
7	0:09:56	7	0:08:44	7	0:09:02
8	0:15:14	8	0:14:44	8	0:15:22
9	0:55:40	8.2	3:00:00	8.1	3:00:00

Table C1: Time Controlled Vibration data for Object 1

SPHERICAL OBJECT

TIME (mins)	Low Density ISOPACK						"Shell-shaped" EPS Loose Fill						"Small s-shape" EPS Loose Fill					
	MIGRATION (inches)						MIGRATION (inches)						MIGRATION (inches)					
	TRIAL 1	TRIAL 2	TRIAL 3	AVG	STD. DEV		TRIAL 1	TRIAL 2	TRIAL 3	AVG	STD. DEV		TRIAL 1	TRIAL 2	TRIAL 3	AVG	STD. DEV	
0.25	1.0	2.0	1.0	1.3	0.6		3.0	3.0	3.0	3.0	0.0		2.0	3.0	3.0	2.7	0.6	
0.50	2.0	2.1	1.5	1.9	0.3		3.3	3.3	3.1	3.2	0.1		3.0	3.3	4.0	3.4	0.5	
0.75	2.5	2.3	1.6	2.1	0.5		3.4	3.6	3.2	3.4	0.2		3.3	3.5	5.0	3.9	0.9	
1.00	3.0	2.4	1.9	2.4	0.6		3.5	3.9	3.2	3.5	0.3		4.0	3.8	5.2	4.3	0.8	
1.25	4.0	2.6	2.0	2.9	1.0		3.6	4.0	3.3	3.6	0.4		4.3	4.0	5.4	4.5	0.7	
1.50	4.3	3.0	2.3	3.2	1.0		3.6	4.2	3.3	3.7	0.5		4.5	4.2	5.5	4.7	0.7	
1.75	4.6	3.2	2.5	3.4	1.1		3.9	4.3	3.3	3.8	0.5		4.6	4.4	5.8	4.9	0.7	
2.00	5.0	3.3	3.0	3.8	1.1		4.0	4.4	3.3	3.9	0.6		4.8	4.6	5.9	5.1	0.7	
2.25	5.0	3.5	3.2	3.9	1.0		4.1	4.5	3.3	4.0	0.6		5.0	4.8	6.0	5.3	0.7	
2.50	5.1	3.5	3.4	4.0	1.0		4.3	4.7	3.4	4.1	0.6		5.2	4.8	6.2	5.4	0.7	
2.75	5.1	3.6	3.6	4.1	0.9		4.5	4.9	3.4	4.3	0.7		5.4	5.0	6.3	5.6	0.7	
3.00	5.1	4.0	4.0	4.4	0.6		4.8	5.0	3.5	4.4	0.8		5.5	5.3	6.5	5.8	0.6	
3.25	5.3	4.0	4.1	4.5	0.7		5.0	5.2	3.5	4.6	0.9		5.6	5.3	6.5	5.8	0.6	
3.50	5.4	4.1	4.2	4.6	0.7		5.3	5.4	3.5	4.7	1.0		5.8	5.5	6.6	5.9	0.6	
3.75	5.4	4.3	4.4	4.7	0.6		5.5	5.6	3.6	4.9	1.1		5.9	5.5	6.6	6.0	0.6	
4.00	5.4	4.3	4.5	4.7	0.6		6.0	5.8	3.6	5.1	1.3		6.0	5.6	6.6	6.1	0.5	
4.25	5.5	4.3	4.5	4.8	0.6		6.1	6.0	3.7	5.3	1.4		6.2	5.6	6.7	6.2	0.5	
4.50	5.6	4.3	4.5	4.8	0.7		6.1	6.2	3.7	5.3	1.4		6.4	5.7	6.8	6.3	0.5	
4.75	5.7	4.3	4.5	4.8	0.7		6.2	6.2	3.8	5.4	1.4		6.5	5.7	6.8	6.3	0.6	
5.00	5.8	4.4	4.5	4.9	0.7		6.3	6.3	3.8	5.4	1.5		6.6	5.8	6.8	6.4	0.5	
5.25	5.9	4.5	4.5	5.0	0.8		6.3	6.4	3.9	5.5	1.4		6.8	5.8	6.8	6.5	0.6	
5.50	5.9	4.7	4.5	5.0	0.7		6.3	6.4	3.9	5.5	1.4		6.9	5.9	7.0	6.6	0.6	
5.75	6.0	4.8	4.5	5.1	0.8		6.4	6.5	3.9	5.6	1.5		7.0	5.9	7.1	6.7	0.6	
6.00	6.0	4.8	4.5	5.1	0.8		6.4	6.5	3.9	5.6	1.5		7.1	5.9	7.3	6.8	0.7	
6.25	6.0	5.0	4.5	5.2	0.8		6.4	6.6	4.0	5.7	1.4		7.3	6.0	7.3	6.9	0.7	
6.50	6.0	5.0	4.6	5.2	0.7		6.5	6.6	4.2	5.8	1.4		7.4	6.2	7.3	7.0	0.7	
6.75	6.0	5.0	4.6	5.2	0.7		6.5	6.7	4.3	5.8	1.3		7.6	6.3	7.3	7.1	0.7	
7.00	6.1	5.2	4.6	5.3	0.8		6.5	6.9	4.4	5.9	1.3		7.8	6.4	7.3	7.2	0.7	
7.25	6.1	5.2	5.0	5.4	0.6		6.5	6.9	4.5	6.0	1.3		7.9	6.4	7.3	7.2	0.7	
7.50	6.1	5.2	5.0	5.4	0.6		6.5	6.9	4.5	6.0	1.3		7.9	6.5	7.4	7.3	0.7	
7.75	6.1	5.2	5.0	5.4	0.6		6.5	6.9	4.6	6.0	1.3		8.0	6.5	7.6	7.4	0.8	
8.00	6.1	5.2	5.0	5.4	0.6		6.6	6.9	4.6	6.0	1.2		8.0	6.6	7.7	7.4	0.7	
8.25	6.1	5.2	5.0	5.4	0.6		6.6	7.0	4.8	6.1	1.2		8.0	6.8	7.9	7.5	0.7	
8.50	6.1	5.2	5.0	5.4	0.6		6.6	7.0	4.9	6.1	1.1		8.0	6.8	8.0	7.6	0.7	
8.75	6.1	5.2	5.0	5.4	0.6		6.6	7.0	5.0	6.2	1.1		8.0	6.8	8.0	7.6	0.7	
9.00	6.1	5.2	5.0	5.4	0.6		6.6	7.0	5.2	6.3	0.9		8.0	6.9	8.0	7.6	0.6	
9.25	6.4	5.3	5.1	5.6	0.7		6.6	7.0	5.3	6.3	0.9		8.0	7.0	8.0	7.7	0.6	
9.50	6.4	5.3	5.1	5.6	0.7		6.6	7.0	5.4	6.3	0.8		8.0	7.0	8.1	7.7	0.6	
9.75	6.4	5.3	5.1	5.6	0.7		6.6	7.0	5.6	6.4	0.7		8.0	7.0	8.1	7.7	0.6	
10.00	6.5	5.4	5.1	5.6	0.8		6.6	7.0	5.7	6.4	0.7		8.0	7.2	8.1	7.7	0.5	
10.25	6.5	5.4	5.2	5.7	0.7		6.6	7.1	5.8	6.5	0.7		8.1	7.2	8.1	7.8	0.5	
10.50	6.5	5.4	5.2	5.7	0.7		6.6	7.3	5.9	6.6	0.7		8.1	7.3	8.1	7.8	0.5	
10.75	6.5	5.4	5.2	5.7	0.7		6.6	7.4	5.9	6.7	0.8		8.1	7.4	8.1	7.9	0.4	
11.00	6.5	5.4	5.2	5.7	0.7		6.6	7.5	6.0	6.7	0.8		8.1	7.5	8.1	7.9	0.3	
11.25	6.6	5.5	5.3	5.8	0.7		6.6	7.5	6.1	6.8	0.7		8.1	7.6	8.2	8.0	0.3	
11.50	6.6	5.5	5.3	5.8	0.7		6.6	7.5	6.1	6.8	0.7		8.1	7.6	8.2	8.0	0.3	
11.75	6.6	5.5	5.3	5.8	0.7		6.6	7.6	6.3	6.8	0.7		8.1	7.6	8.2	8.0	0.3	
12.00	6.6	5.5	5.3	5.8	0.7		6.7	7.6	6.3	6.8	0.7		8.2	7.6	8.2	8.0	0.3	
12.25	6.8	5.8	5.4	6.0	0.7		6.7	7.6	6.4	6.9	0.6		8.3	7.8	8.4	8.1	0.3	
12.50	6.8	5.8	5.4	6.0	0.7		6.7	7.6	6.5	6.9	0.6		8.3	7.8	8.4	8.1	0.3	
12.75	6.8	5.8	5.4	6.0	0.7		6.7	7.6	6.5	6.9	0.6		8.3	7.9	8.4	8.2	0.3	
13.00	6.8	5.8	5.4	6.0	0.7		6.9	7.6	6.6	7.0	0.5		8.3	7.9	8.4	8.2	0.3	
13.25	6.8	6.0	5.5	6.1	0.6		6.9	7.6	6.8	7.1	0.5		8.4	7.9	8.5	8.3	0.3	
13.50	6.8	6.0	5.5	6.1	0.6		6.9	7.6	6.8	7.1	0.5		8.4	7.9	8.5	8.3	0.3	
13.75	6.9	6.0	5.5	6.1	0.7		6.9	7.6	6.9	7.1	0.4		8.4	7.9	8.6	8.3	0.4	
14.00	6.9	6.0	5.5	6.1	0.7		6.9	7.6	6.9	7.1	0.4		8.4	7.9	8.6	8.3	0.4	
14.25	6.9	6.0	5.5	6.1	0.7		6.9	7.6	7.0	7.2	0.4		8.5	8.0	8.6	8.4	0.3	
14.50	6.9	6.0	5.5	6.1	0.7		6.9	7.6	7.2	7.2	0.4		8.5	8.0	8.6	8.4	0.3	
14.75	6.9	6.0	5.7	6.2	0.6		6.9	7.6	7.4	7.3	0.4		8.5	8.0	8.6	8.4	0.3	
15.00	6.9	6.0	5.9	6.3	0.5		6.9	7.6	7.5	7.3	0.4		8.5	8.0	8.8	8.4	0.4	

Table C2: Time Controlled Vibration Data for Object 2

CYLINDRICAL OBJECT: One open end and one protrusion.

TIME (mins)	Low Density ISOPACK						"Shell-shaped" EPS Loose Fill						"Small s-shape" EPS Loose Fill					
	MIGRATION (inches)						MIGRATION (inches)						MIGRATION (inches)					
	TRIAL 1	TRIAL 2	TRIAL 3	AVG	STD. DEV.		TRIAL 1	TRIAL 2	TRIAL 3	AVG	STD. DEV.		TRIAL 1	TRIAL 2	TRIAL 3	AVG	STD. DEV.	
0.25	1.0	2.0	2.0	1.7	0.6		3.0	2.4	3.0	2.8	0.4		3.0	3.0	3.0	3.0	0.0	
0.50	2.0	3.0	2.3	2.4	0.5		4.0	3.0	3.3	3.4	0.5		4.0	3.5	3.5	3.7	0.3	
0.75	3.0	3.5	2.6	3.0	0.5		4.5	3.3	4.3	4.0	0.7		4.5	4.0	5.0	4.5	0.5	
1.00	3.0	4.0	2.7	3.2	0.7		5.0	4.0	4.5	4.5	0.5		5.0	5.0	6.0	5.3	0.6	
1.25	3.0	4.3	2.8	3.4	0.8		5.1	5.0	5.0	5.0	0.1		5.2	5.3	6.1	5.5	0.5	
1.50	3.3	4.3	2.9	3.5	0.7		5.3	5.5	5.2	5.3	0.2		5.4	5.4	6.1	5.7	0.4	
1.75	3.3	4.5	2.9	3.6	0.8		5.4	6.0	5.2	5.5	0.4		5.6	6.0	6.2	5.9	0.3	
2.00	3.5	4.5	3.0	3.7	0.8		5.6	6.1	5.3	5.6	0.4		5.8	6.1	6.2	6.0	0.2	
2.25	3.6	4.5	3.2	3.8	0.7		5.6	6.1	5.3	5.7	0.4		6.1	6.1	6.2	6.1	0.1	
2.50	3.8	4.5	3.2	3.8	0.7		5.8	6.2	5.3	5.8	0.4		6.3	6.1	6.3	6.2	0.1	
2.75	4.0	4.8	3.3	4.0	0.8		5.8	6.3	5.4	5.8	0.4		6.4	6.2	6.3	6.3	0.1	
3.00	4.0	4.9	3.3	4.0	0.8		6.0	6.3	5.4	5.9	0.4		6.4	6.2	6.4	6.3	0.1	
3.25	4.0	5.2	3.3	4.2	1.0		6.1	6.4	5.5	6.0	0.5		6.5	6.3	6.4	6.4	0.1	
3.50	4.1	5.2	3.3	4.2	0.9		6.3	6.4	5.5	6.1	0.5		6.5	6.3	6.4	6.4	0.1	
3.75	4.1	5.3	3.5	4.3	0.9		6.5	6.5	5.5	6.2	0.6		6.6	6.3	6.5	6.5	0.1	
4.00	4.1	5.3	3.7	4.3	0.8		6.5	6.5	5.6	6.2	0.5		6.6	6.4	6.5	6.5	0.1	
4.25	4.1	5.3	3.8	4.4	0.8		6.6	6.6	5.6	6.3	0.6		6.8	6.4	6.5	6.5	0.2	
4.50	4.1	5.4	3.9	4.5	0.8		6.6	6.6	5.7	6.3	0.5		6.8	6.4	6.6	6.6	0.2	
4.75	4.1	5.4	4.0	4.5	0.8		6.6	6.6	5.7	6.3	0.5		6.8	6.6	6.6	6.6	0.1	
5.00	4.1	5.8	4.5	4.8	0.8		6.8	6.7	5.7	6.4	0.6		6.8	6.6	6.6	6.7	0.1	
5.25	4.2	5.8	5.0	5.0	0.8		6.8	6.8	5.8	6.4	0.6		6.9	6.6	6.7	6.7	0.2	
5.50	4.2	5.8	5.3	5.1	0.8		6.8	6.8	5.8	6.5	0.6		6.9	6.6	6.8	6.8	0.1	
5.75	4.2	5.9	5.4	5.2	0.9		6.9	6.9	5.8	6.5	0.7		6.9	6.6	6.8	6.8	0.2	
6.00	4.2	5.9	5.6	5.3	0.9		7.0	7.0	5.9	6.6	0.6		6.9	6.6	6.8	6.8	0.2	
6.25	4.3	6.0	5.9	5.4	1.0		7.0	7.1	6.0	6.7	0.6		6.9	6.6	6.8	6.8	0.2	
6.50	4.3	6.0	5.9	5.4	1.0		7.0	7.3	6.2	6.8	0.6		7.0	6.8	6.8	6.9	0.1	
6.75	4.4	6.1	5.9	5.5	0.9		7.0	7.4	6.3	6.9	0.5		7.0	6.9	6.9	6.9	0.1	
7.00	4.4	6.2	5.9	5.5	1.0		7.0	7.5	6.5	7.0	0.5		7.0	7.0	6.9	7.0	0.0	
7.25	4.4	6.2	5.9	5.5	0.9		7.1	7.6	6.5	7.1	0.5		7.0	7.1	7.0	7.0	0.0	
7.50	4.5	6.2	5.9	5.5	0.9		7.1	7.6	6.6	7.1	0.5		7.0	7.2	7.1	7.1	0.1	
7.75	4.5	6.2	5.9	5.5	0.9		7.1	7.6	6.6	7.1	0.5		7.0	7.3	7.1	7.1	0.1	
8.00	4.5	6.3	6.0	5.6	0.9		7.1	7.7	6.7	7.2	0.5		7.0	7.4	7.2	7.2	0.2	
8.25	4.6	6.3	6.0	5.6	0.9		7.1	7.8	6.8	7.2	0.5		7.1	7.5	7.2	7.3	0.2	
8.50	4.8	6.3	6.0	5.7	0.8		7.1	7.8	6.8	7.2	0.5		7.1	7.6	7.2	7.3	0.3	
8.75	4.8	6.3	6.0	5.7	0.8		7.1	7.8	6.9	7.3	0.4		7.1	7.6	7.3	7.3	0.3	
9.00	5.0	6.3	6.1	5.8	0.7		7.1	7.8	7.0	7.3	0.4		7.1	7.6	7.3	7.3	0.2	
9.25	5.0	6.3	6.1	5.8	0.7		7.1	7.8	7.0	7.3	0.4		7.1	7.7	7.3	7.4	0.3	
9.50	5.1	6.3	6.2	5.9	0.6		7.1	7.9	7.1	7.4	0.5		7.1	7.7	7.3	7.4	0.3	
9.75	5.1	6.3	6.2	5.9	0.6		7.1	7.9	7.1	7.4	0.5		7.1	7.8	7.3	7.4	0.3	
10.00	5.2	6.3	6.2	5.9	0.6		7.1	8.0	7.1	7.4	0.5		7.1	7.8	7.3	7.4	0.3	
10.25	5.3	6.3	6.2	5.9	0.6		7.1	8.1	7.1	7.4	0.5		7.1	7.8	7.4	7.4	0.3	
10.50	5.3	6.3	6.3	5.9	0.6		7.1	8.1	7.2	7.5	0.5		7.1	7.8	7.4	7.5	0.3	
10.75	5.3	6.3	6.3	5.9	0.6		7.1	8.2	7.3	7.5	0.6		7.2	7.8	7.4	7.5	0.3	
11.00	5.3	6.3	6.3	5.9	0.6		7.1	8.2	7.3	7.5	0.6		7.2	7.8	7.5	7.5	0.3	
11.25	5.3	6.3	6.3	5.9	0.5		7.1	8.2	7.4	7.6	0.6		7.2	7.9	7.6	7.5	0.3	
11.50	5.4	6.3	6.3	6.0	0.5		7.2	8.2	7.4	7.6	0.5		7.2	7.9	7.6	7.5	0.3	
11.75	5.4	6.3	6.3	6.0	0.5		7.2	8.3	7.4	7.6	0.6		7.2	8.0	7.6	7.6	0.4	
12.00	5.5	6.3	6.4	6.1	0.5		7.3	8.3	7.4	7.6	0.5		7.2	8.0	7.6	7.6	0.4	
12.25	5.5	6.3	6.4	6.1	0.5		7.3	8.3	7.6	7.7	0.5		7.4	8.1	7.7	7.7	0.3	
12.50	5.5	6.3	6.4	6.1	0.5		7.3	8.3	7.6	7.7	0.5		7.4	8.1	7.8	7.8	0.3	
12.75	5.6	6.3	6.4	6.1	0.5		7.3	8.3	7.7	7.8	0.5		7.6	8.1	7.8	7.9	0.3	
13.00	5.6	6.3	6.5	6.1	0.5		7.3	8.3	7.8	7.8	0.5		7.9	8.3	7.8	8.0	0.2	
13.25	5.6	6.3	6.5	6.1	0.5		7.3	8.4	7.8	7.8	0.6		8.0	8.3	7.8	8.0	0.2	
13.50	5.6	6.3	6.5	6.1	0.4		7.3	8.4	7.8	7.8	0.5		8.2	8.3	7.9	8.1	0.2	
13.75	5.6	6.3	6.5	6.1	0.4		7.3	8.4	7.9	7.9	0.5		8.3	8.3	7.9	8.1	0.2	
14.00	5.6	6.3	6.6	6.1	0.5		7.3	8.4	8.0	7.9	0.6		8.4	8.4	8.0	8.3	0.2	
14.25	5.7	6.3	6.6	6.2	0.5		7.3	8.4	8.1	7.9	0.6		8.5	8.4	8.1	8.3	0.2	
14.50	5.7	6.3	6.6	6.2	0.5		7.3	8.5	8.1	8.0	0.6		8.6	8.4	8.1	8.4	0.2	
14.75	5.8	6.3	6.6	6.2	0.4		7.3	8.6	8.2	8.0	0.6		8.6	8.4	8.3	8.4	0.2	
15.00	6.0	6.3	6.8	6.4	0.4		7.5	8.6	8.3	8.1	0.6		8.7	8.4	8.4	8.5	0.2	

Table C3: Time Controlled Vibration Data for Object 3

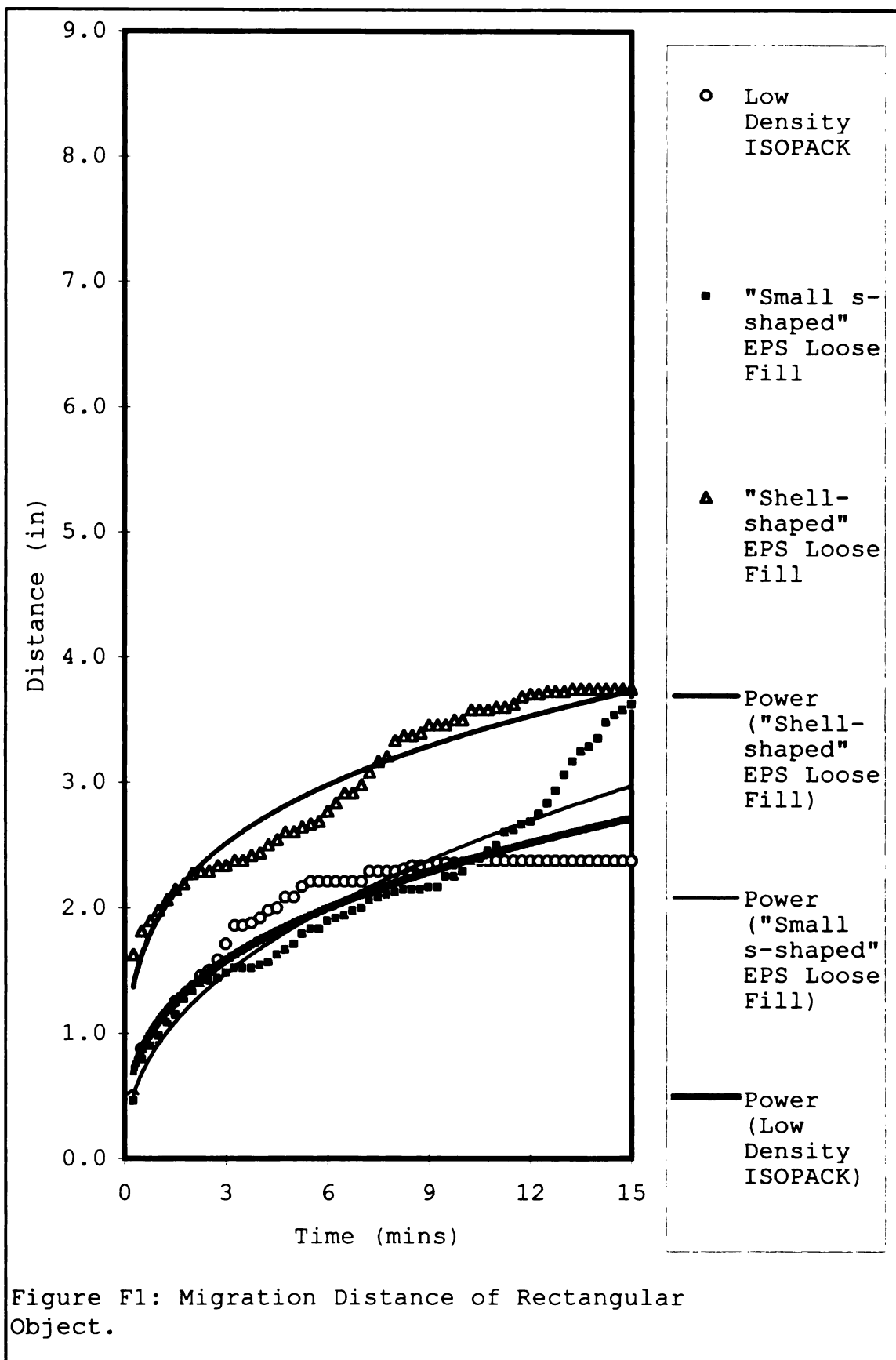
CYLINDRICAL OBJECT: No open end and no protrusions.

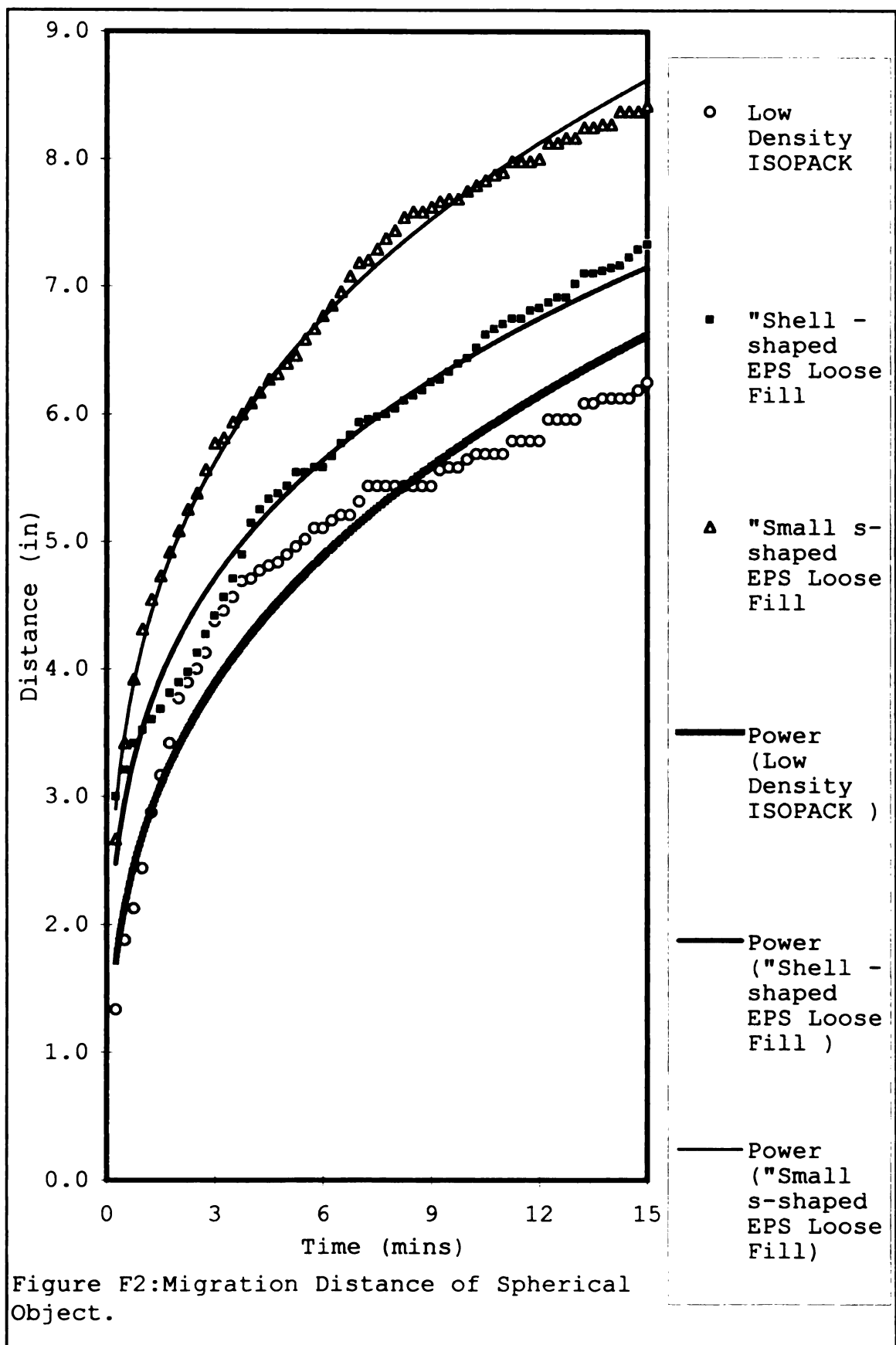
TIME (mins)	Low Density ISOPACK					"Small s-shape" EPS Loose Fill					"Shell-shaped" EPS Loose Fill				
	MIGRATION (inches)					MIGRATION (inches)					MIGRATION (inches)				
	TRIAL 1	TRIAL 2	TRIAL 3	AVG	STD. DEV	TRIAL 1	TRIAL 2	TRIAL 3	AVG	STD. DEV	TRIAL 1	TRIAL 2	TRIAL 3	AVG	STD. DEV
0.25	0.4	0.3	0.4	0.4	0.1	3.5	2.0	1.5	2.3	1.0	1.0	2.0	1.0	1.3	0.6
0.50	0.5	0.3	0.4	0.4	0.1	4.0	2.5	2.0	2.8	1.0	2.0	3.0	2.0	2.3	0.6
0.75	0.5	0.4	0.5	0.5	0.1	4.3	2.6	2.5	3.1	1.0	3.0	4.0	3.0	3.3	0.6
1.00	0.6	0.4	0.5	0.5	0.1	4.5	2.8	3.0	3.4	0.9	3.5	5.0	4.0	4.2	0.8
1.25	0.7	0.5	0.5	0.6	0.1	4.8	2.9	3.2	3.6	1.0	4.0	5.3	4.5	4.6	0.6
1.50	0.7	0.5	0.5	0.6	0.1	5.0	3.0	3.3	3.8	1.1	4.1	5.5	5.0	4.9	0.7
1.75	0.7	0.7	0.5	0.6	0.1	5.1	3.1	3.5	3.9	1.1	4.3	5.8	5.8	5.3	0.9
2.00	0.7	0.7	0.6	0.6	0.1	5.3	3.3	3.7	4.1	1.1	4.5	6.0	5.9	5.5	0.8
2.25	0.8	0.8	0.6	0.7	0.1	5.4	3.3	3.8	4.2	1.1	5.0	6.1	6.0	5.7	0.6
2.50	0.8	0.8	0.6	0.7	0.1	5.5	3.4	3.9	4.3	1.1	5.3	6.2	6.2	5.9	0.5
2.75	0.8	0.9	0.6	0.8	0.1	5.7	3.5	4.0	4.4	1.1	5.5	6.3	6.6	6.1	0.5
3.00	0.8	1.0	0.6	0.8	0.2	5.9	3.6	4.2	4.6	1.2	6.0	6.3	6.8	6.4	0.4
3.25	0.8	1.0	0.7	0.8	0.2	5.9	3.8	5.1	4.9	1.0	6.2	6.4	6.9	6.5	0.4
3.50	0.8	1.0	0.7	0.8	0.2	6.1	3.9	5.2	5.0	1.1	6.4	6.4	7.0	6.6	0.3
3.75	0.8	1.0	0.7	0.8	0.2	6.2	4.0	5.3	5.2	1.1	6.4	6.5	7.2	6.7	0.4
4.00	0.8	1.0	0.7	0.8	0.2	6.5	4.3	5.5	5.4	1.1	6.5	6.6	7.4	6.8	0.5
4.25	0.9	1.0	0.8	0.9	0.1	6.5	4.4	5.6	5.5	1.1	6.6	6.6	7.6	6.9	0.6
4.50	0.9	1.1	0.8	0.9	0.2	6.6	4.5	6.7	5.9	1.2	6.7	6.8	7.8	7.1	0.6
4.75	0.9	1.1	0.8	0.9	0.2	6.6	4.6	5.8	5.6	1.0	6.9	6.9	7.9	7.2	0.6
5.00	0.9	1.1	0.8	0.9	0.2	6.7	4.6	5.8	5.7	1.0	7.0	7.0	8.0	7.3	0.6
5.25	1.0	1.1	0.8	1.0	0.1	6.8	4.8	5.9	5.8	1.0	7.3	7.2	8.1	7.5	0.5
5.50	1.0	1.1	0.9	1.0	0.1	6.8	4.8	6.0	5.9	1.0	7.4	7.3	8.2	7.6	0.5
5.75	1.0	1.1	0.9	1.0	0.1	6.8	4.9	6.2	6.0	1.0	7.4	7.4	8.2	7.7	0.5
6.00	1.0	1.1	0.9	1.0	0.1	7.0	4.9	6.3	6.1	1.0	7.5	7.4	8.3	7.7	0.5
6.25	1.0	1.1	0.9	1.0	0.1	7.1	5.0	6.5	6.2	1.1	7.6	7.5	8.3	7.8	0.4
6.50	1.0	1.1	0.9	1.0	0.1	7.1	5.2	6.5	6.3	1.0	7.8	7.5	8.3	7.9	0.4
6.75	1.0	1.1	0.9	1.0	0.1	7.2	5.4	6.6	6.4	0.9	7.9	7.6	8.4	8.0	0.4
7.00	1.0	1.1	0.9	1.0	0.1	7.2	5.5	6.6	6.4	0.9	8.0	7.6	8.4	8.0	0.4
7.25	1.0	1.1	1.0	1.0	0.1	7.2	5.6	6.8	6.5	0.8	8.2	7.6	8.4	8.1	0.4
7.50	1.0	1.1	1.0	1.0	0.1	7.3	5.7	6.8	6.6	0.8	8.4	7.8	8.5	8.2	0.4
7.75	1.0	1.1	1.0	1.0	0.1	7.3	5.8	6.9	6.7	0.8	8.4	7.9	8.6	8.3	0.4
8.00	1.0	1.1	1.0	1.0	0.1	7.3	5.9	7.0	6.7	0.8	8.5	8.0	8.8	8.4	0.4
8.25	1.1	1.2	1.1	1.1	0.1	7.3	5.0	7.3	6.5	1.3	8.6	8.1	8.8	8.5	0.4
8.50	1.1	1.2	1.1	1.1	0.1	7.4	5.2	7.4	6.7	1.3	8.8	8.2	9.0	8.6	0.4
8.75	1.1	1.3	1.1	1.1	0.1	7.5	5.3	7.5	6.8	1.3	8.9	8.2		8.5	0.5
9.00	1.1	1.3	1.1	1.1	0.1	7.5	5.4	7.6	6.8	1.2	9.0	8.2		8.6	0.6
9.25	1.1	1.3	1.3	1.2	0.1	7.6	5.5	7.6	6.9	1.2		8.3		8.3	
9.50	1.2	1.3	1.3	1.2	0.1	7.6	5.6	7.6	7.0	1.2		8.3		8.3	
9.75	1.2	1.3	1.3	1.2	0.1	7.8	5.7	7.6	7.0	1.2		8.3		8.3	
10.00	1.2	1.3	1.3	1.2	0.1	7.8	5.8	7.6	7.0	1.1		8.3		8.3	
10.25	1.4	1.4	1.3	1.4	0.0	7.9	5.8	7.7	7.1	1.2		8.3		8.3	
10.50	1.4	1.4	1.3	1.4	0.0	7.9	5.8	7.7	7.1	1.2		8.3		8.3	
10.75	1.4	1.4	1.3	1.4	0.0	8.0	5.9	7.7	7.2	1.1		8.3		8.3	
11.00	1.4	1.4	1.3	1.4	0.1	8.0	6.0	7.8	7.3	1.1		8.5		8.5	
11.25	1.5	1.4	1.5	1.5	0.0	8.0	6.1	7.8	7.3	1.0		8.6		8.6	
11.50	1.5	1.4	1.5	1.5	0.0	8.1	6.2	7.8	7.3	1.0		8.7		8.7	
11.75	1.5	1.4	1.5	1.5	0.0	8.1	6.2	7.8	7.3	1.0		8.8		8.8	
12.00	1.5	1.4	1.5	1.5	0.0	8.1	6.3	7.8	7.4	1.0		9.0		9.0	
12.25	1.5	1.5	1.5	1.5	0.0	8.1	6.3	7.8	7.4	1.0					
12.50	1.5	1.5	1.5	1.5	0.0	8.1	6.3	7.8	7.4	1.0					
12.75	1.5	1.5	1.5	1.5	0.0	8.1	6.4	7.9	7.5	0.9					
13.00	1.5	1.5	1.5	1.5	0.0	8.1	6.5	7.9	7.5	0.9					
13.25	1.5	1.5	1.5	1.5	0.0	8.3	6.6	7.9	7.6	0.9					
13.50	1.5	1.5	1.5	1.5	0.0	8.3	6.7	7.9	7.6	0.8					
13.75	1.5	1.5	1.5	1.5	0.0	8.4	6.8	7.9	7.7	0.8					
14.00	1.5	1.5	1.5	1.5	0.0	8.4	6.9	7.9	7.7	0.8					
14.25	1.6	1.5	1.6	1.6	0.1	8.5	7.1	8.2	7.9	0.7					
14.50	1.6	1.5	1.6	1.6	0.1	8.5	7.3	8.3	8.0	0.7					
14.75	1.6	1.5	1.6	1.6	0.1	8.5	7.4	8.3	8.1	0.6					
15.00	1.6	1.5	1.6	1.6	0.1	8.5	7.5	8.3	8.1	0.5					

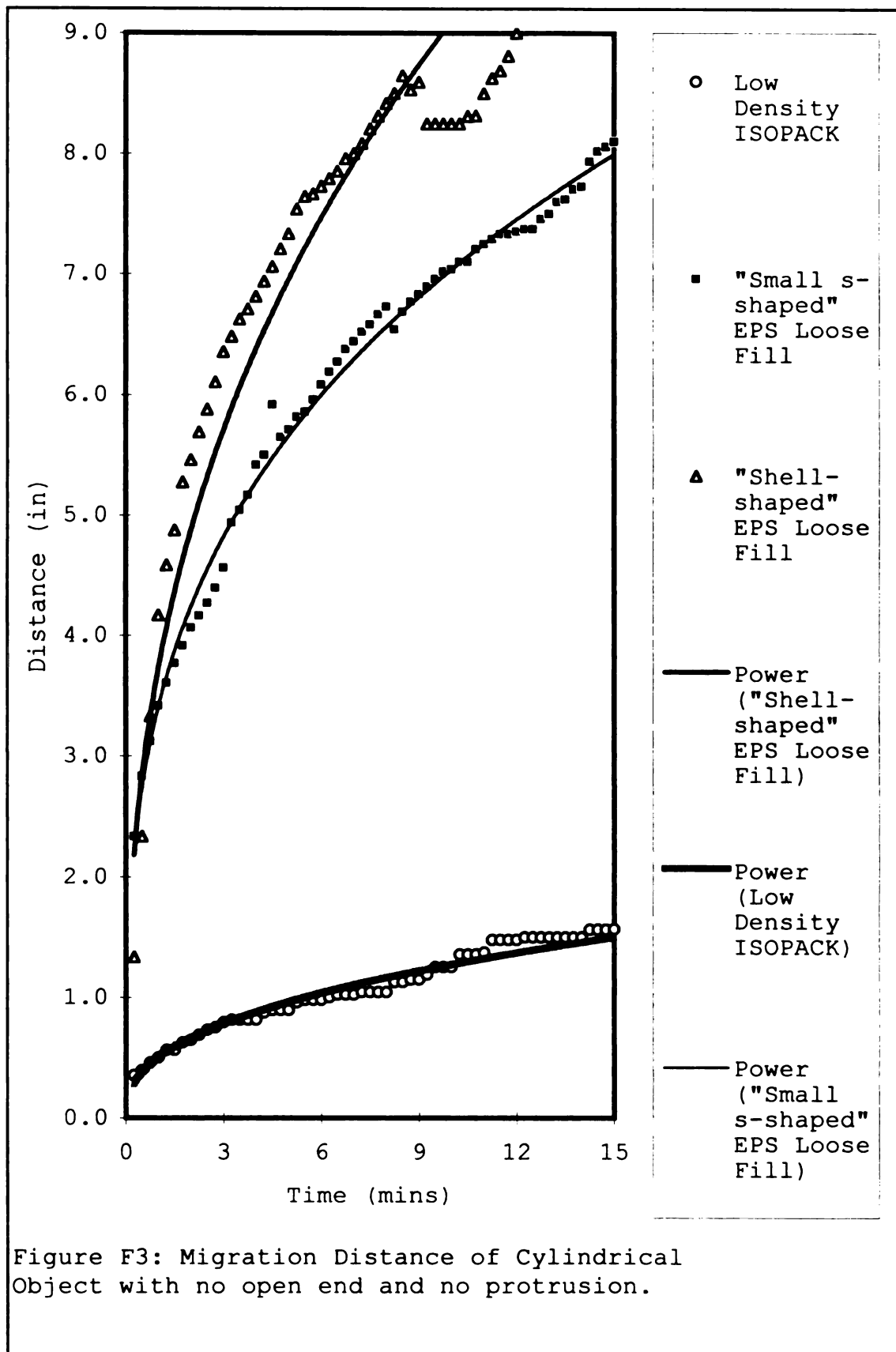
Table C4: Time Controlled Vibration data for Object 4

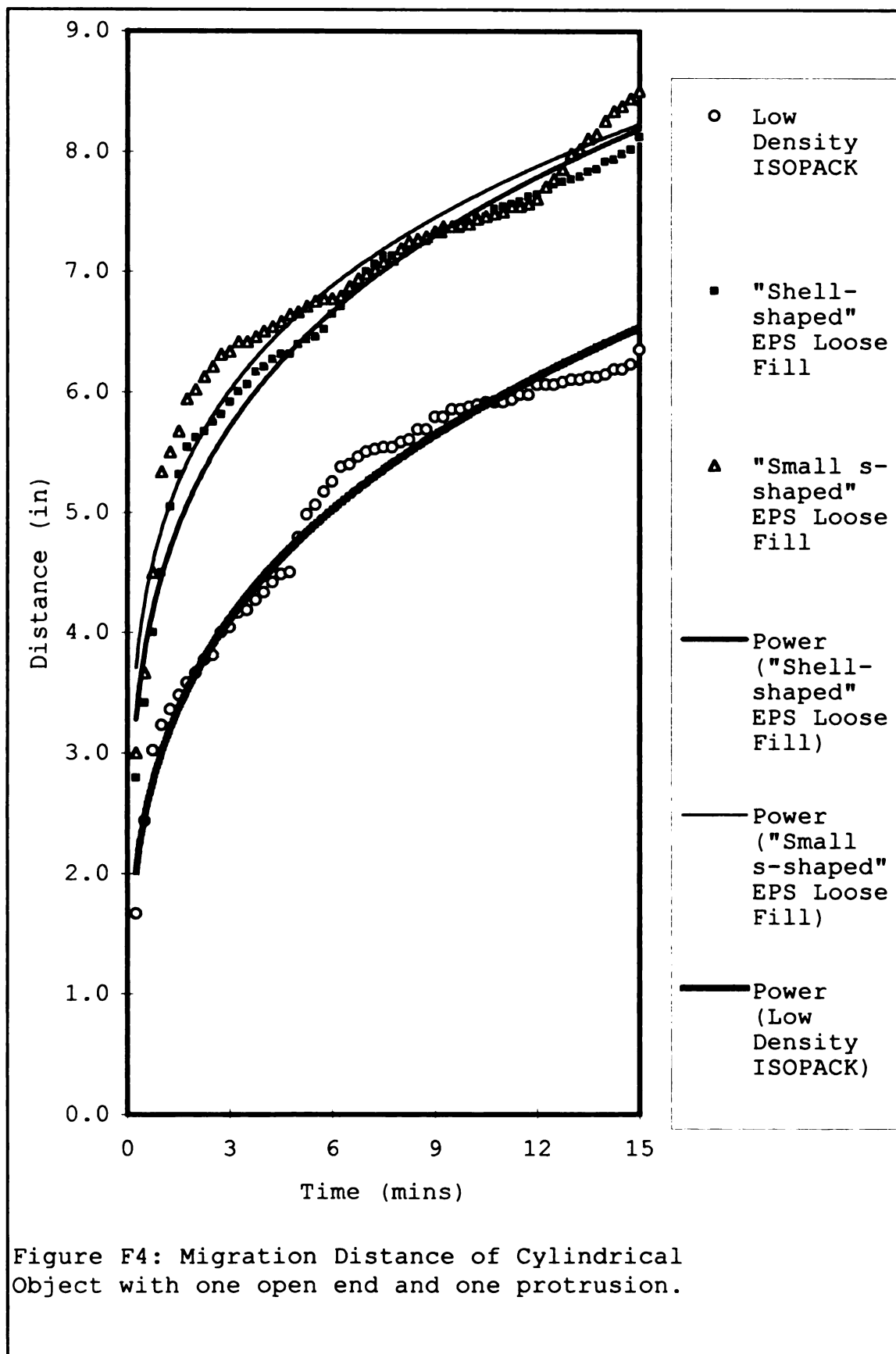
RECTANGULAR/FLAT OBJECT

TIME (mins)	Low Density ISOPACK					"Small s-shape" EPS Loose Fill					"Shell-shaped" EPS Loose Fill				
	MIGRATION (inches)					MIGRATION (inches)					MIGRATION (inches)				
	TRIAL 1	TRIAL 2	TRIAL 3	AVG	STD. DEV	TRIAL 1	TRIAL 2	TRIAL 3	AVG	STD. DEV	TRIAL 1	TRIAL 2	TRIAL 3	AVG	STD. DEV
0.25	0.5	0.5	0.5	0.5	0.0	0.5	0.5	0.4	0.5	0.1	1.5	1.6	1.8	1.6	0.1
0.50	1.0	0.6	1.0	0.9	0.2	1.0	1.0	0.4	0.8	0.4	1.6	1.8	2.0	1.8	0.2
0.75	1.0	0.8	1.0	0.9	0.1	1.1	1.1	0.5	0.9	0.3	1.8	1.9	2.1	1.9	0.2
1.00	1.0	0.9	1.0	1.0	0.1	1.3	1.1	0.6	1.0	0.3	1.9	1.9	2.1	2.0	0.1
1.25	1.3	1.0	1.1	1.1	0.1	1.3	1.1	0.9	1.1	0.2	2.0	2.0	2.2	2.1	0.1
1.50	1.4	1.0	1.4	1.3	0.2	1.3	1.1	1.0	1.1	0.2	2.1	2.1	2.3	2.1	0.1
1.75	1.4	1.1	1.4	1.3	0.1	1.4	1.2	1.2	1.3	0.1	2.1	2.2	2.3	2.2	0.1
2.00	1.5	1.1	1.4	1.3	0.2	1.5	1.2	1.3	1.3	0.2	2.3	2.3	2.3	2.3	0.0
2.25	1.6	1.3	1.5	1.5	0.2	1.5	1.3	1.4	1.4	0.1	2.3	2.3	2.3	2.3	0.0
2.50	1.6	1.4	1.5	1.5	0.1	1.5	1.3	1.4	1.4	0.1	2.3	2.3	2.3	2.3	0.0
2.75	1.6	1.5	1.6	1.6	0.1	1.6	1.3	1.4	1.4	0.1	2.3	2.4	2.4	2.3	0.1
3.00	1.8	1.6	1.8	1.7	0.1	1.7	1.3	1.4	1.5	0.2	2.3	2.4	2.4	2.3	0.1
3.25	1.9	1.8	1.9	1.9	0.1	1.7	1.4	1.5	1.5	0.2	2.3	2.4	2.4	2.4	0.1
3.50	1.9	1.8	1.9	1.9	0.1	1.7	1.4	1.5	1.5	0.2	2.3	2.4	2.4	2.4	0.1
3.75	1.9	1.8	2.0	1.9	0.1	1.7	1.4	1.5	1.5	0.2	2.3	2.4	2.5	2.4	0.1
4.00	1.9	1.9	2.0	1.9	0.1	1.7	1.4	1.5	1.5	0.1	2.3	2.5	2.5	2.4	0.1
4.25	2.0	1.9	2.1	2.0	0.1	1.8	1.4	1.5	1.6	0.2	2.4	2.5	2.6	2.5	0.1
4.50	2.0	1.9	2.1	2.0	0.1	1.8	1.4	1.6	1.6	0.2	2.4	2.6	2.6	2.5	0.1
4.75	2.1	2.0	2.1	2.1	0.1	1.8	1.4	1.8	1.7	0.2	2.4	2.6	2.8	2.6	0.2
5.00	2.1	2.0	2.1	2.1	0.1	1.8	1.5	1.8	1.7	0.2	2.4	2.6	2.8	2.6	0.2
5.25	2.2	2.1	2.3	2.2	0.1	2.0	1.6	1.8	1.8	0.2	2.5	2.6	2.8	2.6	0.2
5.50	2.3	2.1	2.3	2.2	0.1	2.0	1.6	1.9	1.8	0.2	2.5	2.6	2.9	2.7	0.2
5.75	2.3	2.1	2.3	2.2	0.1	2.0	1.6	1.9	1.8	0.2	2.5	2.7	2.9	2.7	0.2
6.00	2.3	2.1	2.3	2.2	0.1	2.1	1.7	1.9	1.9	0.2	2.6	2.8	2.9	2.8	0.2
6.25	2.3	2.1	2.3	2.2	0.1	2.1	1.8	1.9	1.9	0.2	2.8	2.8	2.9	2.8	0.1
6.50	2.3	2.1	2.3	2.2	0.1	2.1	1.8	1.9	1.9	0.2	2.9	2.9	3.0	2.9	0.1
6.75	2.3	2.1	2.3	2.2	0.1	2.1	1.8	2.0	2.0	0.2	2.9	2.9	3.0	2.9	0.1
7.00	2.3	2.1	2.3	2.2	0.1	2.1	1.9	2.0	2.0	0.1	2.9	3.0	3.0	3.0	0.0
7.25	2.4	2.1	2.4	2.3	0.1	2.2	1.9	2.1	2.1	0.1	3.0	3.1	3.1	3.1	0.1
7.50	2.4	2.1	2.4	2.3	0.1	2.2	1.9	2.1	2.1	0.1	3.1	3.1	3.3	3.2	0.1
7.75	2.4	2.1	2.4	2.3	0.1	2.2	1.9	2.2	2.1	0.1	3.1	3.3	3.3	3.2	0.1
8.00	2.4	2.1	2.4	2.3	0.1	2.3	1.9	2.2	2.1	0.2	3.3	3.4	3.4	3.3	0.1
8.25	2.4	2.1	2.4	2.3	0.2	2.3	2.0	2.2	2.1	0.1	3.3	3.4	3.5	3.4	0.1
8.50	2.4	2.2	2.4	2.3	0.1	2.3	2.0	2.2	2.1	0.1	3.3	3.4	3.5	3.4	0.1
8.75	2.4	2.2	2.4	2.3	0.1	2.3	2.0	2.2	2.1	0.1	3.3	3.4	3.5	3.4	0.1
9.00	2.4	2.2	2.4	2.3	0.1	2.3	2.0	2.3	2.2	0.1	3.3	3.5	3.6	3.5	0.2
9.25	2.4	2.3	2.4	2.4	0.1	2.3	2.0	2.3	2.2	0.1	3.3	3.5	3.6	3.5	0.2
9.50	2.4	2.3	2.4	2.4	0.1	2.4	2.1	2.3	2.2	0.2	3.3	3.5	3.6	3.5	0.2
9.75	2.4	2.3	2.4	2.4	0.1	2.4	2.1	2.3	2.2	0.2	3.3	3.5	3.8	3.5	0.3
10.00	2.4	2.3	2.4	2.4	0.1	2.4	2.1	2.3	2.3	0.2	3.3	3.5	3.8	3.5	0.3
10.25	2.4	2.3	2.5	2.4	0.1	2.5	2.2	2.4	2.4	0.2	3.4	3.6	3.8	3.6	0.2
10.50	2.4	2.3	2.5	2.4	0.1	2.5	2.3	2.4	2.4	0.1	3.4	3.6	3.8	3.6	0.2
10.75	2.4	2.3	2.5	2.4	0.1	2.6	2.3	2.5	2.5	0.1	3.4	3.6	3.8	3.6	0.2
11.00	2.4	2.3	2.5	2.4	0.1	2.6	2.4	2.5	2.5	0.1	3.4	3.6	3.8	3.6	0.2
11.25	2.4	2.3	2.5	2.4	0.1	2.8	2.4	2.6	2.6	0.2	3.4	3.6	3.8	3.6	0.2
11.50	2.4	2.3	2.5	2.4	0.1	2.8	2.4	2.6	2.6	0.2	3.4	3.6	3.9	3.6	0.3
11.75	2.4	2.3	2.5	2.4	0.1	2.9	2.5	2.6	2.7	0.2	3.4	3.8	3.9	3.7	0.2
12.00	2.4	2.3	2.5	2.4	0.1	2.9	2.5	2.7	2.7	0.2	3.4	3.8	3.9	3.7	0.3
12.25	2.4	2.3	2.5	2.4	0.1	3.0	2.6	2.7	2.8	0.2	3.4	3.8	3.9	3.7	0.3
12.50	2.4	2.3	2.5	2.4	0.1	3.1	2.6	2.8	2.8	0.3	3.4	3.8	4.0	3.7	0.3
12.75	2.4	2.3	2.5	2.4	0.1	3.3	2.7	2.9	2.9	0.3	3.4	3.8	4.0	3.7	0.3
13.00	2.4	2.3	2.5	2.4	0.1	3.4	2.8	3.0	3.1	0.3	3.4	3.8	4.0	3.7	0.3
13.25	2.4	2.3	2.5	2.4	0.1	3.5	2.9	3.1	3.2	0.3	3.5	3.8	4.0	3.8	0.3
13.50	2.4	2.3	2.5	2.4	0.1	3.6	2.9	3.3	3.3	0.3	3.5	3.8	4.0	3.8	0.3
13.75	2.4	2.3	2.5	2.4	0.1	3.6	2.9	3.3	3.3	0.3	3.5	3.8	4.0	3.8	0.3
14.00	2.4	2.3	2.5	2.4	0.1	3.7	3.0	3.4	3.4	0.3	3.5	3.8	4.0	3.8	0.3
14.25	2.4	2.3	2.5	2.4	0.1	4.0	3.1	3.4	3.5	0.5	3.5	3.8	4.0	3.8	0.3
14.50	2.4	2.3	2.5	2.4	0.1	4.1	3.1	3.4	3.5	0.5	3.5	3.8	4.0	3.8	0.3
14.75	2.4	2.3	2.5	2.4	0.1	4.1	3.2	3.5	3.6	0.4	3.5	3.8	4.0	3.8	0.3
15.00	2.4	2.3	2.5	2.4	0.1	4.1	3.3	3.5	3.6	0.5	3.5	3.8	4.0	3.8	0.3









APPENDIX D

Table 1: Average Dimensions for EPS Loose Fill Peanuts.

sample #	Low and High Density ISOPACK			"small s-shape"			"shell-shape"	
	Thickness (inches)	Length (inches)	Width inches	Thicknes (inches)	Length (inches)	Width (inches)	Thicknes (inches)	Diameter (inches)
1	0.38	3.13	2.06	0.31	1.31	0.69	0.13	1.00
2	0.44	3.19	2.06	0.31	1.25	0.69	0.13	1.13
3	0.38	3.19	2.12	0.31	1.19	0.75	0.06	1.06
4	0.38	3.19	2.06	0.31	1.19	0.63	0.06	1.13
5	0.38	3.19	2.12	0.31	1.19	0.69	0.13	1.06
6	0.38	3.06	2.12	0.38	1.25	0.75	0.19	1.00
7	0.44	3.06	2.06	0.31	1.38	0.63	0.13	1.06
8	0.44	3.00	2.12	0.38	1.25	0.63	0.06	1.13
9	0.44	3.06	2.12	0.31	1.31	0.63	0.19	1.06
10	0.44	3.06	2.12	0.38	1.19	0.75	0.13	1.06
Average	0.41	3.11	2.10	0.33	1.25	0.68	0.12	1.07
Std. Dev.	0.03	0.07	0.03	0.03	0.07	0.05	0.05	0.05

Table 2: Approximate Fragility Levels for various classes of Products.

PRODUCT	FRAGILITY (G's)
PRECISION INSTRUMENTS	15
ELECTRONIC EQUIPMENT	25
SMALL APPLIANCES	75
MACHINERY	100

REFERENCES

LIST OF REFERENCES

- Anon. "Cushioning: The more you know.... The more you'll save", Dow Chemical Company's Publication August 1998, CC No. 66665/0, P. 66-70
- Anon. "EPS Seeks more growth", Plast. Rubber Wkly no. 1672, 1997, P. 8.
- Anon. "Biodegradable Wheat Loosefill", Packaging Week Vol. 10, no. 27, 1 Dec. 1994, p.4.
- Anon. "Polystyrene Major Markets", Modern Plastics, Jan 1995.
- Anon. "Banking on Moldable Loosefill Benefits", Packaging Digest, Feb 1996, p. 46.
- Bakker, M., The Wiley Encyclopedia of Packaging Technology, John Wiley & Sons, Inc., New York 1986.
- Brandenburg, R.K. and Lee, J.J. " Fundamentals of Packaging Dynamics ", L.A.B., New York, 1991, P. 69, 84, 103-105.
- Brown, R.V. " Development and Evaluation of Polyurethane Loose Fill Cushioning Material " , Air force Packaging Evaluation Agency, U S Govt. Reps Announcements vol. 74 no 26 27, 1974 P.168.
- Charnnarong, Nopporn. "On A Comparison Between various Package Cushioning Materials Based on Performance and Environmental Concerns", Master's Thesis, School of Packaging, Michigan State University, 1991.
- Chonhenchob, Vanee. " On A Comparison of Various Packaging Loose Fill Cushioning Materials Based on Protective Performance and Environmental Concerns ", Master's Thesis, School of Packaging, Michigan State University, 1994.
- Demetrakakes, Pan. 1993. " Cushioning Softens blow from "green" criticism", Packaging (Boston, Mass.), Dec. 1993, p.22
- Larson, Melissa. Sept 1992. " The Return of Foam Cushioning ", Packaging Magazine, Vol. 37.
- Liu, Ruogong. " On Development of A Computer Aided Cushion Design Software ", Master's Thesis, School of Packaging, Michigan State University, 1995.

LIST OF REFERENCES CONTINUED.

Noone, W.J. “ Cushioning Materials: Balancing Cost, Environment and Performance “, Packaging Technology, Vol 4, no. 3, 1995 P. 28-30.

Pichyangkura, Atiwadee. “ On Comparison of Various ASTM and NSTA Vibration Test Methods For Product Packaging “, Master’s Thesis, School of Packaging, Michigan State University, 1993.

Schneider, Marvin. 1998. “U.S. production of EPS bead stock in 1997 rises to 10.5% over 1996”, Modern Plastics , mid November 1998, page D-56.

Sealed Air Corporation. 1998 “ Technical Data Report of Air-Filled Bags and Bubble Wrap packaging”.

Singh, S. Paul, 1983. “Effect of Multiple Drops on the Damage Boundary Curve”, Master’s Thesis, School of Packaging, Michigan State University.