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Cushioning Performance of Molded Pulp (E-Cubes) Loosefill

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Geeta Govindan

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CUSHIONING PERFORMANCE OF LOOSE FILL (E- CUBES) MOLDED PULP

BY

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AN ABSTRACT OF A THESIS

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ABSTRACT

CUSHIONING PERFORMANCE OF MOLDED PULP (E-CUBES) LOOSEFILL

BY

Geeta Govindan

This thesis involves a study of a new type of loosefill : E-cubes, made of recycled paper pulp. The two types of E-cubes tested were: Low and High Density. ASTM test procedures were used to check the shock absorbing properties.. The data obtained was plotted as G_{max} versus static loading. This enabled the comparison of data for both types of E–cubes for two different thicknesses and two different drop heights.

ASTM D-4728 was used to check the effect of random vibration on settling of products when loose fill E-cubes are used. Three different sizes of spherical shaped objects were used to determine the settling rate. The settling rate of the spherical objects was compared to that of EPS loosefill.

The results showed that this material is higher in cost than EPS loosefill, and shows a higher shock transmission as comparesd to EPS loosefill. However it has extremely good interlocking capability and prevents products from settling due to vibration.

ACKNOWLEDGEMENTS

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CHAPTER 1: INTRODUCTION

1.1 Why Use Cushioning?

During transportation, a product is subjected to various types of handling and shipping hazards. One type of handling hazard is the accidentally dropping of packages while loading them in vehicles. Due to the weight of the product, and the velocity with which it falls, damage can occur. Transportation hazards could result from the vibration of the truck while traveling. When one packs a product and ships it, it's the individual's responsibility to see that the product reaches the customer safely. During transit, the product is likely to be damaged due to the rigors of transportation. The term used to describe protection given to the product from shock is cushioning. In order to protect products during shipping, one needs to use cushioning materials. The cushioning and protective packaging should be done reliably and at a low cost. (Paine, 1967)

While selecting cushioning materials one needs to account for several properties including the following:

1. It should significantly reduce the damage rates to the product by providing adequate shock absorption during drops. This will keep the G level felt by the product as small as possible.

2. It should try to produce plastic impacts when the product is dropped. The product should not bounce.

3. It should be durable enough to withstand a number of drops and severe weather conditions.

4. It is a requirement that the cushioning be light in weight. This will keep the weight of package low.

5. It should fill voids and keep the product centered in cartons.

6. It should be manufactured with consistent properties.

7. It should be low in cost.

8. Cushioning materials are environmentally preferred if they are reusable or biodegradable.

9. It should not be sharp or cause abrasion to the product surface.

10. It is important that the cushioning material has good '***compression set***' and '***creep resistance***'. Compression set is the inability of the material to return to its initial thickness after shock. A cushion with poor compression set property once compressed remains in that condition leaving a void in package that adds to damage apart from the fact that it has lost its cushioning effectiveness. (United Parcel Service, 1975)

11. The weight of the product on the cushioning material compresses it over a period of time; this is known as '***creep***'. This happens to all types of cushioning materials with a varying degree. Materials with high creep resistance are preferred. (United Parcel Service, 1975)

1.2 Types of cushioning materials:

Various types of cushioning materials are available that can offer product protection during shipping and handling.

1. Air encapsulated plastic (Bubble wrap)
2. Foam
3. Molded custom made inserts
4. Foam in place
5. Airbags
6. Corrugated board
7. Loose fill:
    a) Expanded Polystyrene peanuts (EPS)
    b) Wood Curls
    c) Shredded corrugate board
    d) Shredded Paper
    e) Biodegradable loose fill
    f) E-cubes

1) BUBBLEWRAP:

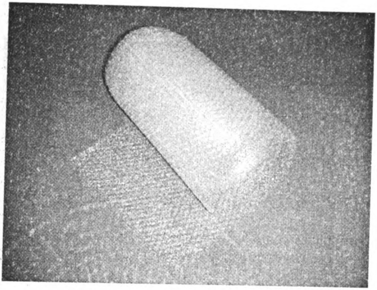


Figure1: Bubble Wrap

Bubble wrap (Figure 1) cushioning is used for protecting all types of fragile products. Bubble wrap is a lightweight material. It is made from flexible polyethylene sheeting encapsulating air pockets, or "bubbles." This cushioning offers versatility of application. It accommodates a variety of sizes and shapes of products requiring cushioning, surface protection, and void fill. Bubble wrap meets packaging requirements for surface protection and small-item cushioning. This cushioning product is commonly used in packaging machine parts, glassware and small electronic elements.

Coatings —bubble wrap cushioning could also have adhesive and cohesive coatings. They can be self-sealing. Using non-staining adhesive enables direct application to products that eliminates surface damage. Cohesive bubble adheres only to itself and offers a wide variety of applications involving insulating products from damage, void filling and keeping products in place during shipping.

2) FOAM

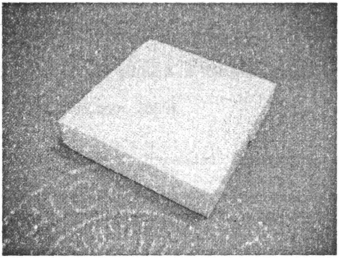


Figure 2: Polyethylene Foam Cushion Block

Foam structures can be of two types: "Closed-cell" foam or " open cell" foam. Closed cell foam consists of individual bubbles of air trapped within a thin unbroken membrane of plastic. The cells are fused together to form the cushion. They absorb energy in an impact by compressing air. Expanded polystyrene is used largely to make end caps for products. They are stiffer durable and better able to cushion heavy products. They are more expensive than the open cell foam. EPS is however not a material of choice while considering packaging of lightweight fragile products that require lower static loading. (Rogers, 1986)

Open cell foam consists of a network of open cells. Air is able to flow between cells. Example: Low-density polyethylene foam (Figure 2).

There is a visible difference between the open and closed cell foam (United Parcel Service, 1975). In addition open cell foam will absorb water and act as a sponge.

Recycled Green: Environmentally friendly green polyethylene foam is manufactured from recycled resins. Fifty percent of the total weight consists of secondary waste of which ten percent of the total weight consisting of post-consumer waste. (Papermart.com, 2000).

Foam products such as EPS (Expanded Polystyrene), EPE (Expanded Polyethylene) and PU (Expanded Polyurethane) are custom made into molded cushions for inserts.

3) Molded: CUSTOM-MADE FOAM INSERTS: -

Depending on the design of a customer's foam, solid cushions can be molded and cut to suit product shapes. They can be made out of EPS (Expanded Polystyrene), EPE and PU.

There are other types of inserts that are made of molded recycled paper. These cushions are low in cost and are mainly for lightweight product such as printer and computer accessories. (Packaging World, 2000)

Advantages of using molded insert are:

1. They do not shift inside the pack.
2. They also absorb a lot more impact energy.

Disadvantages of using molded insert are:

1. They are expensive and are custom made to order.

2. They are not biodegradable or easily recyclable.

Starch-based foam pieces can be molded using water misting. Water soluble starch pellets are lightly misted before packing, causing them to adhere to each other and then molded in place for protective cushioning.

4) Foam in place: It is a chemical, Epoxy Poly Urethane, which is sprayed into the box to form protective cushions. The foam in liquid state rises around the contents and cures to become solid foam cushions. It is used to provide cushioning to irregularly shaped heavy products like machinery parts. Plastic is poured inside the outer pack in the form of a foam. A plastic sheet is kept on top of it and the product is placed with a plastic sheet on top and more foam is sprayed around the product. The box is then closed and the foam is allowed to cure. The foam then expands and forms a kind of protective case around the product. This is as versatile as loose fill cushioning because it takes the shape of the product. It is similar to molded custom made cushioning, and often cannot be reused.

5) Air – Bags: An air bag is a plastic bag filled with air as shown in Figure 3. It is made of Low Density Polyethylene so that it can be heat sealed after filling with air. It could be as small as a bubble wrap, or it could be made as big as a mattress. The large air bags can provide cushioning to pallet loads for lateral shifting in trailers and rail cars.

Advantages:

- It is a low cost cushioning material that is not messy in application.
- Could be used in all weather conditions.

Disadvantages:

- If the product has a sharp edge it may puncture the airbag and deflate it.
- As a result of air pressure inside the bag it may develop thin walls due to the constant stretching of plastic which in due course of time may damage the bag.

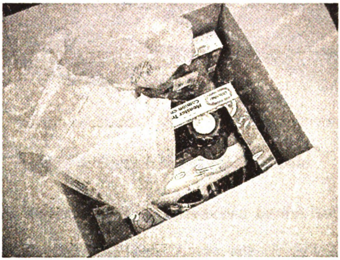


Figure 3:Airbag

6) Corrugated Board:

Corrugated board is made of recycled kraft paper.

6.a) Single Faced Corrugate Board: This is placed around the product so that it absorbs the shocks during transportation. Single faced corrugate board is wrapped around the product to give it cushioning. It is one of the cheapest cushioning materials and can also be recycled. The properties of paper are strongly affected by moisture and age. This type of cushion is sensitive to humidity. These cushions may be able to give adequate protection for single drop situations but are not very effective for multiple drops. (Singh et-al,1994,). Figure 4 shows the single face corrugated cushioning material.

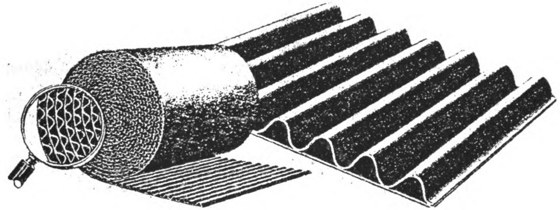


Figure 4: Single faced corrugated board.

6.b) Honey Comb Board: It was first developed by the Structural Research Laboratories at the University of Texas, Austin, specifically to pack single aerial drop of military products. As seen in Figures 5a and 5b honeycomb is made of a network of cells that form the core. The core is glued between two facings. It can be made of different core sizes. The core usually has a 33 pounds basis weight and the two liners have 69 pound basic weight each. Honeycomb offers extremely high compression strength as compared to built-up corrugated board cushions.

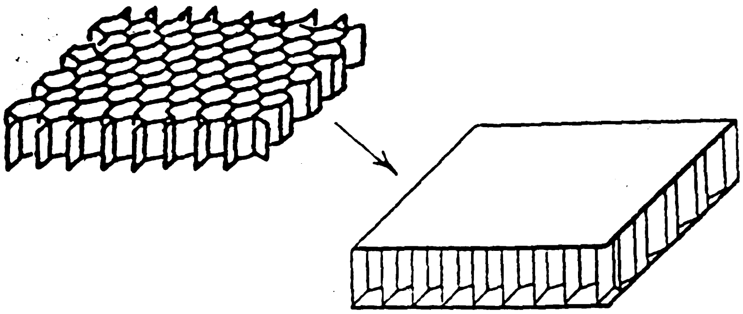


Figure5a: Core Figure5b: Honey Comb Board

7) Loose fill:

A wide variety of materials are used as loose fill cushioning. They are primarily used to provide void filling of spaces in rectangular shaped cartons when packaging odd shaped products. Some of the commonly used loose fill cushioning materials are discussed in this section.

Expanded Polystyrene loosefill:- The plastic pellets are extruded and then expanded with heat. In order to obtain a low density the pellets have to be expanded after heating. Approximate density of EPS loosefill is 0.25 – 0.30 lb/ft^3. One hundred percent recycled EPS is also available. It is green in color to signify that it is recycled. In general Expanded Polystyrene whether it is recycled or virgin is electrostatic sensitive. At low humidity it will cling to the product it is packed in. This makes the packing and unpacking a messy process. (Singh, Chonhenchob and Burgess 1994). However due to its extremely low cost EPS is the most widely used type of loosefill in the United States today.

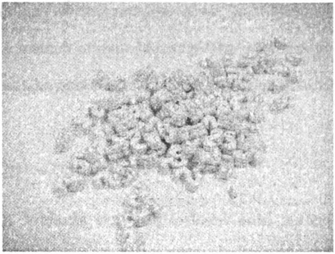


Figure 6: Expanded Polystyrene Loose-fill

Wood shavings:

This material is made from wood waste obtained from the lumber industry.

Figure 7: Wood Curls. (Papermart.com, 2000)

The shavings are of various shapes, sizes, and diameter as there is no consistency in the method of manufacturing. The drawback in using this type of loose fill is that it can be abrasive to the product. (Singh et-al,1994)

Shredded Corrugated Board /Corrufill:

Before 1992, NDL Products Inc. used to throw away the incoming corrugated boxes and used to pack their sports and fitness products in polystyrene peanuts. They did not want to waste the corrugated boxes so they stopped buying polystyrene peanuts. They bought a cardboard shredder and started using the shredded corrugated boxes as loose fill. But the pieces were too large and had a ragged look. They were full of small particles and paper dust. Due to customer complaints they bought a corru-shredder specifically to chop the corrugated board into uniform strips. The machine is 3 ft wide, 8 ft long, weighs about 400 pounds, and is mounted on wheels. It operates on 110 volts AC. The operator prepares the feedstock by flattening the cartons. Then whole boxes are slit into strips, generally 4 to 6 inches wide, using a table saw. The width of the first cut determines the length of a finished piece of packaging material. Next, the wide strips of the box are fed into the corru-shredder for slicing into uniform, 1/8 – inch –wide strips, The finished material, called '***corru-fill***', passes through a strong air current to remove dust, and the material falls into a bulk container. As the container fills, the contents are sprayed with biodegradable insecticide in an alcohol based carrier. Machine maintenance includes daily oiling and occasional sharpening of the four shear blades. On an eight hour shift with manual operators, the machine can produce about 1,500 lb, or approximately 1000 cubic feet of corrufill.

For equal volumes, chopped Corrugated box is significantly heavier than foam polystyrene. However, when corru-fill is dumped loosely around products in cartons, the exposed corrugations on the thin strips causes adjacent pieces to catch on one another, forming a sort of lattice. The air space thus created tends to negate weight difference between the shredded corrugated and Polystyrene as well as reduce the required volume of packaging material.

Shredded paper:

Another form of loose fill consists of using shredded paper enclosed in polyethylene sleeves. Modine Midwest Inc. shreds its office waste paper and puts it into clear plastic sleeves, sealed at both ends to form "sausages" This too helps to absorb shock rather than transmit it to the product. Also the product is free of cushioning dust. (Levine, 1989)

Biodegradable loose fill:

Various types of bio-degradable loose fill materials have also been developed in the last decade. These usually are starch based formulations made from corn or wheat and dissolve completely in water (Figure 8). White biodegradable loose fill is made from natural vegetable starch, which quickly dissolves upon direct contact with water. The complete biodegradability makes it environmentally friendly. This loose fill can also be coloured by using additives. At e Toy's the toy carton is filled with Flo-Pak Bio 8 starch loose fill. (Packaging Digest, 1999)

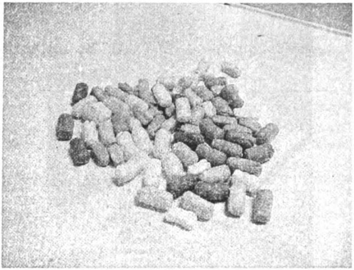


Figure 8: Biodegradable Loose-fill

FP International buys denatured cornstarch, which is then mixed with water and additives in a proprietary, water-soluble formula. After cooking the material, it is extruded through a die, and the water evaporates as it exits the machine, causing the starch to expand. The die shapes it into a tubular '8' shape. It is then stored for 24 hours in a hot humid environment. Then it is ready for shipment. To increase packaging line efficiency, eToys installed two FP International bulk air systems in 1998 as shown in Figure 9. The Bulk Air System (BAS) incorporates overhead, large volume loose fill store bags and automated dispensing to keep each packaging station supplied with loose fill. The BAS is fully automated and requires no manual assistance.

Figure 9: The BAS dispensing at eToys. (Packaging Digest, 1999).

1.3 Comparison between Solid and Loose fill cushioning materials.

Solid Cushion	Loose Fill Cushion
1. Solid Cushion can be cut/molded to desired shape.	1. Loose fill is of a definite small shape. It's just dumped into the shipping container.
2. Capital investment such as die cutting tools is needed in most cases other than foam in place.	2. Loose fill cushioning material is available in market in a ready to use form.

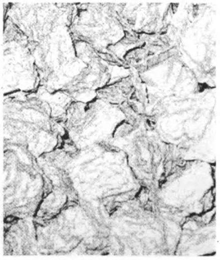
3. Once used solid cushion has to be thrown away as some part of the cushion may have bottomed out	3. Once used bottom cushion may be bottomed out while side and top loose fill can be separated and reused.
4. Economically viable for high volume shipments where mold costs can be justified for large standard orders.	4. Economically viable for low volume shipments and where product shape is not standard.

1.4 E-Cubes :

This research investigated the protective properties of E-cubes. Specifically it measured the shock absorbing capabilities and also the settling of products during vibration. The material is available in two different densities as shown in Figures 10 a and 10 b.

Grey High density E - Cubes

Figure 10a



Green Low density E – Cubes

Figure 10b

E-Cubes are cube shaped molded pulp products. They are made from paper fibers and water. They are used as loose fill while packing to protect the product from hazards of transportation. They absorb impact and minimize rebound that is often found in resilient foam materials, thus reducing the shock levels the product is subjected to.

The benefit of using E-Cubes unlike other plastic loose fill packaging materials is that they are environmental friendly. i.e.: being cellulose in nature they can be easily land filled. E-Cubes are a 100% biodegradable product that is made from only newspapers and water. Expanded Polystyrene peanuts (EPS) are a difficult material to. E-cubes are made of recycled paper. Paper with high degree of thrash is not recommended.

Starch based loose fill cushioning materials are hydroscopic and thus less favorable for use in high humidity and high temperature regions in which the starch biodegrades when exposed to moisture. For environmentally conscious, the biodegradability nature of starch based loose fill makes it a favored cushioning material (Chonhenchob, 1994). However they are significantly high in cost as compared to EPS loosefill. Because of the added cost they have not been able to gain a significant market share in the United States. They have found popularity in Europe where tougher environmental legislation against EPS loosefill offsets the cost factors.

1.5 HOW ARE E-CUBES DIFFERENT FROM OTHER LOOSE FILLS?

The manufacturer of E-CUBES claims that the shape of this loosefill gives them superior energy absorbing properties. E-CUBES compress under impact and then regain their shape. This ability to compress and reset allows E-CUBES to continually protect the product through repetitive impacts, drops and jolts during normal shipping and handling unlike custom foam end caps or rigid foam products.

E-Cubes have been engineered with a rough textured surface having a contoured shape that makes them lock together. Despite the manufacturers claims they are not easy to dispense from current styles of overhead dispensers that were designed for EPS loose fill due to the added weight density.

Changes that need to be done when switching from regular EPS to E-Cubes:-

1. Hopper size needs to be increased as E-cubes have a higher density and occupy more space. So there needs to be more room in the storage magazine from where they can be dispensed on to the pack.

2. E–Cubes are not as slippery as other loose fill materials. The discharge systems need to be adjusted (increased) in size.

1.6 E-CUBES DISPENSING SYSTEM

Bulk Dispensing Systems are designed such that it provides high-speed dispensing in limited warehouse space. All bulk systems are modular in design, which helps during expansion. The advantage of this system is as requirements grow, additional modules can be added without discarding the existing equipment (Figure 11).

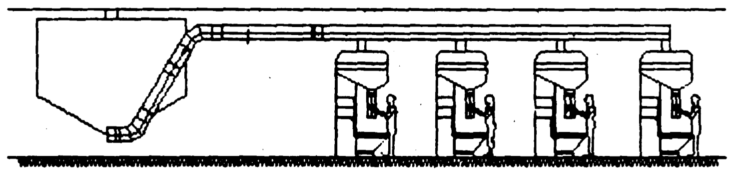


Figure 11: Bulk Dispensing System (www.e-cubes.com).

1.7 Current Applications of E-cubes:

The manufacturer of E-cubes claims that their product is used for a wide range of products in different industries that are listed below:

Auto parts

Computer components

Consumer electronics

Musical instruments

Antiques

Liquids

Medical equipment

Mail order

Ceramics

Fixtures

Lighting

Electronics

Lubricants

Paints

Soaps

Candles

Medical Supplies

Carved wood products

Food Baskets

Glass and cups

It may be possible to pack the above products in E-cubes. But as of today we find that majority of companies are still using EPS peanuts as a loose fill because of cost factors. Polystyrene peanuts come in the shape of peanuts, shells and hooks. Some of the reasons that EPS is still a widely used loosefill are:

- The cost of Polystyrene peanuts is 80 to 90 cents per cu.ft. while that of E-cubes is as much as $2.00 per cu.ft.
- Polystyrene peanuts can be used for a wide temperature range without loss of performance.
- They are generally clean and do not create any residue or dust.

1.8 E-CUBES Current Specifications:

Physical Description

Size	1" x 1" x 1" cube
Composition	Recycled newspaper and corrugated cardboard
Weight	1lb/ft^3 (dependant on raw materials)
Colour	Green, with most colours available by special order

Uses

E-CUBES are a versatile void filling and cushioning material. They are an alternative to virtually all types of packing media including styrofoam inserts, die-cut corrugated, foam-in-place, bubble sheets, foam packs, molded pulp, Kraft paper, etc.

Electrostatic Properties

E-CUBES is intrinsically anti-static. They pass Federal Specification PPP-C-1683A for electrostatic adhesion of packaging material. They also qualify under the Electronics Industries Association test EIA-541 as packaging for electrostatic discharge sensitive electronic devices.

Vibration Settling (Product Migration)

When tested for vibration settling in accordance with federal specification PPP-C-1683A, a box is tightly packed inside another box with 3-inches of E-CUBES all around the inner box. After a half an hour of strong vibration, no visible settling was observed.

Humidity & Spill Containment Effects

E-CUBES' performance is not affected by high humidity. E-CUBES absorb up to six times their weight to contain spills.

Hazard Identification

Overview: E-CUBES is a green, odorless, non-toxic molded paper product. E-CUBES, by their nature of being composed of recycled paper, present no greater health hazard than the cardboard box in which they are packed.

Carcinogenicity: NTP - none, IARC - none, OSHA - none

Potential ecological effects: none

MSDS sheets available upon request.

Industrial Consumer Recycling

E-CUBES can be recycled.

Home Consumer Recycling

E-CUBES can be recycled with other paper products. E-CUBES is an excellent composting medium.

(Warda, Tom, President of E-Tech, 1998)

1. 9 OBJECTIVES:

The literature review in this chapter clearly shows a wide range of cushioning materials that are used for different applications. Each of these materials has distinct advantages and disadvantages for a given applications. Two types of E-Cubes are commercially available and were tested in this study. These are the:

1. Original strength E-cubes, which were green colored and have a low density,
2. High Strength E-Cubes, which are grey colored and have a high density.

The two main objectives of the study were:

1. To test the shock absorbing properties of E – Cube material and develop cushion curves.
2. To test the performance of the E-Cube material during vibration (settling of products).

The tests were conducted using ASTM methods. The experimental design and data analysis are presented in the next section of this thesis.

CHAPTER 2: MATERIALS, METHOD, AND TESTING OF E-CUBES.

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 several hundred packaging standards since its inception in 1914. The committee currently has jurisdiction of over 130 standards published in the Annual Book of ASTM Standards, Volume 15.09, (www.astm.org)

2.1 Shock Test for E-Cubes:

There are two ASTM methods that are currently used to measure the shock absorbing characteristics of cushioning materials. ASTM (D 1596 – 97): Standard Test Method for Dynamic Shock Cushioning Characteristics of Packaging Materials is generally used for materials that are solid cushions which are either molded or fabricated for end use.. In this test method rectangular samples of the test material are used and a dropping weighted platen is used to determine the transmitted shock from different heights. The second method ASTM D 4168 is used for molded foam in place cushioning materials. In this method an instrumented block is placed inside a molded cushion which is then dropped on a programmable shock table using different equivalent free fall drop heights to determine cushioning properties. However there is no existing test method that has been developed to test loose fill cushioning properties by ASTM. In various test studies and research projects conducted by the School of Packaging, Michigan State University a modified versions of ASTM D 4168 is used for loose fill cushioning materials (Chonhenchob, V., 1994, and Zesaguli, C., 1999). The intensity of the shock felt by an instrumented test block that simulates a product in a corrugated box is measured. The accelerometer mounted in the instrumented test block measures the acceleration and duration. This G depends on the type of cushioning material used, its thickness, drop height, and static loading used.

The instrumented test block is a wooden box measuring 8 inches x 8 inches x 8 inches as shown in Figure 17. The test block has provision to insert the ballast weights. These weights could be adjusted to get the desired static loading. The test was first started with low weight and then the static loadings were gradually increased. The test block was kept flat so that the vertical component of the impact would not be lost. Also the weights inside were properly fastened tightly with the help of screws so that they wouldn't collide with each other and give readings with high frequency noise.

On the top of the ballast weight, a 10 mv/g piezoelectric accelerometer was mounted. This was used to measure the signal from the impact. The principle of operation of this type of accelerometer is based on the tendency of certain materials such as quartz and ceramics to produce a charge when compressed. The movement of a small steel mass attached to it generates pressure. As the mass moves in relation to the housing as a result of shock, it places the material either in tension or compression and causes a small electric current to flow through the wires connected to either end. The voltage produced by this device is a direct indication of the magnitude of the acceleration at every instant. In other words the device acts like a little battery whose voltage output is proportional to the instantaneous acceleration.

The accelerometer was placed at the base of a square shaped metal object for which the transmitted shock was to be measured. It was located at the center. It was mounted parallel to the anticipated shock since it records shock only along its axis. This accelerometer records the entire shock pulse. The signal generated by the accelerometer was analyzed using a software package developed by Lansmont Corporation, Monterey, CA (Test Partner).

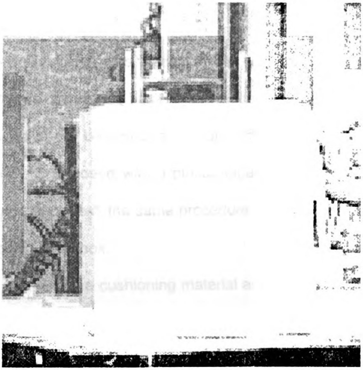


Figure 12. a: Test Block

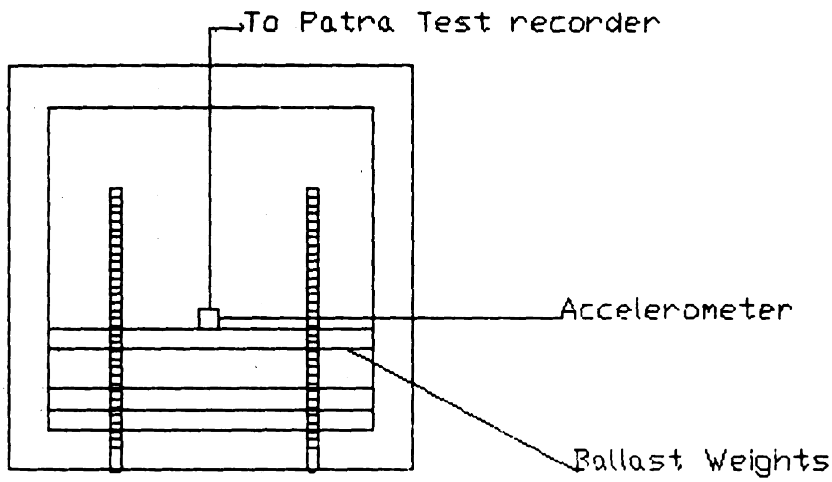


Figure 12. b: Schematic drawing of the Test Block Used for Shock Test.

The instrumented test block was placed at the centre of a 12 x 12-x 12-inch, single wall RSC style corrugated box (regular slotted container). Two inches of E cubes were placed at the bottom and the four sides and top of the corrugated box. The box was then closed with a plastic tape. Similarly for the three inch thick cushioning material test, the same procedure was repeated using a 14 x 14 x 14 inch RSC corrugated box.

The corrugated box with the cushioning material and the wooden test block was restrained on a programmable shock machine as shown in Figure 14. The shock table was then dropped on plastic programmers. The shock machine was calibrated to perform equivalent free fall drops from 24 and 36 inches. Five consecutive drops were made with the same cushioning material and static loading. A filter of 156 Hz was used to remove the disturbance or noise from the shock pulse and the peak G of the shock pulse and duration were recorded.

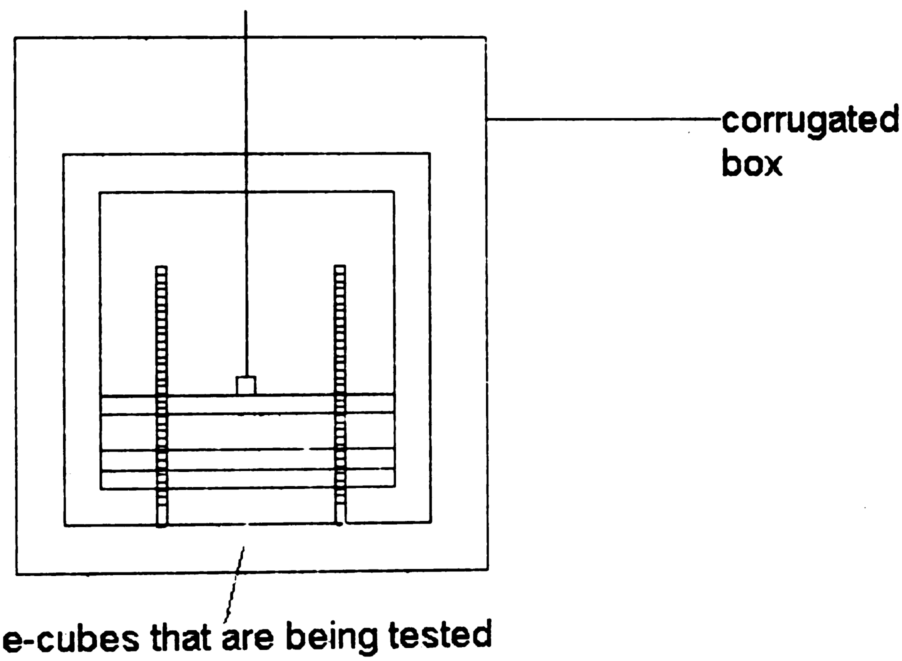


Figure 13: Schematic drawing of the box used for shock test.

The two types of E-cubes tested were:

1. Original - Low density
2. High density E-Cubes.

Both types of loose fill materials were tested at five static loads of 0.15, 0.25, 0.35, 0.504, and 0.799 psi .The static load σ is defined as:

$$\sigma = \frac{\text{Weight of theProduct}}{\text{Area of contact}}$$

The procedure used for the data collection is summarized below:

- A 12 x 12 x 12 inch corrugated box was taken and 2 inches thick of cushioning material was added.
- The test block was placed starting with the lowest static load.
- More E-cubes were added to fill the box tightly so that the test block did not move. The corrugated box was then closed using a plastic tape.
- This was placed on the shock table with plastic programmers.
- The table was set to perform an equivalent free fall drop of 24 inches
- Five consecutive drops were made.
- The shock pulse was recorded and the peak G and duration for each impact recorded.
- The above steps were repeated for all the other static loads.
- The entire procedure was repeated for the 36 inch free fall drop height.
- The experiment was repeated using a 14 x 14 x 14 inch RSC corrugated box to measure transmitted shock properties for a 3 inch thick material.

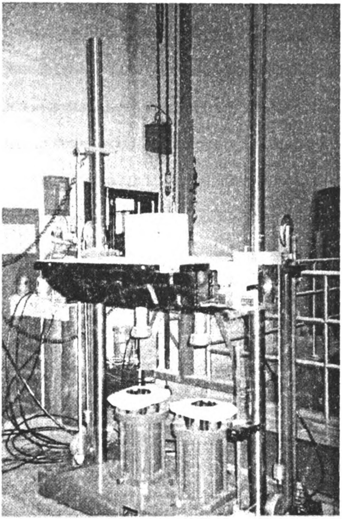


Figure 14: Picture of a shock table

2.2Vibration Test for E-Cubes:

In a previous study conducted at Michigan State University, School of Packaging (Zesaguli, 1999), a test method was developed to study the effects of settling of products in loose fill materials due to transport vibration. In this study three different shaped products (flat, spherical, cylindrical) were used to see the effects of vibration on settling in various types of EPS loose fill. This study found that the spherical shaped products settled the most and would be the product of choice to conduct additional settling studies. In this study three different spherical shaped products were selected that will be used with E-Cubes placed in a corrugated box. The time required for the spherical shaped object to settle a certain distance was measured while the box was subjected to random vibration in accordance with ASTM D4728. The Truck Composite Power Density spectrum was used in accordance with ASTM D 4169, Assurance Level II. Figure 15 shows the test setup of the vibration test.

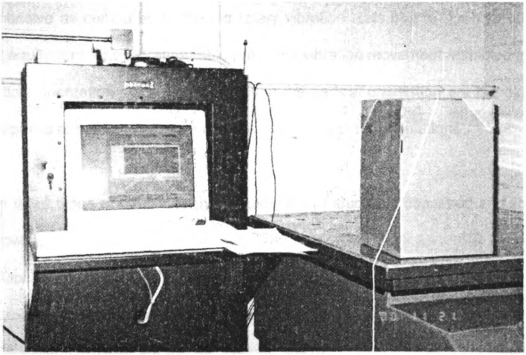


Figure 15: Vibration Test

The ASTM vibration tests using the electro hydraulic vibration table simulate the vertical vibration forces. Additional settling can also occur due to the presence of lateral and longitudinal forces in real life shipments. Real life shipments have both lateral and longitudinal vibrations along with the vertical vibrations (Pichyangkura, 1993)

This study was done to evaluate the settling behaviour of the loose fill cushioning during transportation. An electro hydraulic vibration table was used in the vibration test. The movement of the vibration table is achieved by high-pressure hydraulic fluid placed in a pistons/cylinder arrangement. The fluid is set in motion by a servo-valve, which is controlled by an electrical signal. The valve releases the fluid in step with electrical signal.

The ASTM vibration tests using the electro hydraulic vibration table are more expensive as compared to the old rotary vibration tests due to the 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.

The three types of spherical objects used in this study are described and shown below:

1 Pool Ball (Diameter = 2.5 inches, Weight 169 g)

2 Croquet Ball (Diameter = 3.0 inches, Weight 185 g)

3 Wax Ball (Diameter = 4 inches, Weight 389 g)

A 12 x 12 x 12 inch corrugated box was half filled with E-cubes. A thread was tied to the spherical object, and was passed through two holes on top as shown in the Figure 16. The idea was to keep the thread straight and measure only the penetration of the pool ball with time. The flaps of the corrugate box were kept erect. A piece of board was put above it through which the thread passed and came out of the V- Shaped construction on top. This kept the thread straight so as to reduce error due to thread slack. The thread was pre-marked in the case of distance - controlled vibration and was unmarked in the case of time - controlled vibration measurements.

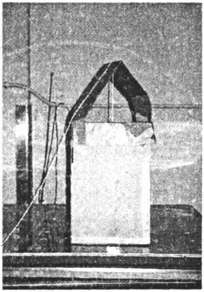


Figure 16: Settling Test Using Random Vibration.

2.2.1 Distance Controlled Vibration Study:

In this test, the ball was tied to a thread, which was marked at an interval of 1 inch for a total of 6 inches. The time for penetrating each inch was recorded for each type of spherical object. The data showed the difference in settling of the object.

Figure 17 shows the croquet ball before the vibration test and Figure 18 shows it after it has settled in the loose fill due to vibration.

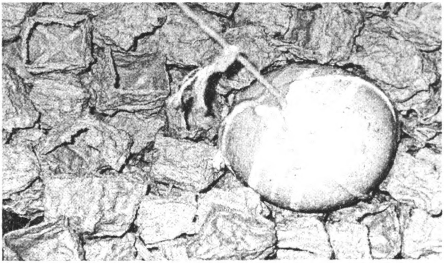


Figure 17 The crocquet ball before the vibration study .

Figure 18: The crocquet ball after the vibration study.

Similarly, Figures 19 and 20 show the other two types of spherical balls used in the settling vibration tests.

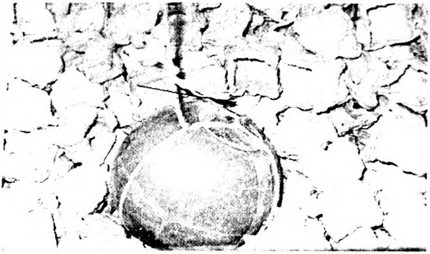


Figure 19: The Wax ball used in the vibration study.

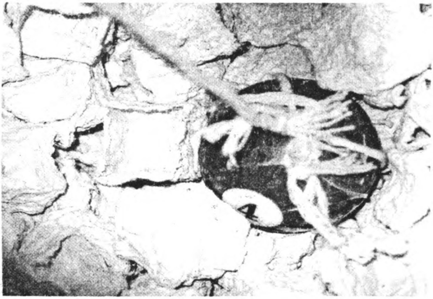


Figure 20: The Pool ball used in the vibration study.

2.2.2 **Time Controlled Vibration Study:**

In this second type of settling test, the table was set to produce random vibration in accordance with ASTM D 4728 using the truck spectrum. Every 15 seconds, the amount of settling of the thread (spherical object) into the corrugated box was measured for a total of 15 minutes or 6 inches of thread travel, whichever occurred first. New corrugated boxes and unused E- Cubes were used for all the above settling tests.

CHAPTER 3: DATA ANALYSIS AND RESULTS

3.1 Transmitted Shock Data:

The transmitted shock data collected for the 2 and 3 inch thick E-Cubes is shown in Tables A-1 to A-8 for both original and high strength samples. These tables show the raw data of peak acceleration G_{max} and shock duration as collected in the laboratory. Five sequential drops were performed at each of the five different static loadings.

Static Loading (S.L) is calculated as:

$$S.L = \frac{\text{Product Weight}}{\text{Cushion Area}}$$

A ***cushion curve*** is a graph of the peak deceleration G_{max} of the product on Y-axis versus static loading on X – axis for a given thickness of material, and drop height.

During an impact, the cushioning material absorbs the shock as much as it can by virtue of its nature and thickness and the remaining is transmitted to the product. The thicker the loose fill used, the better the performance. But not all the loose fill materials are able to keep the shock level 'G' to a lower value even if a large amount of cushioning material is used (Singh, et al, 1994).

The shapes of conventional cushion curves for cushioning materials slope down on increasing the static load, reach a point, and then increase for higher static loadings. However the cushion curves obtained for original density and high density E-Cubes as shown in Figures 21 to 36 do not seem to follow this pattern. The G_{max} values were sometimes low and sometimes high and did not follow a particular pattern for the five static loads. This may be due to the fact that E-cubes shift during the various portions of the test, and are not consistently positioned to offer a perfect flat loading surface for the instrumented test block. Therefore at such conditions, where the test block is not perfectly positioned (flat with the impacting surface), only a component of the vertical acceleration is measured by the single-axis accelerometer. These readings are therefore lower than the true transmitted shock values and therefore the cushion curves developed show a wave type of behaviour as opposed to the conventional arch.

Figure 21 represents the G_{Max} of first drop for a two inch high -density cushion, using a drop height of 24 inches. The values of the G_{Max} obtained in this plot are higher than the one's obtained using a three inch cushion as shown in Figure 23 for same drop height. Similarly the values in both Figure 21 and Figure 23 were much lower than average G_{Max} in Figure 22 and Figure 24. Similar trends can be observed in Figures 25, 26, 27 and 28 where a drop height of 36 inches was used, while other parameters were kept constant.

Comparing Figures 21 and 29 between high density and original density cushion, using the same drop height of 24 inches, it is evident that the G_{Max} in high density is lower than the one in original density E-cubes. The average G_{Max} values were not very comparable as seen in Figure 22 and Figure 30. One of the reasons could be that the cushion material bottomed out. Similar conclusions can be drawn for Figures 31 to 36. The various cushion curves are presented in this section.

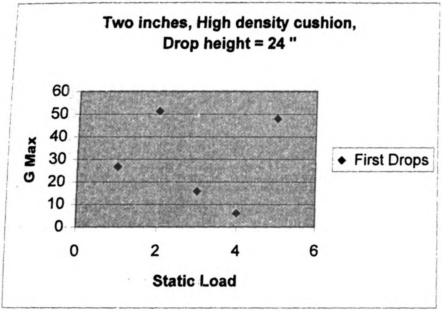


Figure 21: Two inches, High- density cushion, drop height of 24inches, 'G'Max of first drop.

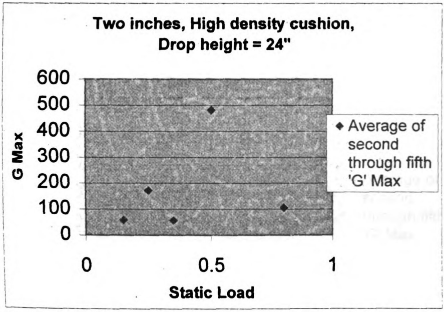


Figure 22: Two inches, High-density cushion, drop height of 24inches, Average G max

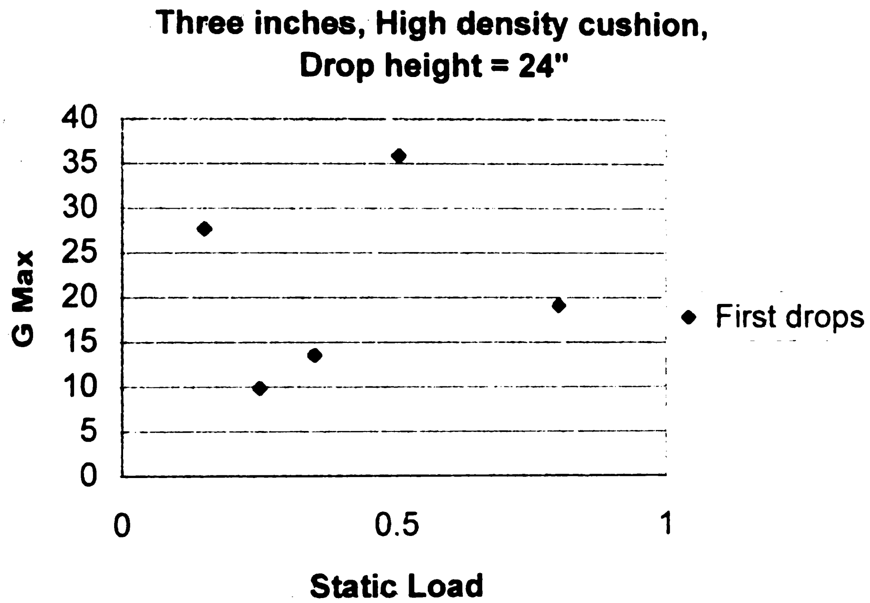


Figure 23: Three inches, High density cushion, drop height of 24inches, 'G'Max of first drop.

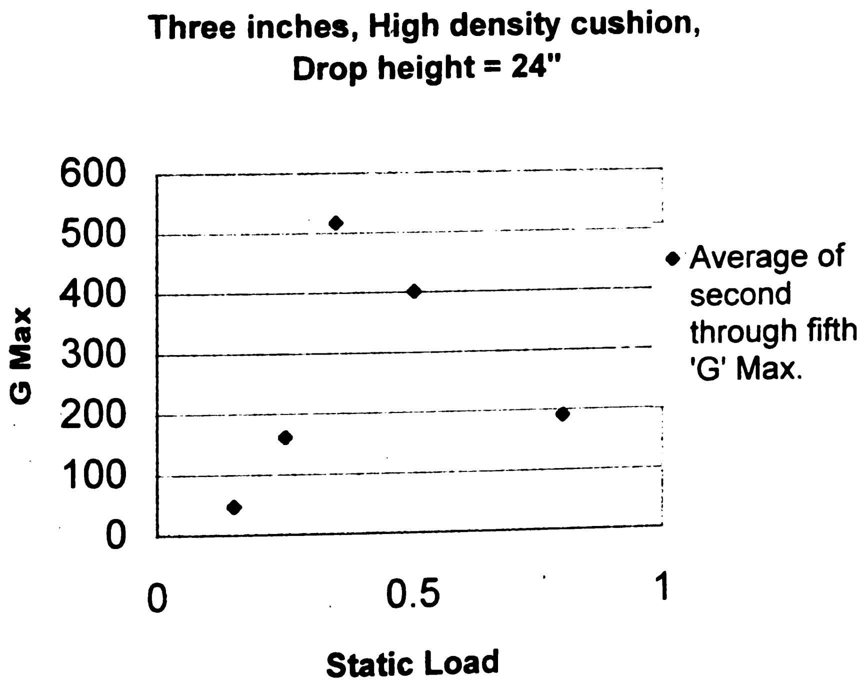


Figure 24: Three inches, High density cushion, drop height of 24inches, Average G max

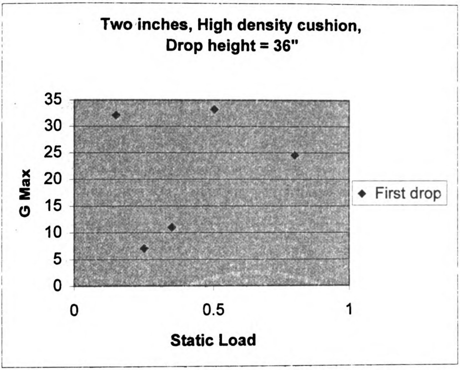


Figure 25: Two inches, High-density cushion, drop height of 36inches, 'G'Max of first drop.

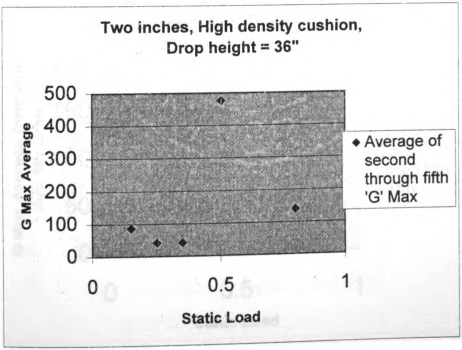


Figure 26: Two inches, High-density density cushion, drop height of 36inches, Average G max

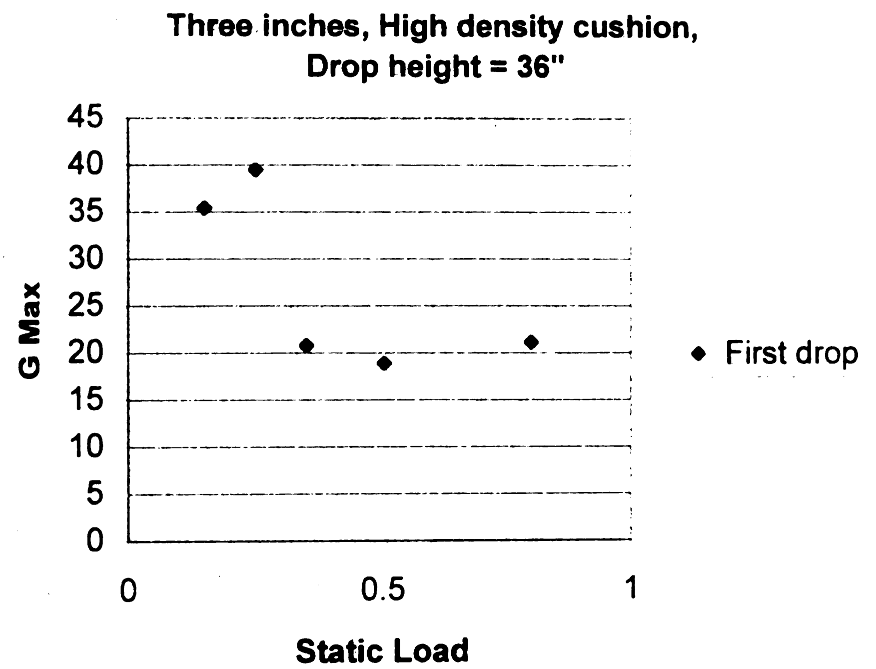


Figure 27: Three inches, High-density cushion, drop height of 36inches, 'G'Max of first drop.

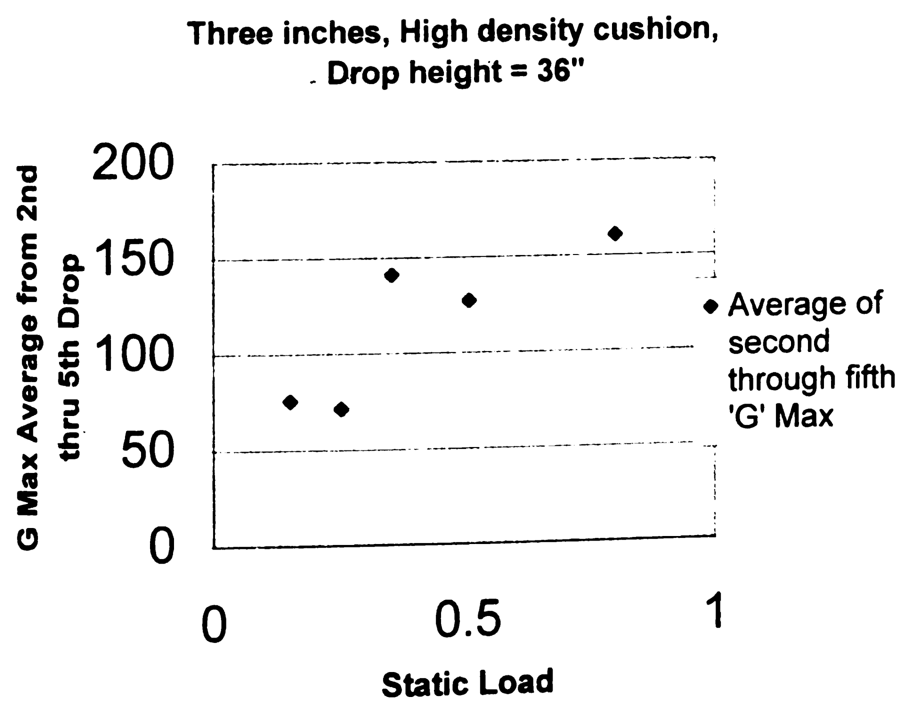


Figure 28: Three inches, High-density cushion, drop height of 36inches, Average G max

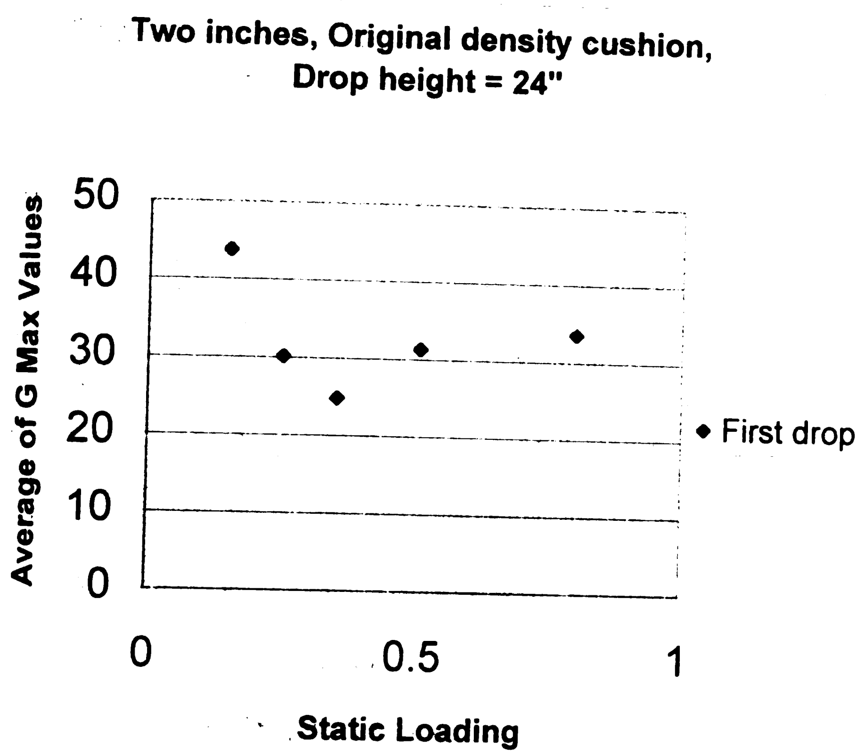


Figure 29: Two inches, Original-density cushion, drop height of 24inches, 'G'Max of first drop.

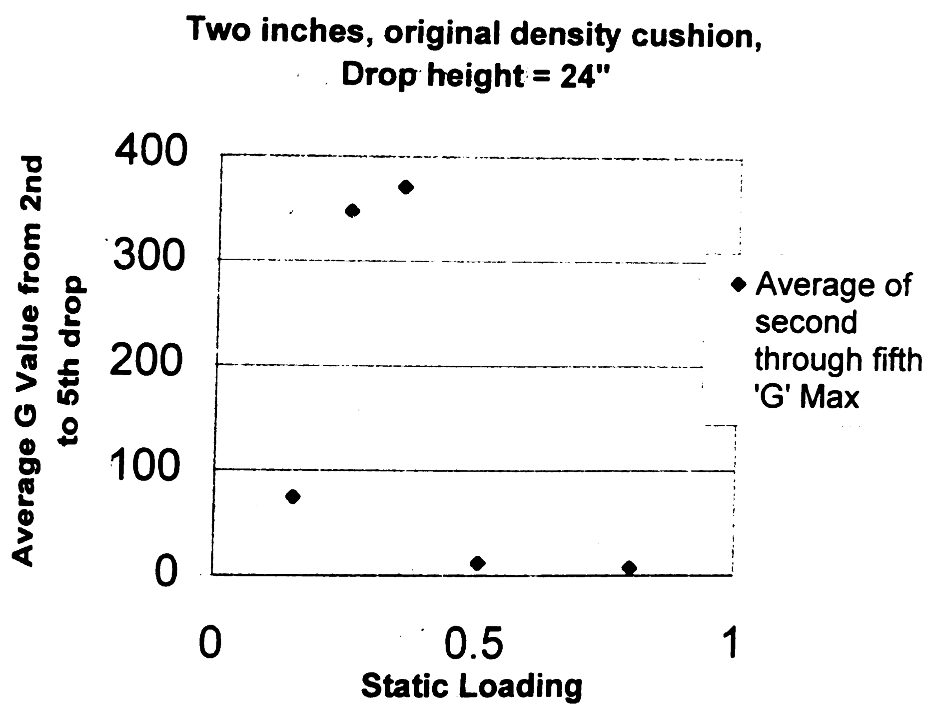


Figure 30: Two inches, original density cushion, drop height of 24inches, Average G max

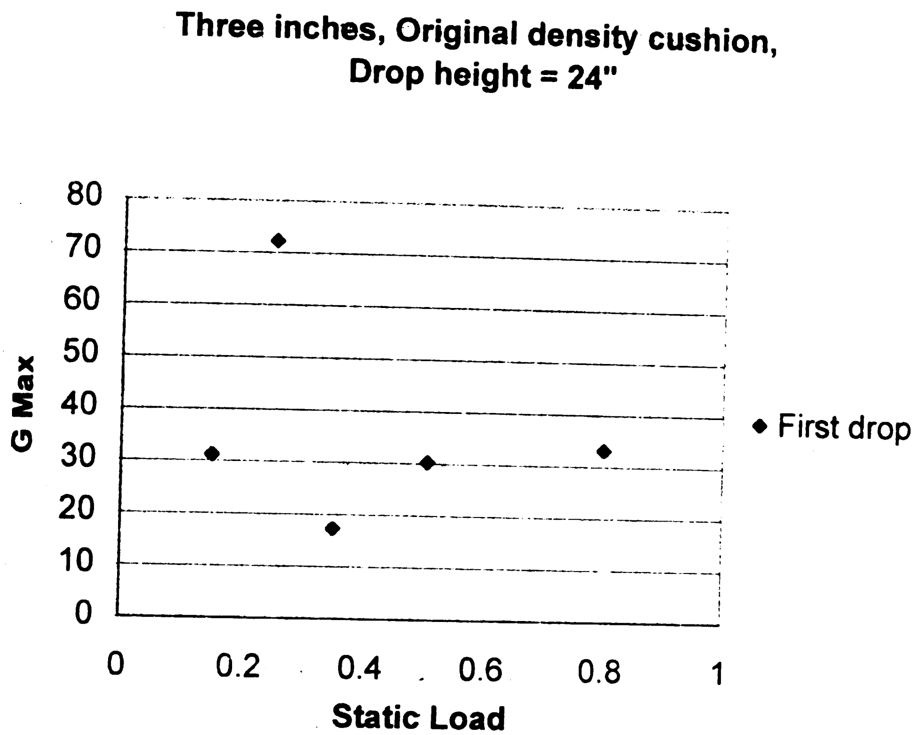


Figure 31: Three inches, Original-density cushion, drop height of 24inches, 'G'Max of first drop.

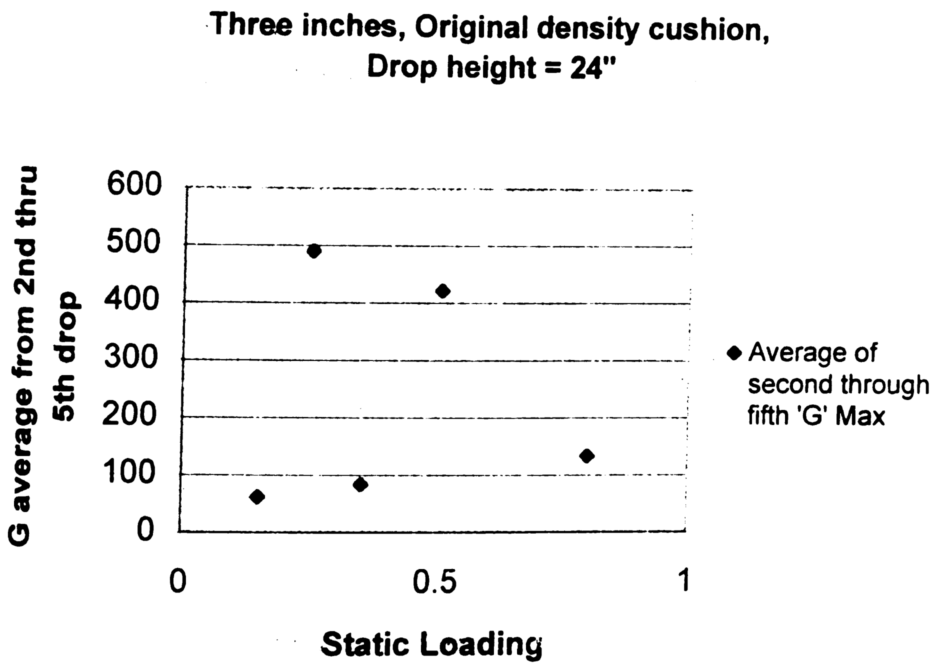


Figure 32: Three inches; original density cushion, drop height of 36inches, Average G max

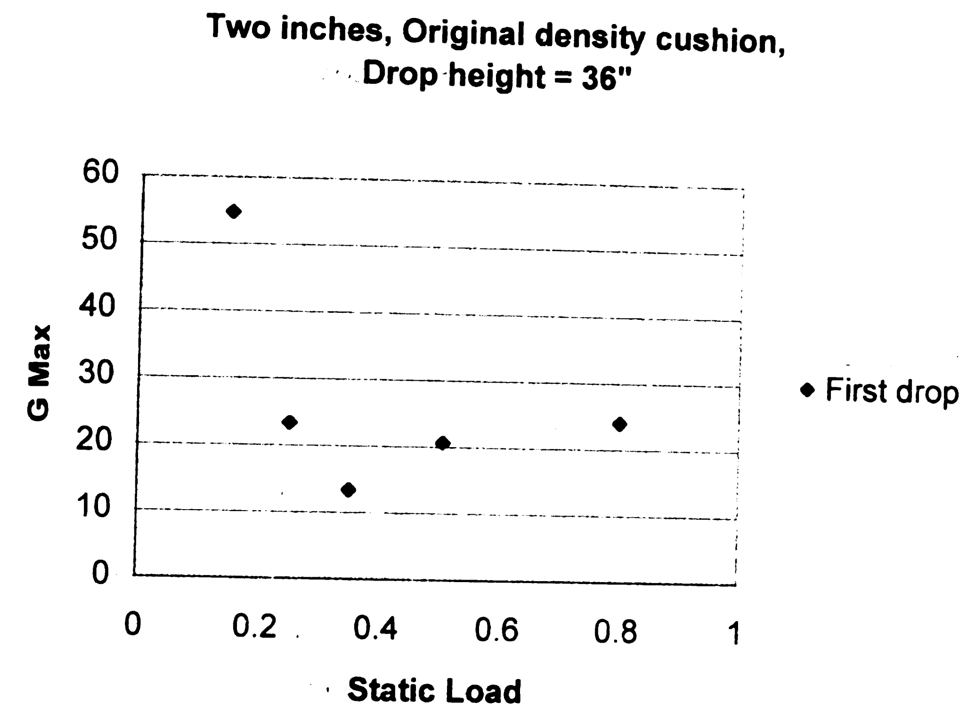


Figure 33: Two inches, Original-density cushion, drop height of 36 inches, 'G'Max of first drop.

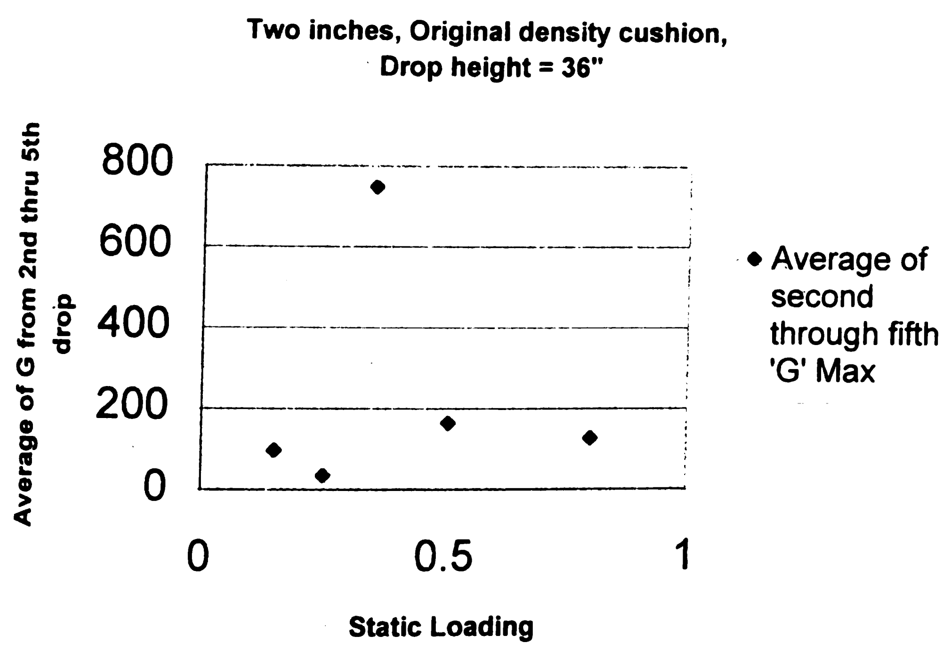


Figure 34: Two inches, original density cushion, drop height of 36inches, Average G max

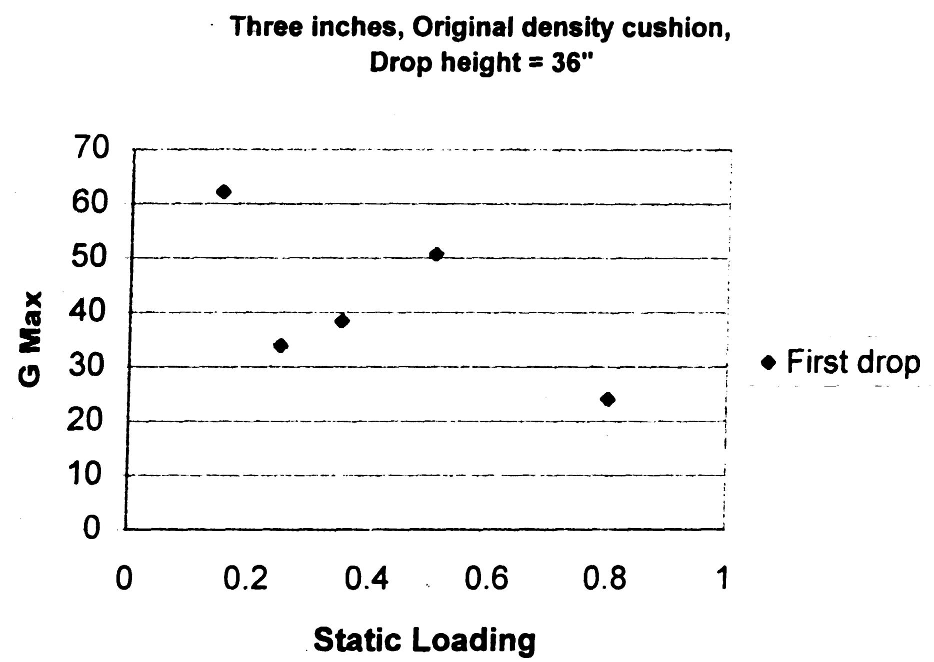


Figure 35: Three inches, Original density cushion, drop height of 36inches, 'G'Max of first drop.

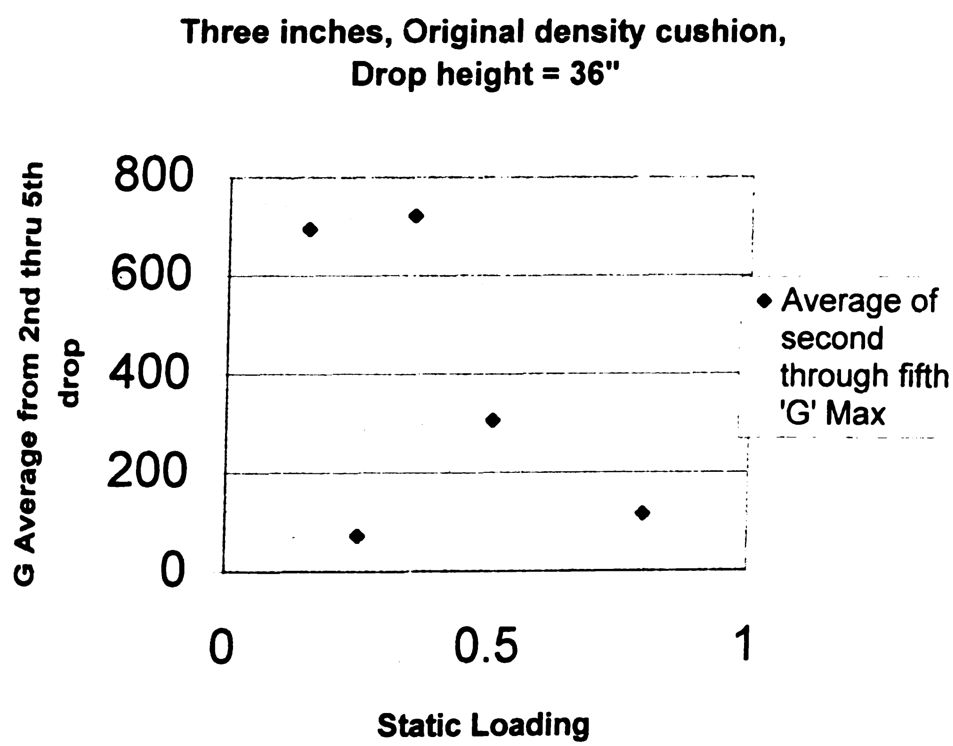


Figure 36: Three inches, original density cushion, drop height of 36inches, Average G max

Some general observations that can be made from the data in Figures 21 to 36 are:

1. 'G'$_{Max}$ of the first drop is significantly lower than the 'G'$_{Max}$ of the average from 2nd to 5th drops.
2. 'G'$_{Max}$ of high strength material is lower than that of original strength E-cubes, but not by a large amount.
3. 'G'$_{Max}$ of E-cubes is higher than the values of 'G'$_{Max}$ for EPS loose fill tested under similar conditions. (Zesaguli,1999)
4. These points were plotted to get a cushion curve, but the values were scattered all over; hence, a true cushion curve could not be developed. This suggests the inability of the material to produce repeatable results like other loose fill materials.

3.2. Discussion of Random Vibration tests:

Tables B1 to B6 represent the raw data collected for the time-controlled vibration tests for 15 minutes each. Tables B7 to B12 represent data for distance-controlled vibration tests. Both these methods are discussed in Chapter 2. While conducting the distance controlled vibration it was seen that whatever settling occurred, it took place within the first 15 minutes. So it was decided to closely observe the migration of the different sizes of spherical balls at an interval of 15 seconds for a maximum of 15 minutes. The three types of objects used were: -

- Pool ball of diameter 2.5 inches and weight 169 g.
- Croquet ball of diameter 3.0 inches and weight 185 g.
- Wax ball of diameter 4.0 inches and weight 389 g.

It was observed that within the first few minutes the loose fill formed a type of interlocking, that slowed and prevented further settling. Also since the E–Cubes have a rough exterior, they do not slip very easily and further help in interlocking.

In distance controlled vibration, the pool ball being of smaller made its way to the bottom of the loose fill quicker than the other two spherical balls of 3.0 and 4.0 inches. In time controlled vibration, the distance travelled by the three types of balls, were compared between original and high strength E – cubes in Figures 42, 43, and 44. Figure 45 compares the distances travelled by all three balls. It can be seen that the ball of 4 inches diameter does not travel very much into E-cubes as compared to the other two balls of diameter 2.5 and 3.0 inches. It could also be seen in the time-controlled vibration tests that the pool ball migrated up to 8 cm as did the croquet ball. But the blue wax ball could go only 2.5 cm. This is true even for high strength E-cubes as shown in Figure 46. The overlap of the two curves on one another shows that the two balls of diameter 2.5 and 3 inches travel at almost the same rate into E-cubes. In original strength E-cubes the objects travel quicker than in high strength E-cubes.

Migration of 2.5 inches diameter Pool ball in two different types of loose fill

When comparing the data of the 2.5 inch pool ball collected for E-Cubes in this study to that of the same ball using the EPS materials in a previous study (Zesaguli, 1999) it is evident that this material shows a better performance and prevents settling and object travel as compared to other loose fill previous studied.

This can also be seen from data on settling from the previous study compared to that presented in Figure 37 and 42 as shown in Appendix D (Zesuguli,1999).

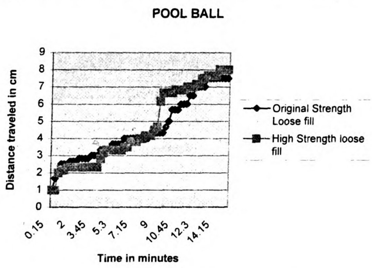


Figure 37: Distance travelled by Pool ball in Original and High strength loose fill.

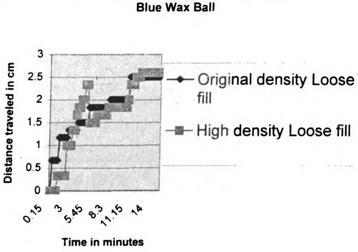


Figure 38: Distance travelled by wax ball in Original & High strength loose fill.

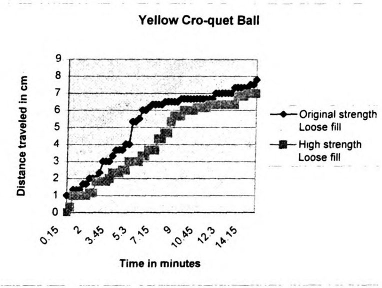


Figure 39: Distance travelled by Croquet ball in Original & High strength loose fill.

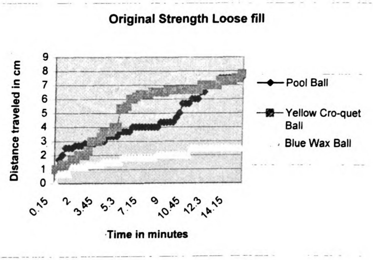


Figure 40: Distance travelled by all three objects in Original strength loose fill.

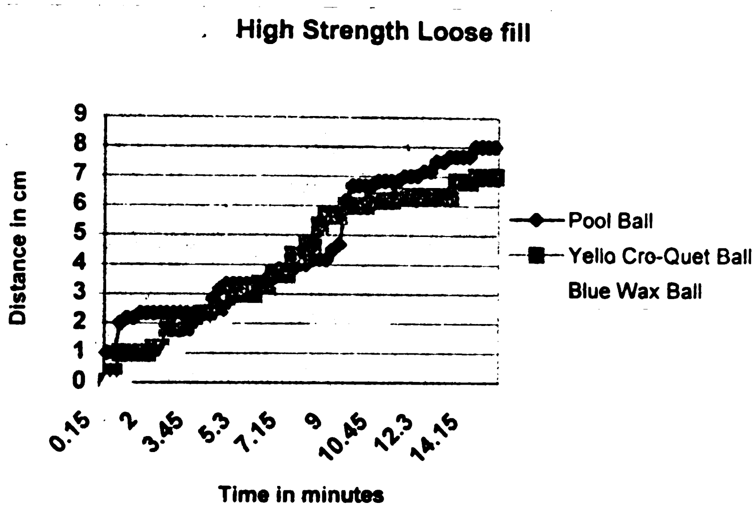


Figure 41: Distance travelled by all three objects in High Strength Loose fill

CHAPTER 4: CONCLUSIONS

Based on the data collected in this study, the following conclusions were reached:

- The High-Density E-Cubes provide better shock protection than Original E-Cubes?
- E-Cubes show higher shock transmission as compared to EPS loose fill previously tested.
- E-Cubes show a better interlocking capability as compared to other types of loose fill materials and prevent objects from settling due to vibration.
- E-Cubes are more expensive than EPS loose fill (Appendix C).

Appendix –A: Shock DATA

Table A1
Cushion Material: High Strength, Drop height: 24", cushion thickness: 2".

Static Loading	Drop Sequence	Duration (m sec)	G Max Value
0.15	1	18.95	26.78
	2	15.35	43.23
	3	13.7	54.72
	4	12.75	63.37
	5	11.45	34.27
0.25	1	9.4	51.32
	2	20.3	72.82
	3	35.85	123.14
	4	16.05	191.23
	5	4.15	303.55
0.35	1	34.25	15.88
	2	21.2	29.5
	3	15.8	52.4
	4	12.95	62.91
	5	11.4	84.21
0.504	1	38.65	6.05
	2	39.85	78.55
	3	29.9	128.33
	4	13.35	731.45
	5	31.6	987.09
0.799	1	16.65	47.95
	2	8.4	80.36
	3	9	94.47
	4	7.25	103.18
	5	6.6	143.94

Table A2 :
Cushion Material : High Strength, Drop height : 24", Cushion Thickness : 3"

Static Loading	Drop Sequence	Duration (m sec)	G Max Value
0.15	1	19.85	27.65
	2	17.95	38.02
	3	15.95	46.04
	4	15.05	50.55
	5	15.25	53.83
0.25	1	8.2	9.8
	2	20	17
	3	28.12	24.83
	4	40.3	203.25
	5	5.65	398.44
0.35	1	37.4	13.52
	2	36.3	77.22
	3	39.75	97.35
	4	6.65	916.54
	5	8	972.46
0.504	1	40.1	35.85
	2	46.6	58.69
	3	34.65	129.67
	4	39.4	425.31
	5	39.95	988.08
0.799	1	19.35	19.07
	2	6.9	99.18
	3	11.3	100.37
	4	6.1	122.52
	5	4.1	438.37

Table A3 :
Cushion Material : High Strength:, Drop height : 36",Cushion Thickness 2"

Static Loading	Drop Sequence	Duration (m sec)	G Max Value
0.15	1	22.95	32.1
	2	15.05	56.74
	3	13.1	75.98
	4	11.6	100.66
	5	13.85	112.54
0.25	1	16.65	7.05
	2	31.7	31.55
	3	32.35	43.55
	4	8.6	71.65
	5	12.6	20.8
0.35	1	40.15	10.98
	2	5.6	17.84
	3	49.55	26.11
	4	11.4	36.48
	5	48.9	88.32
0.504	1	16.9	33.23
	2	1.6	152.22
	3	6.95	159.87
	4	4.45	704.65
	5	7.3	886.17
0.799	1	30.3	24.55
	2	9.85	98.08
	3	15.25	100.07
	4	6.32	120.85
	5	10.25	240.74

Table A4:
Cushion Material : High Strength, Drop height : 36", Cushion Thickness 3"

Static Loading	Drop Sequence	Duration (m sec)	G Max Value
0.15	1	24.1	35.39
	2	28.95	64.04
	3	28.4	67.45
	4	23.6	78.53
	5	40	91.15
0.25	1	8.1	39.45
	2	23.65	40.45
	3	21.35	50.7
	4	13.65	91.85
	5	15.3	102
0.35	1	35.4	20.73
	2	11.75	75.07
	3	7.1	120.74
	4	5.45	188.95
	5	4.95	178.73
0.504	1	35.1	18.86
	2	10.3	82.49
	3	8.35	100
	4	12.2	144.2
	5	6.15	180.91
0.799	1	13.8	21.07
	2	5.9	142.6
	3	4.15	201.54
	4	7	147.63
	5	13.2	150

Table A5:
Cushion Material: Original Strength, Drop height: 24" Cushion Thickness 2"

Static Loading	Drop Sequence	Duration (m sec)	G Max Value
0.15	1	23	43.78
	2	13	63.09
	3	11.15	74.5
	4	10.5	76.69
	5	10.85	83.39
0.25	1	24.05	30.11
	2	14.55	55.72
	3	17.35	57.64
	4	5.05	601.45
	5	5.08	672.61
0.35	1	9.2	24.81
	2	30.68	36.23
	3	32.6	98.27
	4	37.65	362.3
	5	35.6	985.27
0.504	1	13.1	31.29
	2	18.25	50.96
	3	14.05	66.46
	4	12.65	70.69
	5	11.8	78.63
0.799	1	16.6	33.58
	2	11.95	52.4
	3	9.05	74.76
	4	7.45	91.19
	5	7.15	110.78

Table A6:
Cushion Material: Original Strength, Drop height : 24" Cushion Thickness 3"

Static Loading	Drop Sequenc e	Duration (m sec)	G Max Value
0.15	1	20.1	31.14
	2	18.25	43.57
	3	41.45	60.93
	4	13.3	66.25
	5	14.8	74.91
0.25	1	15.65	72.2
	2	40.1	87.41
	3	36.5	480.21
	4	39.25	402.46
	5	38.8	986.84
0.35	1	13.8	17.29
	2	25.8	19.08
	3	37.85	98.01
	4	38.15	84.55
	5	12.95	131.27
0.504	1	5	30.21
	2	18.85	32.81
	3	38.75	317.06
	4	37.6	348.5
	5	12.55	984.7
0.799	1	16.5	33.07
	2	12.05	57.67
	3	10.25	84.87
	4	5.85	153.63
	5	4.65	233.09

Table A7:
Cushion Material : Original Strength, Drop height : 36" Cushion Thickness 2"

Static Loading	Drop Sequence	Duration (m sec)	G Max Value
0.15	1	14.9	54.73
	2	10.85	77.55
	3	10.8	92.7
	4	15.7	103
	5	9.45	111.41
0.25	1	9.87	23.27
	2	3.75	22 17
	3	27.8	62.6
	4	10.45	31.27
	5	5.3	20.5
0.35	1	6.55	13.313
	2	14.6	89.03
	3	8.9	939.24
	4	35.85	979.69
	5	29.1	981.68
0.504	1	19.95	20.61
	2	15.15	48.04
	3	11.45	70.29
	4	8.5	120.92
	5	3.35	413.92
0.799	1	27.6	23.97
	2	13.35	52.5
	3	8.1	102.81
	4	5.3	159.33
	5	4.95	190.9

Table A8:
Cushion Material: Original Strength, Drop height: 36" Cushion Thickness 3"

Static Loading	Drop Sequence	Duration (m sec)	G Max Value
0.15	1	25.65	62.11
	2	7.1	98.5
	3	7.45	983.38
	4	4.35	825.5
	5	10.4	865.78
0.25	1	24.95	33.77
	2	20.9	48.89
	3	14.3	55.19
	4	19.7	58.19
	5	5.65	126.04
0.35	1	15.14	38.32
	2	17.15	384.25
	3	17.75	757.23
	4	3.1	749.85
	5	16.5	990.53
0.504	1	14.85	50.7
	2	11.45	73.5
	3	8.7	101.03
	4	8	104.74
	5	8.85	944.29
0.799	1	27.25	24.02
	2	13.3	57.77
	3	8.75	107.16
	4	6.1	143.72
	5	7.12	150.25

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Appendix – B - Vibration Studies

Table B1: Time controlled Vibration

Materials Used:

- High density loose fill
- Blue wax Ball of 4 inches diameter.

Study Duration: 15 minutes.

Time (min)	Trial 1 (cm)	Trial 2 (cm)	Trial 3 (cm)	Average (cm)
0.15	0.0	0.0	0.0	0.0
0.30	0.0	1.0	1.0	0.66
0.45	0.0	1.0	1.0	0.66
1.00	0.0	1.0	1.0	0.66
1.15	0.0	1.0	1.0	0.66
1.30	1.0	1.0	1.5	1.16
1.45	1.0	1.0	1.5	1.16
2.00	1.0	1.0	1.5	1.16
2.15	1.0	1.0	1.5	1.16
2.30	1.0	1.0	1.5	1.16
2.45	1.0	1.5	1.5	1. 33
3.00	1.0	1.5	1.5	1. 33
3.15	1.0	1.5	1.5	1. 33
3.30	1.0	1.5	1.5	1. 33
3.45	1.0	1.5	1.5	1. 33
4.00	1.5	1.5	1.5	1.5
4.15	1.5	1.5	1.5	1.5
4.30	1.5	1.5	1.5	1.5
4.45	1.5	1.5	1.5	1.5
5.00	1.5	1.5	1.5	1.5
5.15	1.5	1.5	1.5	1.5
5.30	1.5	2.0	2.0	1.83
5.45	1.5	2.0	2.0	1.83
6.00	1.5	2.0	2.0	1.83
6.15	1.5	2.0	2.0	1.83
6.30	1.5	2.0	2.0	1.83
6.45	1.5	2.0	2.0	1.83
7.00	1.5	2.0	2.0	1.83
7.15	1.5	2.0	2.0	1.83
7.30	1.5	2.0	2.0	1.83
7.45	1.5	2.0	2.0	1.83
8.00	1.5	2.0	2.0	1.83
8.15	2.0	2.0	2.0	2.0
8.30	2.0	2.0	2.0	2.0

Time (min)	Trial 1 (cm)	Trial 2 (cm)	Trial 3 (cm)	Average (cm)
8.45	2.0	2.0	2.0	2.0
9.0	2.0	2.0	2.0	2.0
9.15	2.0	2.0	2.0	2.0
9.30	2.0	2.0	2.0	2.0
9.45	2.0	2.0	2.0	2.0
10.00	2.0	2.0	2.0	2.0
10.15	2.0	2.0	2.0	2.0
10.30	2.0	2.0	2.0	2.0
10.45	2.0	2.0	2.0	2.0
11.00	2.5	2.5	2.5	2.5
11.15	2.5	2.5	2.5	2.5
11.30	2.5	2.5	2.5	2.5
11.45	2.5	2.5	2.5	2.5
12.00	2.5	2.5	2.5	2.5
12.15	2.5	2.5	2.5	2.5
12.30	2.5	2.5	2.5	2.5
12.45	2.5	2.5	2.5	2.5
13.00	2.5	2.5	2.5	2.5
13.15	2.5	2.5	2.5	2.5
13.30	2.5	2.5	2.5	2.5
13.45	2.5	2.5	2.5	2.5
14.00	2.5	2.5	2.5	2.5
14.15	2.5	2.5	2.5	2.5
14.30	2.5	2.5	2.5	2.5
14.45	2.5	2.5	2.5	2.5
15.00	2.5	2.5	2.5	2.5

Vibration Studies:

Table B2 : Time controlled Vibration.

Materials Used:

- High density loose fill
- Pool Ball of 2.5 inches diameter.

Study Duration: 15 minutes.

Time (min)	Trial 1 (cm)	Trial 2 (cm)	Trial 3 (cm)	Average (cm)
0.15	1.0	1.0	1.0	1
0.30	2.0	2.0	1.0	1.66
0.45	2.5	2.5	1.5	2.0
1.00	3.0	2.5	2.0	2.5
1.15	3.0	2.5	2.0	2.5
1.30	3.0	2.5	2.0	2.5
1.45	3.0	2.5	2.52	2.66
2.00	3.0	2.5	2.52	2.66
2.15	3.0	2.5	2.52	2.66
2.30	3.0	3.0	2.52	2.83
2.45	3.0	3.0	2.52	2.83
3.00	3.0	3.0	2.52	2.83
3.15	3.0	3.0	2.52	2.83
3.30	3.0	3.0	3.0	3.0
3.45	3.0	3.0	3.0	3.0
4.00	3.0	3.0	3.0	3.0
4.15	4.0	3.0	3.0	3.33
4.30	4.0	3.0	3.0	3.33
4.45	4.0	3.0	3.0	3.33
5.00	4.0	3.0	3.0	3.33
5.15	4.0	3.0	4.0	3.66
5.30	4.0	3.0	4.0	3.66
5.45	4.0	3.0	4.0	3.66
6.00	4.0	3.0	4.0	3.66
6.15	4.0	4.0	4.0	4.0
6.30	4.0	4.0	4.0	4.0
6.45	4.0	4.0	4.0	4.0
7.00	4.0	4.0	4.0	4.0
7.15	4.0	4.0	4.0	4.0
7.30	4.0	4.0	4.0	4.0
7.45	4.0	4.0	4.0	4.0
8.00	4.0	4.0	4.0	4.0
8.15	4.0	4.0	4.0	4.0
8.30	5.0	4.0	4.0	4.33

Time (min)	Trial 1 (cm)	Trial 2 (cm)	Trial 3 (cm)	Average (cm)
8.45	5.0	4.0	4.0	4.33
9.00	5.0	4.0	4.0	4.33
9.15	5.0	4.0	4.0	4.33
9.30	5.0	4.0	4.0	4.33
9.45	5.0	5.0	4.0	4.66
10.00	6.0	5.0	4.0	5.0
10.15	6.0	5.0	6.0	5.66
10.30	6.0	5.0	6.0	5.66
10.45	6.0	5.0	6.0	5.66
11.00	6.0	6.0	6.0	6.0
11.15	6.0	6.0	6.0	6.0
11.30	6.0	6.0	6.0	6.0
11.45	7.5	6.0	6.0	6.0
12.00	7.5	6.0	6.0	7
12.15	7.5	6.0	7.5	7.0
12.30	7.5	6.0	7.5	7.0
12.45	7.5	6.0	7.5	7.0
13.00	7.5	6.0	7.5	7.0
13.15	7.5	7.5	7.5	7.5
13.30	7.5	7.5	7.5	7.5
13.45	7.5	7.5	7.5	7.5
14.00	7.5	7.5	7.5	7.5
14.15	7.5	7.5	7.5	7.5
14.30	7.5	7.5	7.5	7.5
14.45	7.5	7.5	7.5	7.5
15.00	7.5	7.5	7.5	7.5

Vibration Studies:

Table B3: Time controlled Vibration.

Materials Used:

- High density loose fill
- Cro-quet ball of 3 inch diameter

Study Duration: 15 minutes.

Time (min)	Trial 1 (cm)	Trial 2 (cm)	Trial 3 (cm)	Average (cm)
0.15	1.0	1.0	1.0	1.0
0.30	1.0	1.0	1.0	1.0
0.45	2.0	1.0	1.0	1.33
1.00	2.0	1.0	1.0	1.33
1.15	2.0	1.0	1.0	1.33
1.30	3.0	1.0	1.0	1.66
1.45	3.0	1.0	1.0	1.66
2.00	3.0	1.0	2.0	2.0
2.15	3.0	1.0	2.0	2.0
2.30	3.0	1.0	2.0	2.0
2.45	3.0	2.0	2.0	2.33
3.00	5.0	2.0	2.0	3.0
3.15	5.0	2.0	2.0	3.0
3.30	5.0	2.0	2.0	3.0
3.45	5.0	2.0	3.0	3.33
4.00	5.0	3.0	3.0	3.66
4.15	5.0	3.0	3.0	3.66
4.30	5.0	3.0	3.0	3.66
4.45	5.0	3.0	4.0	4.0
5.00	5.0	3.0	4.0	4.0
5.15	6.0	6.0	4.0	5.33
5.30	6.0	6.0	4.0	5.33
5.45	6.5	6.0	4.0	5.5
6.00	6.5	6.0	5.5	6.0
6.15	6.5	6.0	5.5	6.0
6.30	6.5	6.5	5.5	6.16
6.45	7.0	6.5	5.5	6.33
7.00	7.0	6.5	5.5	6.33
7.15	7.0	6.5	5.5	6.33
7.30	7.0	6.5	5.5	6.33
7.45	7.0	6.5	6.0	6.5
8.00	7.0	6.5	6.0	6.5
8.15	7.0	6.5	6.0	6.5
8.30	7.0	6.5	6.0	6.5

Time (min)	Trial 1 (cm)	Trial 2 (cm)	Trial 3 (cm)	Average (cm)
8.45	7.0	6.5	6.0	6.5
9.00	7.0	7.0	6.0	6.66
9.15	7.0	7.0	6.0	6.66
9.30	7.0	7.0	6.0	6.66
9.45	7.0	7.0	6.0	6.66
10.00	7.0	7.0	6.0	6.66
10.15	7.0	7.0	6.0	6.66
10.30	7.0	7.0	6.0	6.66
10.45	7.0	7.0	6.0	6.66
11.00	7.0	7.0	6.0	6.66
11.15	7.0	7.0	6.0	6.66
11.30	7.0	7.0	6.0	6.66
11.45	7.0	7.0	7.0	7.0
12.00	7.0	7.0	7.0	7.0
12.15	7.0	7.0	7.0	7.0
12.30	7.0	7.0	7.0	7.0
12.45	7.0	7.0	7.0	7.0
13.00	7.0	7.0	7.0	7.0
13.15	7.5	7.0	7.5	7.33
13.30	7.5	7.0	7.5	7.33
13.45	7.5	7.0	7.5	7.33
14.00	7.5	7.0	7.5	7.33
14.15	7.5	7.0	7.5	7.33
14.30	7.5	7.5	7.5	7.5
14.45	7.5	7.5	7.5	7.5
15.00	7.8	7.8	7.8	7.8

Vibration Studies:

<u>Table B4: Time controlled Vibration.</u>

Materials Used:

- Original density loose fill
- Blue wax Ball of 4 inches diameter.

Study Duration: 15 minutes.

Time (min)	Trial 1 (cm)	Trial 2 (cm)	Trial 3 (cm)	Average (cm)
0.15	0.0	0.0	0.0	0.0
0.30	0.0	0.0	0.0	0.0
0.45	0.0	0.0	0.0	0.0
1.00	0.0	0.0	0.0	0.0
1.15	0.0	0.0	1.0	0.33
1.30	0.0	0.0	1.0	0.33
1.45	0.0	0.0	1.0	0.33
2.00	0.0	0.0	1.0	0.33
2.15	0.0	0.0	1.0	0.33
2.30	1.0	0.0	1.5	1.0
2.45	1.0	0.0	1.5	1.0
3.00	1.0	0.0	1.5	1.0
3.15	1.0	1.0	1.5	1.33
3.30	1.0	1.0	1.5	1.33
3.45	1.0	1.0	1.5	1.33
4.00	1.0	1.0	1.5	1.33
4.15	1.0	1.0	1.5	1.33
4.30	1.0	1.0	1.5	1.33
4.45	1.0	1.0	1.5	1.33
5.00	1.5	1.5	1.5	1.5
5.15	1.5	1.5	1.5	1.5
5.30	1.5	1.5	1.5	1.5
5.45	1.5	1.5	1.5	1.5
6.00	1.5	1.5	1.5	1.5
6.15	1.5	1.5	1.5	1.5
6.30	2.0	1.5	1.5	1.66
6.45	2.0	1.5	1.5	1.66
7.00	2.0	1.5	1.5	1.66
7.15	2.0	1.5	1.5	1.66
7.30	2.0	1.5	1.5	1.66
7.45	2.0	1.5	1.5	1.66
8.00	2.0	2.0	1.5	1.83
8.15	2.0	2.0	1.5	1.83
8.30	2.0	2.0	1.5	1.83

Time (min)	Trial 1 (cm)	Trial 2 (cm)	Trial 3 (cm)	Average (cm)
8.45	2.0	2.0	1.5	1.83
9.00	2.0	2.0	1.5	1.83
9.15	2.0	2.0	1.5	1.83
9.30	2.0	2.0	1.5	1.83
9.45	2.0	2.0	1.5	1.83
10.00	2.0	2.0	1.5	1.83
10.15	2.0	2.0	1.5	1.83
10.30	2.0	2.0	1.5	1.83
10.45	2.0	2.0	2.0	2.0
11.00	2.5	2.5	2.0	2.33
11.15	2.5	2.5	2.0	2.33
11.30	2.5	2.5	2.0	2.33
11.45	2.5	2.5	2.5	2.5
12.00	2.5	2.5	2.5	2.5
12.15	2.5	2.5	2.5	2.5
12.30	2.5	2.5	2.8	2.6
12.45	2.5	2.5	2.8	2.6
13.00	2.5	2.5	2.8	2.6
13.15	2.5	2.5	2.8	2.6
13.30	2.5	2.5	2.8	2.6
13.45	2.5	2.5	2.8	2.6
14.00	2.5	2.5	2.8	2.6
14.15	2.5	2.5	2.8	2.6
14.30	2.5	2.5	2.8	2.6
14.45	2.5	2.5	2.8	2.6
15.00	2.5	2.5	2.8	2.6

Vibration Studies:
Table B5: Time controlled Vibration.
Materials Used:

- Original density loose fill
- Pool Ball of 2.5 inches diameter.

Study Duration: 15 minutes.

Time (min)	Trial 1 (cm)	Trial 2 (cm)	Trial 3 (cm)	Average (cm)
0.15	1.0	1.0	1.0	1.0
0.30	1.0	1.0	1.0	1.0
0.45	2.0	2.0	2.0	2.0
1.00	2.0	2.0	2.5	2.16
1.15	2.0	2.0	2.5	2.16
1.30	2.0	2.5	2.5	2.33
1.45	2.0	2.5	2.5	2.33
2.00	2.0	2.5	2.5	2.33
2.15	2.0	2.5	2.5	2.33
2.30	2.0	2.5	2.5	2.33
2.45	2.0	2.5	2.5	2.33
3.00	2.0	2.5	2.5	2.33
3.15	2.0	2.5	2.5	2.33
3.30	2.0	2.5	2.5	2.33
3.45	2.0	2.5	2.5	2.33
4.00	2.0	2.5	2.5	2.33
4.15	3.0	2.5	3.0	2.83
4.30	3.0	3.0	3.5	3.16
4.45	3.5	3.0	3.5	3.33
5.00	3.5	3.0	3.5	3.33
5.15	3.5	3.0	3.5	3.33
5.30	3.5	3.0	3.5	3.33
5.45	3.5	3.0	3.5	3.33
6.00	3.5	3.0	3.5	3.33
6.15	3.5	3.5	3.5	3.5
6.30	3.5	3.5	3.5	3.5
6.45	4.0	3.5	4.0	3.83
7.00	4.0	3.5	4.0	3.83
7.15	4.0	3.5	4.0	3.83
7.30	4.0	3.5	4.5	4.0
7.45	4.0	3.5	4.5	4.0
8.00	4.0	4.0	4.5	4.16
8.15	4.0	4.0	4.5	4.16
8.30	4.0	4.0	4.5	4.16

Time (min)	Trial 1 (cm)	Trial 2 (cm)	Trial 3 (cm)	Average (cm)
8.45	4.0	4.5	4.5	4.5
9.00	4.0	5.0	5.0	4.66
9.15	7.0	6.0	6.5	6.16
9.30	7.0	6.0	7.0	6.66
9.45	7.0	6.0	7.0	6.66
10.00	7.0	6.0	7.0	6.66
10.15	7.0	6.0	7.0	6.66
10.30	7.0	6.5	7.0	6.83
10.45	7.0	6.5	7.0	6.83
11.00	7.0	6.5	7.0	6.83
11.15	7.0	6.5	7.0	6.83
11.30	7.0	7.0	7.0	7.0
11.45	7.0	7.0	7.0	7.0
12.00	7.0	7.0	7.0	7.0
12.15	7.0	7.5	7.0	7.16
12.30	7.0	7.5	7.0	7.16
12.45	7.0	7.5	8.0	7.5
13.00	7.0	7.5	8.0	7.5
13.15	7.5	7.5	8.0	7.66
13.30	7.5	7.5	8.0	7.66
13.45	7.5	7.5	8.0	7.66
14.00	7.5	7.5	8.0	7.66
14.15	8.0	8.0	8.0	8.0
14.30	8.0	8.0	8.0	8.0
14.45	8.0	8.0	8.0	8.0
15.00	8.0	8.0	8.0	8.0

Vibration Studies:
Table B6: Time controlled Vibration.
Materials Used:

- Original density loose fill
- Croquet Ball of 3 inches diameter.

Study Duration: 15 minutes.

Time (min)	Trial 1 (cm)	Trial 2 (cm)	Trial 3 (cm)	Average (cm)
0.15	0.0	0.0	0.0	0.0
0.30	0.0	1.0	0.0	0.33
0.45	1.0	1.0	1.0	1.0
1.00	1.0	1.0	1.0	1.0
1.15	1.0	1.0	1.0	1.0
1.30	1.0	1.0	1.0	1.0
1.45	1.0	1.0	1.0	1.0
2.00	1.0	1.5	1.0	1.16
2.15	1.0	1.5	1.0	1.16
2.30	2.0	1.5	2.0	1.83
2.45	2.0	1.5	2.0	1.83
3.00	2.0	1.5	2.0	1.83
3.15	2.0	1.5	2.0	1.83
3.30	2.0	2.0	2.0	2.0
3.45	2.5	2.0	2.5	2.33
4.00	2.5	2.0	2.5	2.33
4.15	2.5	2.0	2.5	2.33
4.30	2.5	2.5	2.5	2.5
4.45	2.5	2.5	2.5	2.5
5.00	4.0	2.5	2.5	3.0
5.15	4.0	2.5	2.5	3.0
5.30	4.0	2.5	2.5	3.0
5.45	4.0	2.5	2.5	3.0
6.00	4.0	3.0	3.0	3.33
6.15	4.0	3.0	3.0	3.33
6.30	5.0	3.0	3.0	3.66
6.45	5.0	3.0	3.0	3.66
7.00	5.0	3.0	3.0	3.66
7.15	5.0	4.0	4.0	4.33
7.30	5.0	4.0	4.0	4.33
7.45	5.0	4.0	5.0	4.66
8.00	5.0	4.0	5.0	4.66
8.15	6.0	4.0	6.0	5.33
8.30	6.0	5.0	6.0	5.66

Time (min)	Trial 1 (cm)	Trial 2 (cm)	Trial 3 (cm)	Average (cm)
8.45	6.0	5.0	6.0	5.66
9.00	6.0	5.0	6.0	5.66
9.15	6.0	6.0	6.0	6.0
9.30	6.0	6.0	6.0	6.0
9.45	6.0	6.0	6.0	6.0
10.00	6.0	6.0	6.0	6.0
10.15	6.0	6.0	6.5	6.16
10.30	6.0	6.0	6.5	6.16
10.45	6.0	6.0	6.5	6.16
11.00	6.0	6.0	6.5	6.16
11.15	6.0	6.5	6.5	6.33
11.30	6.0	6.5	6.5	6.33
11.45	6.0	6.5	6.5	6.33
12.00	6.0	6.5	6.5	6.33
12.15	6.0	6.5	6.5	6.33
12.30	6.0	6.5	6.5	6.33
12.45	6.0	6.5	6.5	6.33
13.00	6.0	6.5	6.5	6.33
13.15	6.0	6.5	6.5	6.33
13.30	7.0	6.5	7.0	6.83
13.45	7.0	6.5	7.0	6.83
14.00	7.0	6.5	7.0	6.83
14.15	7.0	7.0	7.0	7.0
14.30	7.0	7.0	7.0	7.0
14.45	7.0	7.0	7.0	7.0
15.00	7.0	7.0	7.0	7.0

Table B-7

Distance controlled Vibration Data

2.5 inches diameter Pool ball

Original density E-cubes

Trial 1		Trial 2		Trial 3	
Distance	Time	Distance	Time	Distance	Time
Inches		Inches		Inches	
1	0.00.5	1	0.00.17	1	0.00.6
2	0.00.6	2	0.01.2	2	0.00.19
3	0.02.49	3	0.03.17	3	0.02.30
4	0.19.20	4	0.14.59	4	0.03.20
5	1.35.45	5	0.17.29	5	0.06.30
6	1.45.20	6	0.18.38	6	0.07.40
6.5	3.00.00	6.5	N/A	6.5	N/A
7		7	0.19.30	7	0.20.52
8		8	0.20.40	8	0.25.55
9		9	0.24.11	9	0.39.54

Table B-8

Distance controlled Vibration Data

2.5 inches diameter Pool ball

High Density E-cubes

Trial 1		Trial 2		Trial 3	
Distance	Time	Distance	Time	Distance	Time
Inches		Inches		Inches	
1	0.00.8	1	0.00.8	1	0.00.25
2	0.00.17	2	0.00.16	2	0.00.45
3	0.00.30	3	0.00.32	3	0.04.24
4	0.03.17	4	0.35.44	4	0.10.51
5	0.03.39	5	0.45.39	5	0.36.11
6	0.03.53	6	0.58.15	6	1.05.48
7	0.04.07	7	1.22.16	7	1.27.06
8	0.04.13	8	1.47.12	8	1.43.30
9	2.00.00	9	1.51.43	9	1.46.32

Table B-9

Distance controlled Vibration Data

3 inches diameter Yellow crocket ball

Original density E-cubes

Trial 1		Trial 2		Trial 3	
Distance	Time	Distance	Time	Distance	Time
Inches		Inches		Inches	
1	0.00.42	1	0.00.15	1	0.00.30
2	0.01.58	2	0.01.12	2	0.01.57
3	0.02.14	3	0.02.30	3	0.08.55
4	0.07.26	4	0.02.55	4	0.10.08
5	0.08.55	5	0.03.00	5	0.11.58
6	0.09.45	6	0.03.49	6	0.14.28
7	0.26.20	7	0.09.51	7	0.20.22
8	0.32.47	8	0.12.26	8	0.27.32
9	1.10.15	9	0.25.35	9	0.31.02

Table B-10

Distance controlled Vibration Data

3 inches diameter Yellow crocket ball

High Density E-cubes

Trial 1		Trial 2		Trial 3	
Distance	Time	Distance	Time	Distance	Time
Inches		Inches		Inches	
1	0.00.20	1	0.00.28	1	0.02.28
2	0.01.10	2	0.00.47	2	0.05.42
3	0.05.49	3	0.02.32	3	0.16.00
4	0.25.27	4	0.03.25	4	0.28.04
5	0.27.23	5	0.04.39	5	1.05.23
6	0.29.32	6	0.10.11	6	1.12.35
7	0.43.31	7	0.11.59	7	1.14.52
8	0.52.20	8	0.32.52	8	1.47.58
9	1.30.54	9	0.36.52	9	2.50.33

Table B-11

Distance controlled Vibration Data

4 inches diameter Blue Wax ball

Original density E-cubes

Trial 1		Trial 2		Trial 3	
Distance	Time	Distance	Time	Distance	Time
Inches		Inches		Inches	
1	0.00.28	1	0.00.49	1	0.00.25
2	0.01.02	2	0.02.26	2	0.01.00
3	0.05.09	3	0.03.31	3	0.01.17
4	0.06.10	4	0.03.55	4	0.05.15
5	0.30.14	5	0.04.00	5	0.06.16
6	1.18.22	6	0.04.24	6	0.08.19
7	1.38.20	7	3.00.00	7	0.12.58
8	3.00.00	8		8	2.16.06
9		9		9	2.32.29

Table B-12

Distance controlled Vibration Data

4 inches diameter Blue Wax ball

High Density E-cubes

Trial 1		Trial 2		Trial 3	
Distance	Time	Distance	Time	Distance	Time
Inches		Inches		Inches	
1	0.01.21	1	0.00.53	1	0.01.12
2	0.05.40	2	0.05.20	2	0.01.34
3	0.20.25	3	0.08.59	3	0.03.01
4	0.23.22	4	0.14.10	4	0.09.11
5	0.26.30	5	0.30.59	5	1.11.45
6	1.45.25	6	0.33.20	6	1.12.23
7	1.50.13	7	0.34.22	7	1.13.20
8	2.00.50	8	0.36.23	8	1.14.18
9	2.05.20	9	0.41.16	9	2.14.52

APPENDIX C

(E-mail : Larry Goers, 09 Nov 2000)

PACKAGING COST COMPARISON
Prepared for Artiquities
Results of the repack done by Larry Goers on Package received on 10-18-00.
Prices for materials are taken from U-line distributor catalog.

Using Your current Packaging Method

Material	Amount per Box	Multiplied by	Cost per Unit	Cost per Box
Inner Box	1	X	$1.18 ea	= $ 1.18
Outer Box	1	X	$1.18 ea	= $ 1.59
Peanuts	1.2 cubic feet	X	$0.87 cubic foot	= $ 1.04
Foam Plank	4.7 feet @ 1' x 24' Wide	X	$0.50 foot	= $ 2.35
Bubble Wrap	4.0 feet @ 1/2' x 24" Wide	X	$0.38 foot	= $ 1.52
Packaging Labor	4 minutes	x	$10.20 per hour	= $ 0.68
			Total Current Cost	= $ 8.36

Using E-cubes instead

Material	Amount per Box	Multiplied by	Cost per Unit	Cost per Box
E-cubes	2.15 cubic feet	X	$2.00 ea	= $ 4.30
Box	1	X	$1.54 ea	= $ 1.54
Packing Labour	45 seconds	X	$10.20 per hour	= $ 0.13
Other Benefits - E-cubes reduce/eliminate any breakage/damage - E-cubes reduce packaging time tremendously - E-cubes are recyclable - E-cubes reduce international packaging tariffs associated with plastics.			Total cost using E-cubes	= $ 5.97
			Your savings per box with E-cubes	= $ 2.40
			If you pack	400 boxes per week

Using e-cubes your savings per week = $ 958.60
Or per month = $ 4,153.93
Or per Year = $ 49,847.20

E-tech products inc – 4975 Paris Street Denver, Colorado 80239 – (303) 373 – 0200 FAX, www.e-techproducts.com

APPENDIX-D

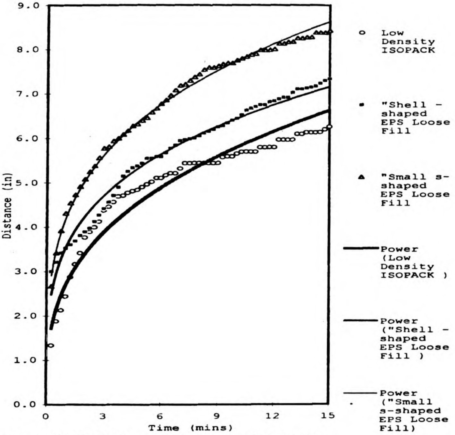

Figure F2:Migration Distance of Spherical Object.

Figure 42: Distance travelled by the Poll ball in EPS

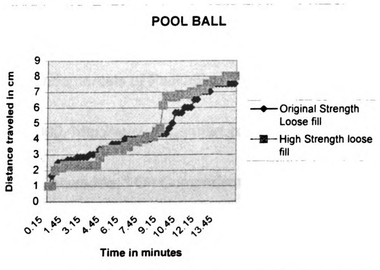

Figure37: Distance travelled by Pool ball in E-Cubes.

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