THE EFFECT OF LOAD STABILIZER SELECTION ON LOAD SHIFT WITHIN UNIT LOADS

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ABSTRACT

Research on unit load stability aids manufacturing facilities in selecting the most efficient load stabilizer when shipping their products to market. This study's objective was to compare the performance a variety of different commonly used load stabilizers to stretch hooding. Stretch hooding is a method of load stabilization in which a tubular film is heat sealed at the top, stretched by four mechanical arms to a desired width, pulled down over the unit load. The film is slowly released as the arms descend, and is released under the pallet.

400ga stretch hooding, 80ga and 63ga stretch wrap and strapping were tested. Twenty unit loads for both vibration and impact testing were used, with 5 replications per load stabilizer. Container displacement and pallet-container displacement were measured, and the number of tares in the load stabilizer film, on the corners of the test units, after testing, was noted.

Container displacement was significantly greater during impact testing than in vibration testing. Strapping was the most effective stabilizer during vibration testing because of its ability to restrict vertical displacement. The stretch hooding was the most effective stabilizer during impact testing because of its ability to restrict horizontal displacement.

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1.0 INTRODUCTION

1.1 Background

Research by Carolina Supply Chain Services (CSCS) revealed that in 2005, poor load stabilization led to $388 million dollars in unsalable goods. It identified major causes of damage to unit loads through an examination of more than 28,000 of them in 886 shipments of dry, chilled and frozen goods. This study indicated that the most common occurrences of damage were from load shifting, ripped or lose packaging, crushing, water damage and infestation (Dow Chemical Company, 2006).

The 2006 Unsaleables Benchmark Report (UBR) confirms these findings. It details the amount of unsaleables that are removed from their normal channel of distribution due to such harm. The UBR concluded that “packaging improvements were one of the major factors in manufacturers reducing their payments for unsaleables between 2004 and 2005” (R2N, 2006).

In the transport industry, proper load stabilization is necessary to prevent product damage, load shift, repackaging charges, and to ensure the safety of those who handle the loads. There are several stabilization procedures in use, including stretch wrap and strapping (the two most common), pallet sheets, break-away adhesive, stretch tape, shrink wrap, and stretch hooding. The goal of these stabilizers is to hold the unitized product together and to keep the load on the pallet. All of these methods vary in effectiveness and cost. Employing the optimum unit load stabilization technique is important in order to reduce the cost of tertiary packaging, product damage, reclamation and to reduce worker injuries.

Research by Rotondo found that stretch wrap can stabilize unit loads horizontally (Rotondo, 2006). However, common stretch wrapping techniques may not provide the necessary vertical stabilization required to properly protect a unit load during transport. Small, consistent, and repetitive vertical displacement or a single large vertical displacement can destabilize unit loads. When a truck is moving, many different factors cause the unit load to experience vertical motion, such as pot holes, poor suspensions, rough road surfaces, flexing of the trailer floor and improperly balanced tires. These factors can lead to large stresses on and within the unit load, possibly causing displacements of product and packaging. Displacements are typically greatest at the top of the unit load and in between the top deck boards of the pallet and the bottom layer of product.

Product in the top layer of the unit load will experience more dynamic stress because it has the least amount of vertical and horizontal force keeping them attached to the unit load and because each packaging layer beneath acts as a spring. The bottom layer will experience more static stress. Static stresses are caused by the total weight of the load stacked on top of this layer. These two stresses can cause damage to products and containers during shipping.

There are three major considerations when choosing the correct load stabilizer.

- The shape of the unit load. An effective stabilizer for a generic unit load may not apply to a unit load that is strangely shaped with awkward protrusions. Even small differences in unit loads, such as whether or not the load covers the entire footprint of the pallet, may change the load stabilizer needed for the application.
- Density and fragility of the product. Determining the density and fragility of a product will help establish how much containment force a load stabilizer should exert on the product without damaging it.
- Material handling environment. Having complete knowledge of exactly how far the unit load will travel, the method of transport, and the equipment used to handle the unit load is critical for selecting the correct load stabilizer.

CSCS suggests that some common supply chain issues could be solved by implementing a load stabilizing alternative called stretch hooding. CSCS and the stretch hooding industry claim that stretch hoods improve load stability vertically and help to reduce shifting and protrusions that come from within the unit load by helping to connect the load to the pallet (Dow Chemical Company, 2006). However, little research has been published to support these claims.

This research compares the performance of a variety of commonly used stabilizers with stretch hooding.

1.2 Research Objectives

The goal of this research was to measure and compare the load shift within unit loads stabilized with 400ga stretch hooding and three common methods of unit load stabilization. These methods are 80ga stretch wrap, 63ga stretch wrap, and strapping. Load shift was induced by vibration and impact testing.

For each testing method, the following methods of evaluation were used:

- Displacement between containers (Container Displacement)
- Containment Force of the stabilizers
- Displacement between the bottom layer of containers and the pallet deck (Pallet Container Displacement)
- Load Stabilizer Film Torn at Corners
- Natural Frequency and Transmissibility during vibration testing

2.0 LITERATURE REVIEW

2.1 Corrugated Container Failure

According to Ievans, the strength of a corrugated container is increasingly compromised as the bottom of the container receives less support. He concluded that for single wall corrugated containers, one inch of overhang in the length, width, and two adjacent panels (corner) would result in a strength loss of 24%, 16% and 39% respectively. When the strength of a panel is compromised, the remaining panels are burdened with an extra load, which increases the likelihood of container failure. If a corrugated container fails at the bottom of a column, the stability of the entire column is jeopardized, and in turn, the integrity of the entire unit load could be reduced (Ievans, 1974).

2.2 Stretch Hood

A stretch hood is a tubular plastic film that is heat sealed at the top, stretched horizontally, pulled down over a unit load, and released under the pallet. Stretch hood machines provide control over the amount of stretch applied to the film. This allows for more precision tuning when dealing with loads that are sensitive to high containment forces. Some machines are more versatile and allow multiple gauges of film to be held in the same machine. This allows the user to adjust the amount of stretch required for different unit loads.

In a press release from 2004, “New and Improved Technology,” a research team at Lachenmeier claimed there are several advantages to using stretch hooding as a stabilizer (Lachenmeier, 2004). Stretch hoods create water proofing on the top and sides of the unit load that does not need additional flat film sheets like other methods. They claimed excellent vertical and horizontal film tension that provides long-term stability. The smooth surfaces of the stretch hood also allow for high product visibility. This helps material handlers identify fragile products and helps deter load tampering attempts. Furthermore, because there is only one layer of film, a minimal amount of film is consumed, which can be easily recycled. Drawbacks of this process include the cost of the machinery, the space required, and that it must be used in a semi-clean environment (Lachenmeier, 2004).

2.3 Stretch Wrap

Stretch wrap is an elastic film that is stretched and wrapped around a unit load to maintain load stability and provide product protection during transport and storage. The following properties directly affect a film's ability to maintain unit load integrity during storage and transport:

- Stretch is the ability of a film to elongate when a pulling force is applied. The longer it is stretched in the machine direction, typically the direction of wrap, the more the film loses its thickness and width (Forest Products Laboratory, 1986).
- Cling or Tack is the ability of a film to stick to itself. This attribute is usually affected by both internal and external film attributes. Externally, the environment's percentage of humidity and dust can have a direct effect, as the film will have less contact with itself, reducing the area in which cling is available. Internally, adding cling additives will make the film smooth and glossy, increasing cling. These additives migrate to the exterior of the film when used and create a "wetting effect" at the film's interface to help enhance the cling (Forest Products Laboratory, 1986).
- Stiffness is determined by the polymer used, density of the polymer, film thickness, additives used and the temperature at which the stretch wrap is applied. Note that stiffness affects cling because stiffer films tend to pull away from the previous layer and reduce the area of contact (Forest Products Laboratory, 1986).
- Puncture Resistance is the film's ability to resist the act of piercing or perforating, which is typically caused by a pointed instrument or object (Forest Products Laboratory, 1986).

- Resistance to Tear Propagation refers to the resistance to tear that has been started by a puncture while the film is under tension. This property is more critical in the cross machine direction of the film (perpendicular to direction of wrap). If the film tears easily in the cross machine direction, the film can quickly remove itself from the unit load. Conversely, if the film tears easily in the machine direction (typically the direction of the wrap) the integrity of the unit load is maintained (Forest Products Laboratory, 1986).
- Toughness is the combination of puncture resistance and tear propagation resistance of film. It is the ability of a film to elongate and resist punctures and tears (Forest Products Laboratory, 1986).
- Stress Retention is the ability of a stretch film to retain the tension applied during application. Once applied, all films will try to resist the stretch that has been applied, causing the stretch wrap to tighten up to two hours after application (Forest Products Laboratory, 1986).

According to Hernandez, stretch films typically have more than one layer of polymer within them. Internal polymers help with stretching, tear propagation, opacity and have many other desired properties. There are many basic polymers. One, Linear Low-Density Polyethylene (LLDPE), not only has excellent cling properties but also other properties that are typically good to excellent. LLDPE and its derivatives are the most common in the current market. Ethylene Vinyl Acetate copolymers (EVA) have cling, stretch, toughness and stress retention properties that are usually very good to excellent. Polyvinyl Chloride (PVC) is characterized by good stretch, excellent cling and good toughness, but typically has poor stress retention. It is typically used at the retail level. Metallocene achieves increased puncture resistance, opacity and stretch, while retaining average properties of all other characteristics (Hernandez, 2000).

There are two different methods of manufacturing stretch wrap. One is a blown process and the other, “cast”, is an extrusion process. The blown process starts by forcing molten resin through a circular die. It is then pulled to a desired height, usually from 20’ to over 100’, at which point air is blown through the middle of the circular die causing the film to balloon. The balloon is then flattened, cut into the desired widths, and rolled. Due to the manufacturing process, blown films are typically bi-axially oriented. The main advantages of blown film are puncture and abrasion resistance and its ability to hold a high containment force. The disadvantages are the loss of clarity in the film, the loud application noise, and that the film is not usually well suited to run on high speed equipment (Hernandez, 2000).

Cast Film is produced when molten resin is sent through an extruder and forced out as a thin sheet. The sheet is then rolled over a cooling drum, cut to width and rolled. Due to the manufacturing process, cast films are typically uni-axially oriented. The advantages of cast film are that the process of manufacturing allows for higher tolerance control for thickness and width, the clarity of the film is higher, and it can be applied at high speeds with more consistency. The disadvantages are the limited tear and puncture resistance. Cast film is the most commonly used stretch film (Hernandez, 2000).

Stretch films are predominantly sold on a 20 inch roll. The method for applying the stretch film to the unit load affects film performance. In general, there are three methods of application.

The hand held reel is the most basic method to apply stretch wrap and typically is used for low output facilities. The employee will either walk around the load with the reel, wrapping as he goes in a predetermined pattern, or he will stand still while the unit load is put on a turn-table and is rotated in front of him (Forest Products Laboratory, 1986).

Semiautomatic rotary systems require specific floor space set aside for the stretch wrapping process. The unit load must be brought to the area and put onto the machine for wrapping. The operator will manually start the preprogrammed cycle and will cut film off at the end of the cycle. The unit load is then removed from the machine. These systems are generally designed for medium output facilities (Forest Products Laboratory, 1986).

Fully automatic systems allow the unit load to be fed from a conveyor and automatically put into wrapping position. The unit load will then be wrapped as programmed and conveyed out from the wrapping position without operator assistance. These systems are typically continuous, without need for any manual material handling. They are also able to handle the wrapping of non-palletized loads and slip-sheet loads. These systems are generally designed for high output facilities (Forest Products Laboratory, 1986).

Research by White at Virginia Tech focused on stretch wrap as a unit load stabilizer. One study focused on the effect of the stretch wrapping around the unit load including the pallet. Wrapping around the pallet provided a significant stability improvement compared to not overlapping the pallet. Six pallets were used per test - three with stretch wrap overlapping the pallet and three without overlap (White, 2006).

Two ASTM tests were conducted on the test units - ASTM D 5414 Standard Test Method for Evaluation of Horizontal Impact Performance of Load Utilizing Stretch Wrap Films and ASTM D 5415 Standard Test Method for Evaluating Load Containment Performance of Stretch Wrap Films by Vibrating Tests (White, 2006).

The results of this study indicated that 1) Overlapping the stretch wrap increased unit load stability during vibration testing and 2) Overlapping the stretch wrap did not increase unit load stability during inline impact testing (White, 2006).

Another study at Virginia Tech by Rotondo compared two different gauges of stretch wrap, two different unit load wrapping patterns, and two corrugated stacking patterns (Rotondo, 2006).

Two ASTM tests were again conducted on the test units. ASTM D 5414 Standard Test Method for Evaluation of Horizontal Impact Performance of Load Utilizing Stretch Wrap Films and ASTM D 5415 Standard Test Method for Evaluating Load Containment Performance of Stretch Wrap Films by Vibrating Tests were used (Rotondo, 2006).

The results of this study indicated that 1) 80ga stretch wrap allowed less displacement than 60ga during the horizontal impact test, 2) three 100% overlapping layers of stretch wrap are more effective than three 50% overlapping layers, and 3) using column stack or an interlock stacking pattern for corrugated boxes did not influence the displacement of the boxes under these testing conditions (Rotondo, 2006).

2.4 Strapping

According to *Modern Plastics*, steel strapping was once the only strapping option available for stabilizing unit loads. In the last 40 years, polymeric strapping has become available. They are primarily used for palletizing, unitizing and crating medium to light weight goods for storage and distribution. Although not as strong, polymeric straps offer great advantages over steel. They have elastic properties which allow the straps to be stretched when tightened, and they maintain a constant force on the load for an extended period of time. They also tend to be less damaging to the product they are containing, lighter weight, and easier to dispose of. In addition, there is a large human safety factor. For example, when steel straps are cut, they can spring off the load in an unpredictable manner at high speeds. At these speeds, the strap becomes a metal whip and can seriously hurt a worker (Modern Plastics, 1965).

Polymeric straps are available in two grades- 1) Manual strapping is typically embossed to prevent slippage of seals and buckles, and 2) Machine strapping has very small dimensional variation and very little curvature, which allows proper flow through strapping machines. Application methods of both straps include manual, semi-automatic and fully automatic systems. The two pieces of strapping can be fastened with buckles, seals, heat seals or friction welds (McKinlay, 2004).

According to Auguston, polyester is the most common form of non-metal strapping that rivals steel strapping in strength. Although polyester does not retain its tension well, it is cheap, light weight, simple to apply and recyclable (Auguston, 1991).

2.5 Vibration Testing

According to Ostrem, in transportation via tractor trailer, a unit load may experience a range of frequencies from 2-20 Hz. A frequency of 0-5 Hz can be caused by the suspension systems, from 5-10 Hz- the structural elements of the trailer, and from 10-20 Hz- the physical interaction between the wheels, axles, and suspension system. Determining the natural frequency during testing is important in order to ascertain if any of the stabilizers were able to shift the natural frequency of the test unit outside the range of the tractor trailer frequencies. When these natural frequencies overlap, resonance occurs and the amount of dynamic force that a unit load could experience in transport is increased by an order of magnitude (Ostrem, 1979).

It is important to note the acceleration level on top of the unit load during testing versus the input acceleration level of the vibration table. The ratio is referred to as transmissibility. The test units experiencing a higher ratio are more likely to experience load shift within unit loads and consequently, larger amounts of damage to individual containers.

2.6 Impact Testing

During transport, a unit load experiences many horizontal shocks at varying intensities. The average level of these shocks has been studied and the results have been implemented into the Code of Federal Regulations (CFR). Page 61220 of Volume 67, No. 188 of CFR 49, entitled "Performance Criteria," addresses these results. Specifically, the CFR requirements "concern longitudinal, lateral, and vertical acceleration that cargo securement systems must withstand" (CRF 49). The requirements state that if 1 g is defined as the force of acceleration at 32.3 ft/sec, then a cargo securement system must withstand 0.8 g deceleration in the forward direction (CFR, 2002).

3.0 MATERIALS AND METHODS

3.1 Experimental Design

Four different load stabilizers were applied to a standard test unit. Five replications of each stabilizer were performed for each of the twp types of ASTM tests – Vibration and Impact. The ten test units per stabilizer were comprised of one type of load on one type of pallet. Each test unit was exposed to one ASTM test. Table 3.1 shows the experimental design. It utilized a complete random block design to help ensure that the true differences between the stabilizers were observed.

Table 3.1 Experimental Design

	Stretch Hood	80ga Stretch Wrap	63ga Stretch Wrap	Strapping
ASTM Tests	2	2	2	2
Pallet	1	1	1	1
Product	1	1	1	1
Replicates	5	5	5	5

3.2 Materials

3.2.1 Test Unit

Forty-five corrugated boxes (test container) were used to construct the load for each test unit. The 69-23-69 C flute RSC containers had inside dimensions of 16” long x 12.5” wide x 10” deep. Each test container was packed with 19 2x4s (Lumber Grade SPF) that were cut to 15.5” in length and stacked as shown in Figure 3.1. Each test container weighed 34 pounds.

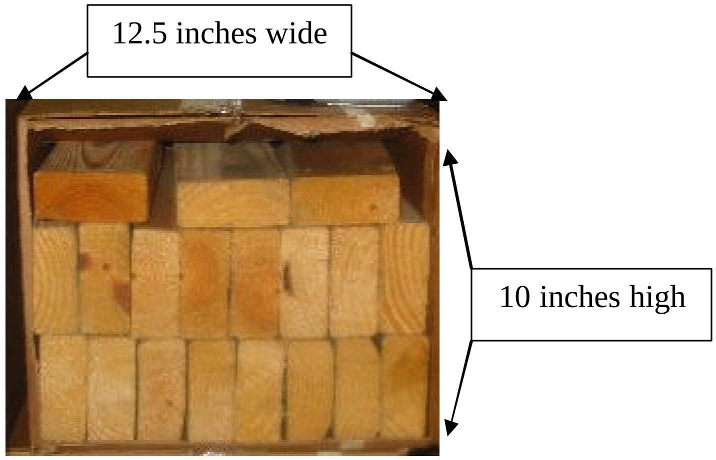


Figure 3.1 End View of Stacking Pattern of 2x4s within Each Corrugated Box

The test containers were placed on a 48" long x 40" wide, three stringer pallet (test pallet) that weighed 42 pounds. A specification of the test pallet is found in Appendix C. The dimensions of the test unit measured 49.5" long x 38.5" wide x 56" high. Each test unit incorporated nine (9) columns of boxes with five (5) boxes per layer for a total of 45 test containers. The test unit weighed 1577 pounds. A photograph of the standard test unit is shown in Figure 3.2.

Figure 3.2 Photograph of the Standard Test Unit

3.2.2 Stretch Hood

The polymers used in the 400ga stretch hoods were Exxon Mobil's Nexxstar™ resins, which are a copolymer of ethylene and vinyl acetate. The melt index of the film is .5g/10min and the film is 7.5% vinyl acetate by weight (Exxon Mobil, 2007).

The stretch hoods were applied at Lachenmeier in Hollywood, Florida using a Multi Flex stretch hooding machine. The test units were initially loosely hooded on June 4, 2007 while the correct film was determined. The correct film was applied on August 1, 2007 and shipped to The Center for Unit Load Design at Virginia Tech on August 10, 2007. Vibration tests were conducted soon after. Impact testing started on September 17, 2007. A photograph of a stretch hooded test unit is shown in Figure 3.3.

Figure 3.3 Photograph of a Stretch Hooded Test Unit

3.2.3 Stretch Wrap

Two stretch wrap films were selected based on their common desirable properties within industry application. They were 1) AEP's Alpha Series (A12) 80ga cast film and 2) Atlantis Plastics 63g LLDPE based cast film. Both films came on a twenty inch wide roll.

A Wulftech Smart Series stretch wrap machine, model number WSML-150_B was used to stretch wrap all test loads in this study. A photograph of the stretch wrapper is shown in Figure 3.4.

Figure 3.4 Photograph of the Wulftech Stretch Wrap Machine used to Apply Stretch Wrap to the Test Units

For application of both wraps a 200% prestretch was applied by the rollers in the carriage of the stretch wrap machine. In addition to the standard prestretch, another 200% prestretch occurred when the 80ga film was applied, and 150% occurred when applying the 63ga film due to the tension to load.

The slowest available carriage speed was used for all test units. When using the machine, the only variable setting was the table rotation speed, which was measured in Rotations Per Minute (RPM). The settings were 7.5 RPM for the side of the 80ga test units and 6 RPM for the side of the 63ga test units. The top of the test units required 4 RPM to prevent the stretch wrap from ripping over the top corners of the test unit during application. The rotation speeds were adjusted manually during wrapping. A stop watch was used to measure the rotation times.

The wrap pattern of each test unit consisted of three layers of overlap on the top and three and one-half layers on the bottom, which is a common commercial wrapping pattern. Between the top and bottom layers there were 27.6” for the 80ga and 21.3” for the 63ga to cover. This was covered using 5.5 and 3.35 rotations resulting in 58% and 60% overlap respectively. The wrapping patterns were kept the same for both stabilizers because Rotondo found that changes in wrapping patterns varied testing results which would have created another undesirable variable (Rotondo, 2006).

The loads where assembled and tested over a three month period, from the beginning of August 2007 to the end of October 2007. Each load was tested after sitting for at least an hour. A photograph of a stretch wrapped test unit is shown in Figure 3.5.

Figure 3.5 Photograph of a Stretch Wrapped Test Unit

3.2.4 Strapping

Polyester strapping was selected based on its common desirable properties within industry application. The strapping selected for this study was a half inch wide polyester strap that was 0.02" thick, with a maximum capacity of 600 pounds in tension. Two Signode ½ x ¾ inch sandpaper clips were used to fasten the straps together. Paperboard corner protectors were placed under the strapping to distribute the containment force of the straps throughout the entire test unit. The corner protectors were 2.25" x 2.25", .25" thick and 36" long.

Four straps were used to strap each test unit, two parallel straps on each face. Each strap was placed 6" in from a vertical edge of the test unit, and the corner posts were centered on all four top edges. Two straps went through the pallet parallel with the stringers. The other two straps went through the stringers (5/8" hole) of the pallet, under the middle of the second deck board, and in from each end of the pallet. The straps were tightened using a Signode wtd-2 tensioner. The strap was then torqued to 60 inch/pounds (5 foot/pounds) and the clips were crimped on each strap to secure them. A photograph of a strapped test unit is shown in Figure 3.6.

Figure 3.6 Photograph of a Strapped Test Unit

3.2.5 Containment Force

A Shimpo digital force gauge was used to measure the containment force of each load stabilizer. Because it is a destructive procedure that would affect the stabilizer performance, containment force of the stretch hood and stretch wrapped test units was measured after each test. It was measured by referencing ASTM D 4649 Annex A1.10.1, the 4 inch pull method. A four inch incision, parallel to the pallet, was cut into the stabilizer in the middle of layers 1, 3 and 5 on each side of the test unit after testing. A four inch rod attached to the force gauge was placed in the incision and turned perpendicular to the direction of cut. The rod was then pulled four inches from the corrugated container and the force recorded. This procedure was conducted on each face of the test unit in the middle of layers 1, 3 and 5.

For the strapped test units, the containment force was measured by pulling the strap, attached to the force gauge via a hook, four inches from the corrugated containers of the test unit, in the middle of each strap, on each face of the test unit.

Average containment forces were calculated by taking the average containment force by face and averaging it with the average containment force by layer. For the strapped test units, an average of the vibration and impact testing containment forces by face was calculated. This was used in place of an average containment force by layer. The resulting containment force averages for vibrated test units are shown in Figure 3.7, and the average containment force for impacted test units are shown in Figure 3.8.

Figure 3.7: Average Containment Force After Vibration Testing as a Function of Load Stabilizer

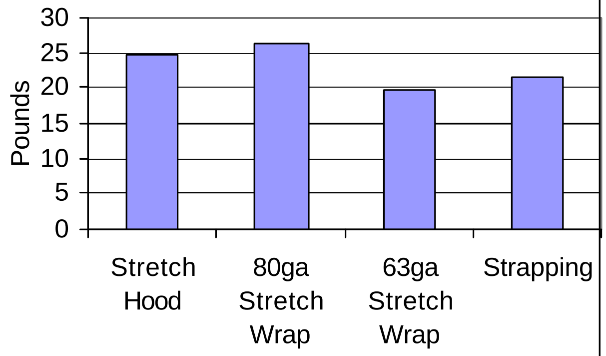
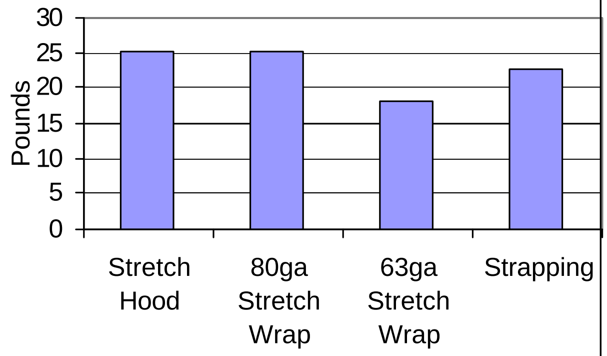


Figure 3.8: Average Contianment Force After Impact Testing as a Function of Load Stabilizer



The stretch hooding film and application specifications were selected by Lachenmeier, where the test hoods had been applied. After receiving the test loads and measuring the containment force of the stretch hoods, a decision was made to try and achieve the same containment force between all the load stabilizers. If a consistent containment force was achieved, then a more accurate comparison of the load stabilizers could be conducted. However, it was quickly evident that this was not viable for 63ga stretch wrap due to the inadequate strength of the film. Nor was it viable for strapping, since point loading on the corners of the test unit at higher containment forces, causing damage to them.

A Tukey's HSD test was conducted at a 95% confidence level to see if the containment forces between stabilizers, per test, were statistically different. There was no difference in containment force after vibration testing when comparing stretch hooding versus 80ga stretch wrap, and 63ga stretch wrap versus strapping; however, the latter grouping provided less containment force. After impact testing, the containment force of stretch hooding and 80ga stretch wrap was the largest and statistically the same. The containment force of strapping was statistically less than the previous grouping, and 63ga stretch wrap had the lowest containment force. For an explanation of why a Tukey's HSD test was used see Section 3.4.1.

In trying to achieve a standard containment force, different amounts of material were used for each stabilizer. Table 3.2 shows the different weights of the stabilizers used, with the weight of the strapping includes the weight of the corner protectors and the clips. Stretch hooding used the most amount of material, followed by strapping, 80ga stretch wrap and 63ga stretch wrap. More 63ga stretch wrap could have been added to increase containment force but this would have added the undesirable variable of wrapping pattern.

Table 3.2 Weight Per Load of Stabilizer (lbs)	
Stretch Hood	1.58
80ga Stretch Wrap	0.53
63ga Stretch Wrap	0.45
Strapping	0.84

63ga stretch wrap had the lowest overall containment force and the least amount of material used. Strapping had the second lowest amount of containment force but utilized twice as much material in load stabilization. By conventional wisdom, because their containment forces were lower, a larger amount of displacement should have occurred during testing.

3.3 Methods

3.3.1 Vibration Testing

Vibration tests were conducted according to ASTM D 5415 - Evaluating Load Containment Performance of Stretch Wrap Films by Vibration Testing. A LAB Instruments vibration table using Signal Calc 350 Vibration Controller Software was used. A photograph of the vibration table is shown in Figure 3.9. For the test parameters ASTM D 4169 - Performance Testing of Shipping Containers and Systems, Section 12 Schedule D was referenced. A random tractor trailer simulation was run at Assurance level 3 with an overall g_{RMS} of 0.37. Assurance level 3 was selected because it would ensure quantitative values for all test samples. A higher assurance level could result in failure of a load stabilizer, allowing for non-quantitative values.

In addition, the amount of displacement that occurs at level 3 would be proportional to the amount that would occur at level 1; while the numeric values would change, the differences between the numbers would stay the same.

Stanchions were placed on the outside edges of the vibration table to prevent the test units from walking off the table during vibration. The stanchions were placed in line with the middle columns of the corrugated boxes, within the test units, so they would not interfere with any displacement of the boxes during testing. A minimum of two inches was left in between the test unit and the stanchions.

For all vibration tests, the input and output acceleration, natural frequency, RMS and control Y were taken from the Signal Calc software output. The output acceleration was divided by the input acceleration to calculate the transmissibility of the load.

Figure 3.9 Photograph of the LAB Vibration Table Used. The Stanchions Used Are Seen On Top of the Table

3.3.2 Impact Testing

Impact tests were conducted according to ASTM D 5414 - Evaluation of Horizontal Impact Performance. The incline impact tester was manufactured by Gaynes Engineering Co.

The angle of the track was 10 degrees from the floor and the trolley rode parallel to the track. To simulate a standard horizontal impact test, the incline impact tester was modified by retrofitting the impact trolley with a steel leveling table. The pallets were placed on the steel leveling table with the deck boards parallel to the impact surface or perpendicular to the direction of the stringers. A "pallet stop" fabricated into the steel leveling table ensured the pallet stopped when the sled impacted the bumper, allowing the test load to move freely. There was a 3 inch bumper between the end of the track and the backstop intersect. This allowed a maximum displacement distance of 4.5 inches at the bottom of the test unit and 11.5 inches at the top. Photographs of the testing apparatus are shown in Figures 3.10 and 3.11.

Each unit received one impact from a distance of 44 inches, measured from the front of the sled to front of the bumper. This results in an impact velocity of 5.75 feet per second or 3 miles per hour, as required in ISTA procedure 1E. Photographs were taken of all test units before and after testing.

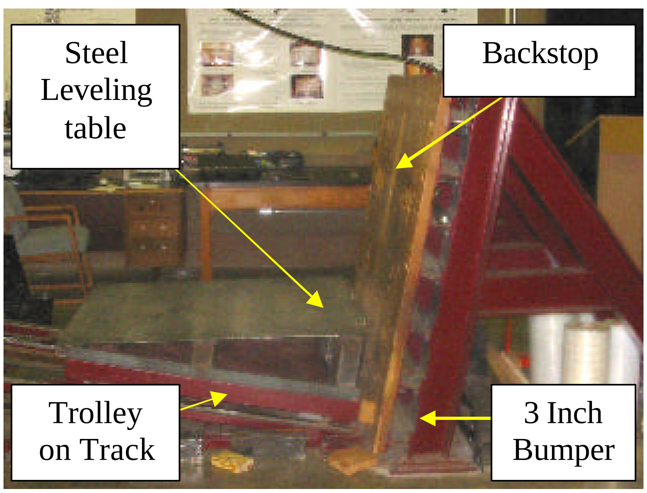


Figure 3.10 Photograph of the Incline Impact Tester Used in Testing, With Steel Leveling Table in Place

Figure 3.11 Photograph of the Pallet Stop Fabricated into the Steel Leveling Table

The Code of Federal Regulations (CFR), Section 49, part 392, page 61220, states that for any cargo securement system in or on a trailer, the minimum forward restraint should resist the load accelerated by .8g's. The following is the calculation of the amount of G's our test unit experienced:

Equation: V=Sqrt(2*(g*sin?)*h) (American National Standard Mh1 – 2005)

H = 44 inches   V= 5.75 feet/sec

g= (((V^2)/2)/(H/12))/(sin 10)

g= 25.96 feet/ sec^2

Equation: g/G= g% (the percentage of gravity experienced by the load)

G= 31.174 feet/sec^2

g%=25.69/31.174= .832

There was a total of .832g exerted on the test unit when the sled hit the bumper in the impact test. Because this exceeds .8g, this test level exceeded the cargo retainment requirements in CFR 49.

3.4 Measurement of Load Stability

3.4.1 Container Displacement

The container displacement is defined as the displacement of one test container layer relative to another.

To measure the container displacement, eight vertical masking tape lines (3/4"), two per face, were placed approximately 6" in from the four outside corners of the test unit directly onto the corrugated boxes. The location of the lines is shown in Figure 3.12.

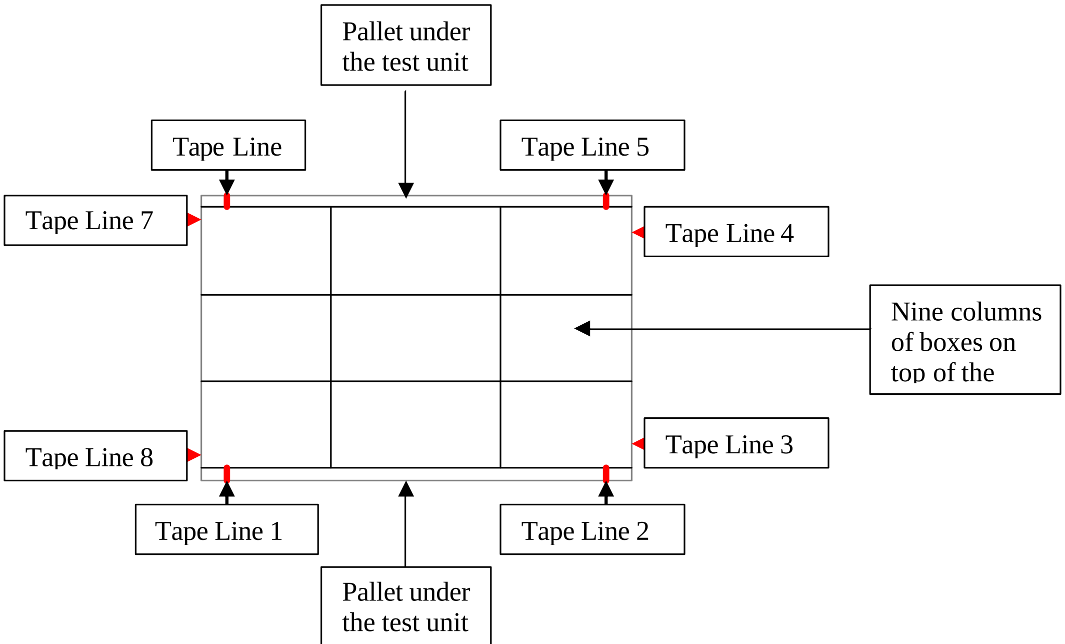


Figure 3.12 Top View of Pallet Indicating Where Tape Lines Were Placed On Each Side of the Test Unit

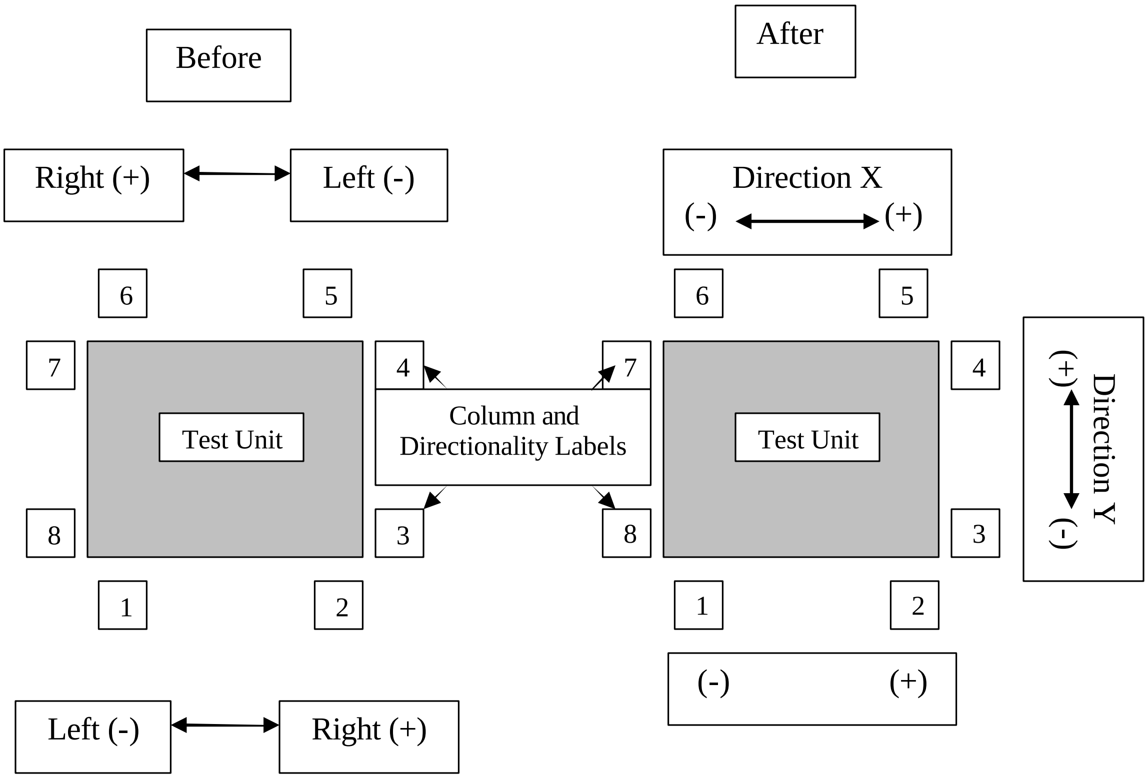
Each vertical box intersection was labeled along the tape line. The tape was then cut with a razor blade to allow natural displacement during testing. The locations of the intersections are shown in Figure 3.13.

Figure 3.13 Photograph of the Side View of the Pallet Indicating Where the 5 Measurements of Displacement Were Taken On Each Tape Line

After the appropriate stabilization method was applied to the load, any shifting along the tape lines, on all faces of the test unit, was measured with a ruler to the nearest 1/32" before testing. Displacement to the right was positive and displacement to the left was negative. Once a test was performed, the displacement of each tape intersection on every face was measured again in the same manner. This method was used on all test units.

Displacement data was collected on each face of the test unit to ensure the entire movement of the unit load was captured. Displacement to the right was recorded as positive and displacement left was recorded as negative. First, the total displacement due to testing was determined for each layer on each face (final container displacement minus initial container displacement). The cumulative displacement of the layers (a through c) from the pallet up was calculated. Before the displacement of each face could be accurately compared, the sign notation of the displacements had to be corrected. When viewing the test unit from above and attempting to average all displacement into two directions (X and Y), displacement to the right in direction X was positive on one face and negative on the opposite face. The same was true for direction Y. To correct for this, the signs on two sides of the test units were inverted, allowing all displacement to the right to be positive and all displacement to the left to be negative for both directions. A visual interpretation is shown in Figure 3.14.

Figure 3.14 Visual Column Sign Inversion Explanation



To eliminate the directionality of the displacement data, the absolute value of the cumulative displacement was used as a measure of displacement.

It is not clear whether average load displacement or maximum load displacement is the most appropriate measure of load shift. The maximum displacement experienced could be statistically insignificant, but the average displacement may not correctly identify when failure occurs. Therefore, both measures were used. First, the Cumulative Average Displacement (CAD) was calculated by using the average container displacements by direction, per column, by layer and across the five test units. Then, the Cumulative Average Maximum Displacement (CAMD) was calculated as the maximum displacement by direction, per column, by layer and across the five test units.

Statistical Analysis Software (SAS) was used to interpret the data in its raw form. A Tukey's HSD was conducted on CAD in directions X and Y and CAMD in direction X. The amount of displacement per the stabilization type interaction was calculated at a 95% confidence level. A Tukey analysis was conducted because of the block design of the experiment and it is based on the "studentized range distribution," which allows testing the differences between any amount of pairs of means.

3.4.2 Pallet Container Displacement

The Pallet Container Displacement is defined as the amount that layer "e" moved, which is the amount of displacement between the bottom layer of test containers and the top deck boards. This was measured because corrugated containers loose strength as the amount of overhang over the pallet increases (Section 2.1). If the entire side of a unit load is overhung by an inch, 39% of the strength has been compromised in the three overhung columns, creating a scenario which could lead to unit load lean or even failure.

3.4.3 Load Stabilizer Film Torn at Corners

A corner was defined as a box to box, or box to pallet interaction on an outside corner of the test unit. The number of torn corners was noted before and after testing for each film based test unit. The number of corners torn before testing was subtracted from the number of corners torn after testing to obtain the total number of corners torn during the testing of each load. An average was then taken across the five test repetitions, and results per load stabilizer were compared.

4.0 RESULTS AND DISCUSSION

4.1 Overview

Research was conducted in the order of stretch hooding, 80ga stretch wrap, 63ga stretch wrap and then strapping for both testing procedures. The experimental design and testing setup are given in section 3.0 Materials and Methods. Photographs were taken of all test units before and after testing.

4.2 Vibration Testing

Displacement that occurs during vibration testing is typically bidirectional. The vibration table is truly level which allows the boxes to "walk" in any direction. Displacements in directions X and Y were averaged to more accurately assess the overall displacement.

Shown below in Table 4.1 are the average transmissibility and average natural frequencies of the test units. An effective stabilizer should help minimize transmissibility, which none of the stabilizers were able to do.

One reason why a stabilizer is applied to a unit load is to either increase or decrease the natural frequency of the load to outside the natural frequency of the transportation method. None of the load stabilizers moved the natural frequency beyond the typical input frequencies of a tractor trailer (2 to 20 hz). Therefore, the load stabilizers used had minimal effect on transmissibility and natural frequency.

Table 4.1 Average Transmissibility and Natural Frequency during Vibration Testing

	Average Transmissibility	Average Natural Frequency (Hz)
1. Stretch Hooding	2.20	7.63
2. 80g Stretch Wrap	2.32	9.03
3. 63g Stretch Wrap	2.23	10.11
4. Strapping	2.17	10.17

4.2.1 Container Displacement

Figures 4.1 and 4.2 compare the performance of the different load stabilizers through Cumulative Average Displacement (CAD) and Cumulative Average Maximum Displacement (CAMD) respectively. Using both calculation methods, the least amount of displacement occurred in the strapped test units and the most displacement occurred in the stretch hooded test units. The strapped test units appeared to perform an order of magnitude better than the stretch wrapped test units, which performed equally well. The stretch hooded test units performed the worst.

Figure 4.1 CAD During Vibration Testing

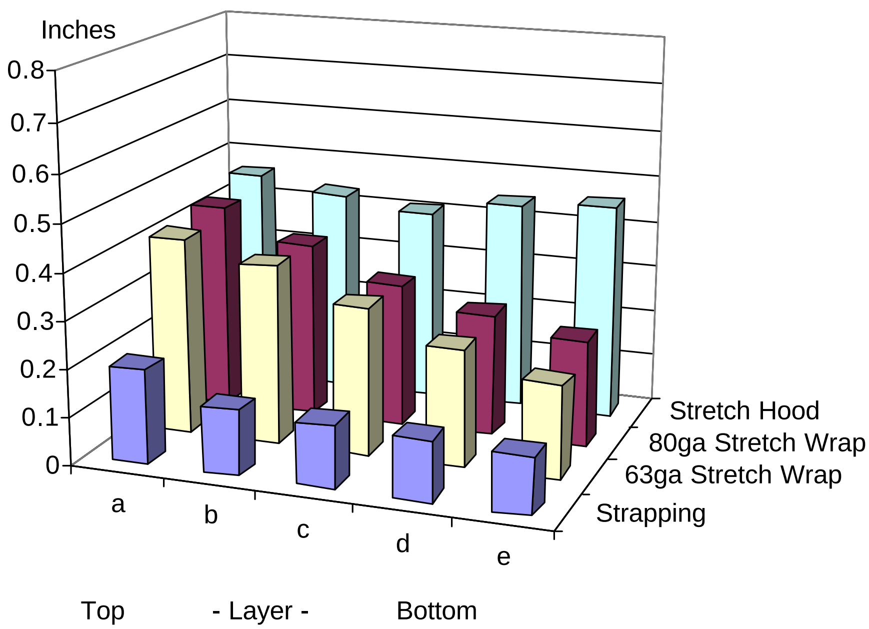
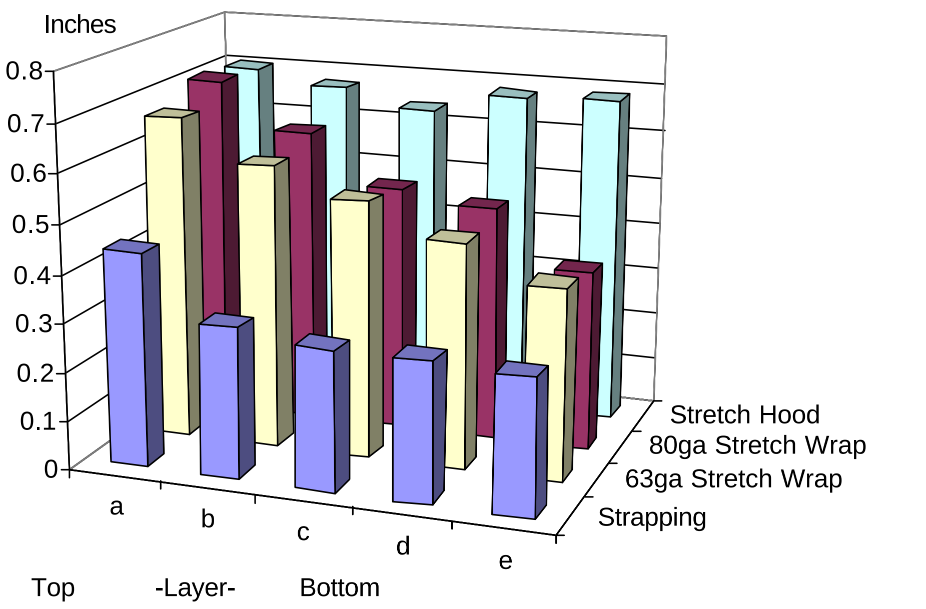


Figure 4.2 CAMD During Vibration Testing



To analyze the statistical effectiveness of each stabilizer, individual comparisons of direction per stabilizer were conducted. A Tukey's HSD test was used to determine the statistical differences in the CAD and CAMD. The results are shown in Table 4.2 and 4.3 respectively.

For CAD, in direction X, stretch hooding is statistically different from 63ga and 80ga stretch wrap test units, which are statistically the same. 80ga stretch wrap and strapping are statistically the same, but are different from the 63ga and 80ga stretch wrap grouping. In direction Y, strapping is statistically different from stretch hooding and the 80ga and 63ga stretch wrap, which are all grouped as statistically the same.

Table 4.2 Tukey Grouping for CAD in Vibration Testing				
Direction	**X**			**Y**
Stretch Hood	a		Stretch Hood	a
63ga Stretch Wrap	b		80ga Stretch Wrap	a
80ga Stretch Wrap	b	c	63ga Stretch Wrap	a
Strapping		c	Strapping	b

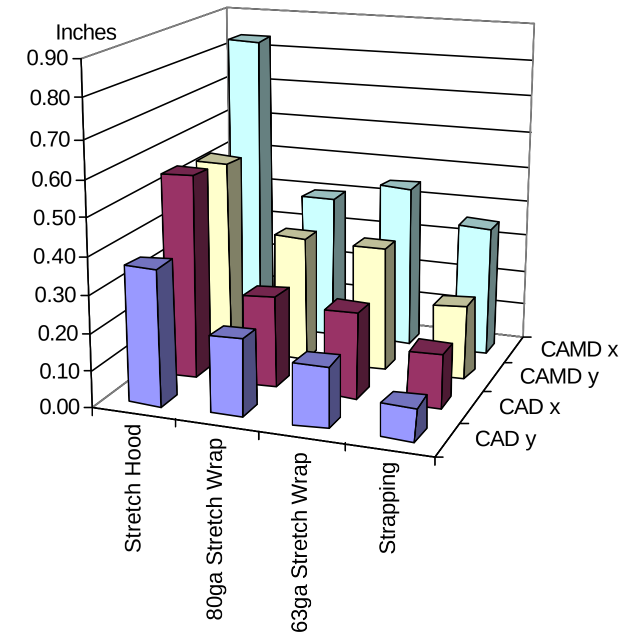
For CAMD, in direction X, stretch hooding and the 63ga and 80ga stretch wrap were statistically the same. However, although 80ga and 63ga stretch wrap and strapping were statistically the same, the groups are statistically different. In direction Y, strapping is statistically different from stretch hooding, 80ga, and 63ga stretch wrap which, are all grouped as statistically the same.

Table 4.3 Tukey Grouping for CMAD in Vibration Testing				
Direction	**X**			**Y**
Stretch Hood	a		Stretch Hood	a
63ga Stretch Wrap	a	b	80ga Stretch Wrap	a
80ga Stretch Wrap	a	b	63ga Stretch Wrap	a
Strapping		b	Strapping	b

Overall, the displacements during vibration testing were relatively small. The amount of movement experienced in the CAD was less than 0.55" and the amount of movement in the CAMD was less than 0.85".

4.2.2 Pallet-Container Displacement

Figure 4.3 shows the amount of displacement that occurred at intersection "e" during vibration testing. The least amount of displacement occurred in the strapped test units, followed by the 63ga and the 80ga stretch wrapped test units respectively. The most amount of displacement occurred in the stretch hooded test units. The greatest amount of pallet container displacement was 0.81”, which occurred in the stretch hooded test units. This amount of pallet-container displacement could lead to overhang which can be significantly detrimental to the performance of the test containers.



4.2.3 Load Stabilizer Film Torn at Corners

The average number of corners torn was 1.2, 4.6 and 4.8 for stretch hooding, 63ga stretch wrap and 80ga stretch wrap, respectively. The thicker film of the stretch hood is more resistant to tearing from repetitious stresses experienced during vibration testing.

It should be noted that the stretch hooded test units were prepared off-site and shipped to the testing location. Changes in the specimens during transport could have affected the performance of the stretch hooded test units during testing.

The 63ga stretch wrap may have performed better that the 80ga stretch wrap due to the superior tear propagation properties of the film.

4.3 Impact Testing

Displacement that occurs in impact testing is typically unidirectional. Since the test is designed to force the test unit to shift in one direction, the direction of impact, this direction was the only one analyzed. The pallet end impacted was noted for each test.

Any negative displacement in the upper layers of the pallet may be associated with the load impacting the backstop of the testing apparatus. Overall, since the pallet-container displacement results are proportional to the container displacement results, having some of the test containers impact the wall did not appear to affect the ranking of stabilizer performance. However, this phenomenon did affect maximum displacement of the test containers during testing, therefore altering the relative effectiveness assigned.

4.3.1 Container Displacement

Figures 4.4 and 4.5 compare the performance of the different load stabilizers through CAD and CAMD respectively. Using both calculation methods, the least amount of displacement occurred in the stretch hooded test units and the most displacement occurred in the 63ga test units. The stretch hooded and the strapped test units appeared to perform an order of magnitude better than the stretch wrapped test units.

Figure 4.4 CAD During Impact Testing

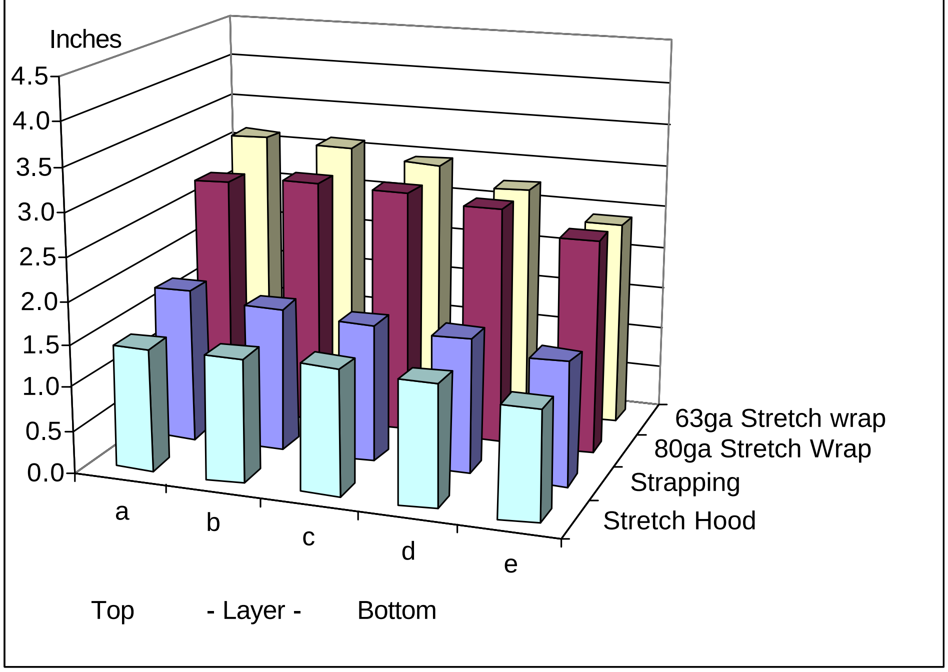
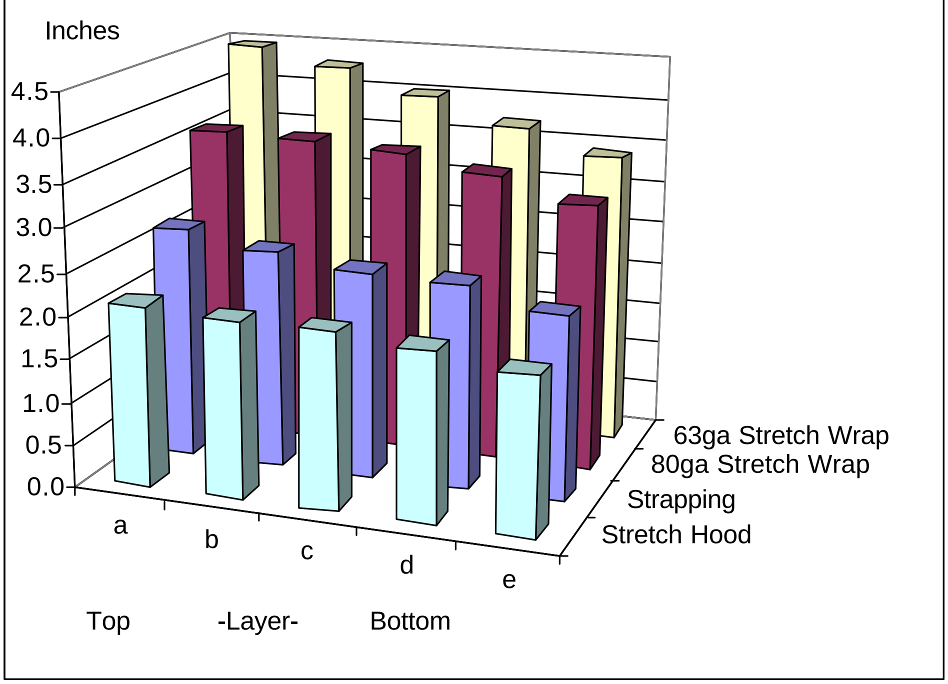


Figure 4.5 CAMD During Impact Testing



As in vibration testing, to analyze the statistical effectiveness of each stabilizer, individual comparisons of direction per stabilizer were conducted. A Tukey's HSD test was again used to determine if there were any statistical differences between the CAD and CAMD. The results are shown in Tables 4.4 and 4.5 respectively.

For CAD and CAMD stretch hooding and strapping were statistically the same. The 80ga and 63ga stretch wrap were also statistically the same, but the groups were statistically different, with the latter grouping allowing for more displacement.

Table 4.4 Tukey Grouping for CAD in Impact Testing

63ga Stretch Wrap	a
80ga Stretch Wrap	a
Strapping	b
Stretch Hood	b

Table 4.5: Tukey Grouping for CAMD in Impact Testing

Stretch Hood	a
Strapping	a
80ga Stretch Wrap	b
63ga Stretch Wrap	b

Overall, the displacements that occurred during impact testing were quite large. Stretch hooding was the best performer in CAD and CAMD, and allowed 1.45" and 2.1" respectively. The worst performer, 63ga stretch wrap, allowed 3.14" and 4.47" for CAD and CAMD respectively.

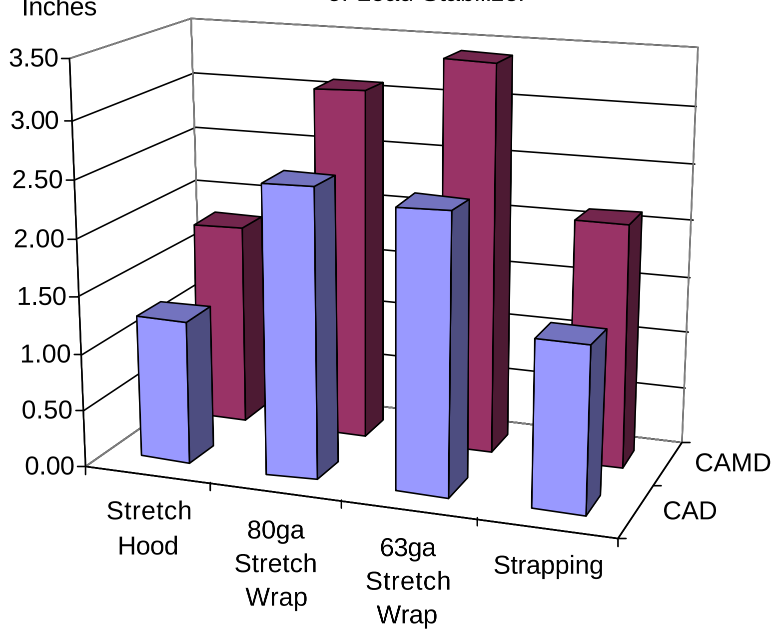
It was observed that during testing a large number of all the test units were hitting the backstop upon impact. The top one or two layers of the stretch hooded and strapped test units hit, while at least the top three layers of the stretch wrapped test units were impacting the backstop. This may have decreased the amount of displacement that occurred in the upper levels of the unit load. Sometimes negative displacement may have occurred due to rebound from the large impact forces. In addition, the containment force coupled with smaller rebound forces may have created enough negative force to move the top layers significantly.

4.3.2 Pallet Container Displacement

Figure 4.6 shows the amount of displacement that occurred at intersection “e” during impact testing. The least amount of displacement occurred in the stretch hooded test units at 1.26”, which was closely followed by the strapped test units at 1.44”. This, According to Ievans, leads to an approximate strength reduction of 24% for the bottom container in the middle column, and a 39 % reduction for the bottom containers in the corner columns (Ievans, 1974).

The stretch wrapped test units performed an order of magnitude worse than the other stabilizers. The amount of displacement that occurred in the 63ga and the 80ga stretch wrapped test units in CAD and CAMD was above 2” and 3” respectively. This amount of pallet-container displacement could lead to overhang which, again, can be significantly detrimental to the performance of the test containers.

Figure 4.6 Impact Pallet Container Displacement as a Function of Load Stabilizer



4.3.3 Load Stabilizer Film Torn at Corners

The average number of torn corners in stretch hooded unit loads was 4.4, whereas there were 5.4 and 4.6 corners torn for 80ga stretch wrap and 63ga stretch wrap respectively. The extreme shock of the impact test caused all of the films to experience similar failure modes.

The thin film of the stretch wrapped loads was not enough to resist the extreme forces experienced in impact testing.

4.4 Containment Force

In Section 3.2.5 it was assumed that a higher containment force on the sides of the test units would reduce the amount of displacement during testing. The results are inconclusive. Stretch hooding had the second highest containment force; but was the poorest performer during vibration testing and the best performer during impact testing. Strapping, which had a low containment force performed well in both vibration and impact testing.

While the second example is valid, it is not as strong as the first. Stretch hooding and stretch wrapping provide a more consistent containment force on the four vertical faces of the unit load while strapping only provides containment force via the straps and corner boards. There is no corresponding standard for containment force measurement of strapping. Thus this comparison was not altogether reliable.

The vertical containment force was not measured due to the lack of a standard method. In the future, a method should be developed to measure the vertical containment force of a stabilizer. When horizontal and vertical containment forces are understood, it may be possible to quantify the effectiveness of a load stabilizer.

5.0 SUMMARY AND CONCLUSIONS

5.1 Summary of Results

Summary tables of testing results are shown below. 100% effectiveness indicates the best performing stabilizer. The percentages are calculated by using the best performing stabilizer as a benchmark.

Table 5.1 Vibration Testing Results

Container Displacement CAD	Relative Effectiveness	Container Displacement CMAD	Relative Effectiveness
Strapping	100%	Strapping	100%
63ga stretch wrap	47%	63ga stretch wrap	66%
80ga stretch wrap	45%	80ga stretch wrap	62%
Stretch hood	39%	Stretch hood	60%
Pallet Container Displacement CAD	**Relative Effectiveness**	**Pallet Container Displacement CAMD**	**Relative Effectiveness**
Strapping	100%	Strapping	100%
63ga stretch wrap	60%	80ga stretch wrap	75%
80ga stretch wrap	52%	63ga stretch wrap	71%
Stretch hood	26%	Stretch hood	41%
Corners Torn	**Relative Effectiveness**	**Transmissibility**	**Relative Effectiveness**
Stretch hood	100%	Strapping	100%
63ga stretch wrap	30%	Stretch hood	99%
80ga stretch wrap	25%	63ga stretch wrap	97%
n/a for strapping		80ga stretch wrap	94%

Table 5.2 Impact Testing Results			
Container Displacement CAD	Relative Effectiveness	Container Displacement CMAD	Relative Effectiveness
Stretch hood	100%	Stretch hood	100%
Strapping	82%	Strapping	78%
80ga stretch wrap	50%	80ga stretch wrap	58%
63ga stretch wrap	46%	63ga stretch wrap	48%
Pallet Container Displacement CAD	Relative Effectiveness	Pallet Container Displacement CAMD	Relative Effectiveness
Stretch hood	100%	Stretch hood	100%
Strapping	88%	80ga stretch wrap	84%
63ga stretch wrap	52%	Strapping	58%
80ga stretch wrap	50%	63ga stretch wrap	53%
Corners Torn	Relative Effectiveness		
Stretch hood	100%		
63ga stretch wrap	96%		
80ga stretch wrap	81%		
n/a for strapping			

5.2 Conclusions

The goal of this research was to measure and compare load shift and container displacement within unit loads that are stabilized with stretch hooding, 80ga stretch wrap, 63ga stretch wrap and strapping. The results were:

- Impact testing resulted in significantly more load shifting than vibration testing.
- Strapping was the most effective stabilizer during vibration testing, followed by 63ga stretch wrap, 80ga stretch wrap, and stretch hooding.
  - Container Displacement- Strapping was most effective.
  - Pallet Container Displacement- Strapping was the most effective.
  - Transmissibility- Strapping was the most effective.
  - Load Stabilizer Film Torn at Corners - Stretch hooding had the least amount of corners torn during testing

- Stretch hooding was the most effective in resisting displacement during impact testing, followed by strapping, 80ga stretch wrap and 63ga stretch wrap.
    - Container Displacement-Stretch hooding was most effective.
    - Pallet Container Displacement- Stretch hooding was most effective.
    - Load Stabilizer Film Torn at Corners - Stretch hooding had the least amount of corners torn during testing.
- Though not statistically significant, the 80ga stretch wrapped test units performed better than the 63ga test units overall.
- Container displacement generally increased from the bottom to the top layer of test containers.
- Neither CAD nor CAMD was a more effective measure of container displacement.

These results only relate to the specific materials tested. When different amounts of a load stabilizer are applied to a unit load, different outcomes result. In addition, different load stabilizers have different application costs, which should be weighed against their effectiveness for every stabilizer selection.

6.0 PRELIMINARY EVALUATION OF ADDITIONAL LOAD STABILIZERS

6.1 INTRODUCTION

6.1.1 Overview

There were two unit load stabilizers that were of interest but were not included in Sections 1 through 5 because of time and equipment availability. They were stretch netting and horizontal stretch wrap.

Stretch netting is exactly as its name suggests, a net that stretches. It is designed to allow airflow to the unitized load while acting as a load stabilizer.

Horizontal stretch wrap is applied around the vertical axis of the pallet. It is called horizontal wrapping because of its typical direction of flow through the machines that apply the wrap.

6.1.2 Objective

The objective of this section was a preliminary comparison of the stabilization performance of stretch netting and horizontal stretch wrapping with the more common stabilizers previously tested.

6.2 MATERIALS AND METHODS

6.2.1 Background

6.2.1.1 Horizontal Stretch Wrap

There are two reasons why horizontal stretch wrap is used. First, in theory it wraps the unit load horizontally creating more vertical stabilization for the unit load. Second, the unit load may be too awkward or long to use with a standard vertical stretch wrapper.

Horizontal stretch wrap is not formulated any differently than traditional stretch wrap. The difference is the machinery required to apply the wrap. Horizontal stretch wrappers are much more expensive than typical stretch wrap machines. They are also typically in-line wrappers, allowing the product to approach and leave the wrapping area on a conveyor belt.

6.2.1.2 Stretch Netting

According to Hanlon, stretch netting is applied to a unit load that requires chilling or atmospheric changes during distribution, such as bulk quantities of produce. It lets the atmosphere affect the load evenly, ensuring that the temperature throughout the unit load stays consistent with the outside environment, thus allowing less condensation on the unit load (Hanlon, 1998).

Stretch netting requires less material per linear foot than traditional stretch wrap and is therefore easier to dispose of. It is typically more expensive per linear foot than traditional stretch wraps due to the smaller economies of scale. Stretch netting allows portions of the net to tear while maintaining its strength. This property allows it to stretch over non uniform loads with some sharp edges. There are two forms of stretch netting. The first applies a constant containment force on the unit load. The second only applies containment force in the parallel to wrap direction (Hanlon, 1998).

6.2.2 Materials

6.2.2.1 Horizontal Stretch Wrap

AEP's Alpha Series (A12) 80ga cast film with a hand applicator was used. The test load was put onto fork truck tines, raised in the air and wrapped manually, with two people attempting to achieve the tightest wrap they could. The attempted wrapping pattern consisted of three full wraps on each end and a 50% overlap in the middle. A photograph of a horizontally wrapped test unit is shown in Figure 6.1.

Figure 6.1 Photograph of a Horizontally Wrapped Test Unit

6.2.2.2 Stretch Netting

Conweb Plastics's 20 pound weight netting (RO4865) was used. The same Wulftech Smart Series stretch wrap machine that was used in 3.2.3 was used to stretch net both the test units in this study.

For the application of stretch netting, the netting was placed through only half of the available rollers. This was due to the netting not being able to withstand the preprogrammed prestretch, causing breakage of the netting if all the rollers were used. A photograph of the threading pattern used is shown in Figure 6.2.

Figure 6.2 Photograph of the Threading Pattern For Stretch Netting in the Wulftech Carriage

The slowest available carriage speed was used for both test units. When using the machine, the only variable setting allowed was the table rotation speed. The rotation speed was 6 RPM for the sides of the unit and 4 RPM for the top to prevent the stretch netting from ripping over the top corners of the test unit during application. The rotation speeds were adjusted manually during wrapping. A stop watch was used to measure the rotation times.

The wrap pattern of each test unit consisted of three layers of overlap on the top and three and a half rotations on the bottom. Due to necking, the netting had to cover 20.8 inches (between the top and bottom wraps), which was covered in 3.21 rotations with 65% overlap.

The loads were assembled and tested over a 48 hour period from 11/26/07-11/28/07. Each load was tested after sitting for at least an hour. A photograph of a stretch netted test unit is shown in Figure 3.3.

Figure 6.3 Photograph of a Stretch Netted Test Unit

6.2.3 Methods

The test procedures are the same as those outlined in Sections 3.3.1 and 3.3.2.

6.2.4 Measurements of Load Stability

6.2.4.1 Container Displacement

The test procedures are the same as those outlined in Sections 3.4.1

6.2.4.2 Pallet Container Displacement

The test procedures are the same as those outlined in Sections 3.4.2

6.2.4.3 Containment Force

See Section 3.2.5 for complete description. For stretch netting, a four inch rod was pushed through the "holes" in the net. The rod was then turned parallel to the floor and pulled four inches from the corrugated container under the stabilizer. The maximum force was noted on layers 1, 3 and 5 on all faces of the test unit.

For horizontal stretch wrap, a four inch incision was cut into the stabilizer perpendicular to the floor in the middle of layers 1, 3 and 5 on both faces of the pallet covered by stretch wrap.

A four inch rod was placed in the incision and turned perpendicular to the direction of the cut. The rod was then pulled four inches from the corrugated container under the stabilizer. The maximum force was noted.

Figure 6.4 shows the average containment force of the stretch netted and horizontally stretch wrapped load after vibration testing, compared to the results attained in Section 3.2.5. The containment force exerted by stretch netting was lower than the other stabilizers; however, horizontal stretch wrap exerted a significantly larger amount of containment force.

Figure 6.4: Average Containment Force for Horizontal Stretch Wrap in Vibration Testing

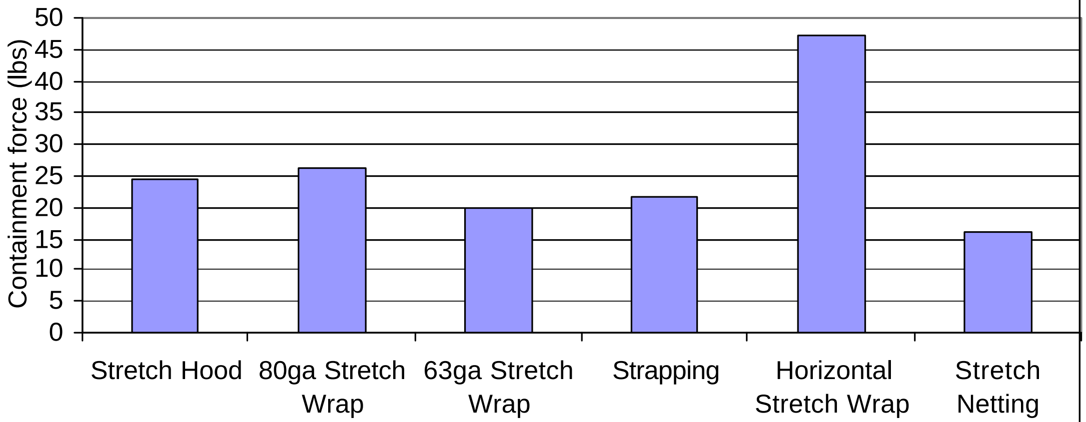
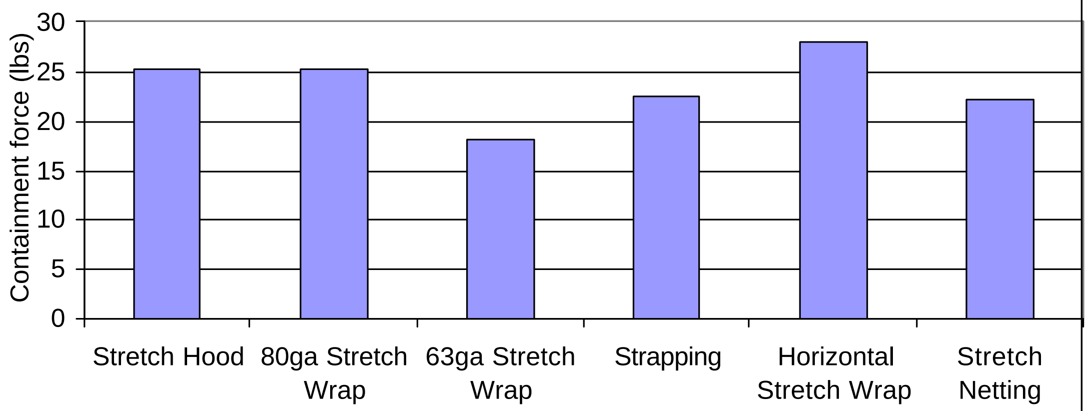


Figure 6.5 shows the average containment force of the stretch netted and horizontally stretch wrapped load after impact testing, compared to the results attained in Section 3.2.5. The containment force exerted by stretch netting was in line with the other stabilizers, while horizontal stretch wrap exerted a slightly higher containment force on the test unit.

Figure 6.5: Average Containment Force for Horizontal Stretch Wrap in Impact Testing



6.3 RESULTS AND DISCUSSION

6.3.1 Vibration Testing

As discussed in Section 4.2, displacement that occurs in vibration testing is typically unidirectional. However, since the vibration table is truly level, the boxes may "walk" in any direction. Displacements in directions X and Y were again averaged to more accurately assess the overall displacement.

Remembering that an effective stabilizer should minimize transmissibility, Table 6.1 shows the average transmissibility and average natural frequencies of the preliminary stabilizers compared to the stabilizers tested in Section 4.0.

The transmissibility that occurred in the horizontally stretch wrapped and stretch netted test units was 2.78 and 2.29, and natural frequency of 7.31 and 8.58 respectively. The transmissibility of the stretch netted test unit was equivalent to the stabilizers tested in Section 4.0. The transmissibility of the horizontally stretch wrapped test unit was slightly higher, although still not significant. The natural frequencies that occurred in the stretch netted and horizontally wrapped test units were similar to the frequencies that occurred in the test units in Section 4.

Table 6.1 Average Transmissibility and Natural Frequency during Vibration Testing of Preliminary Stabilizers

	Average Transmissibility	Average Natural Frequency (Hz)
1. Stretch Hooding	2.20	7.63
2. 80g Stretch Wrap	2.32	9.03
3. 63g Stretch Wrap	2.23	10.11
4. Strapping	2.17	10.17
5. Stretch Netting	2.29	8.58
6. Horizontal Stretch Wrap	2.78	7.31

Container Displacement

Figures 6.6 and 6.7 compare the performance of the preliminary stabilizers during vibration testing with the stabilizers tested in Section 4.0 through CAD and CAMD respectively. In CAD, the stretch netting performed better than the stretch hooded test units but worse than the 80ga stretch wrapped test units. The horizontally stretch wrapped test unit was the worst performer. In CAMD, stretch netting was the worst performer and horizontal stretch wrap performed better than the stretch netted test units but worse than the stretch hooded test units.

Figure 6.6 CAD During Vibration Testing of Preliminary Stabilizers

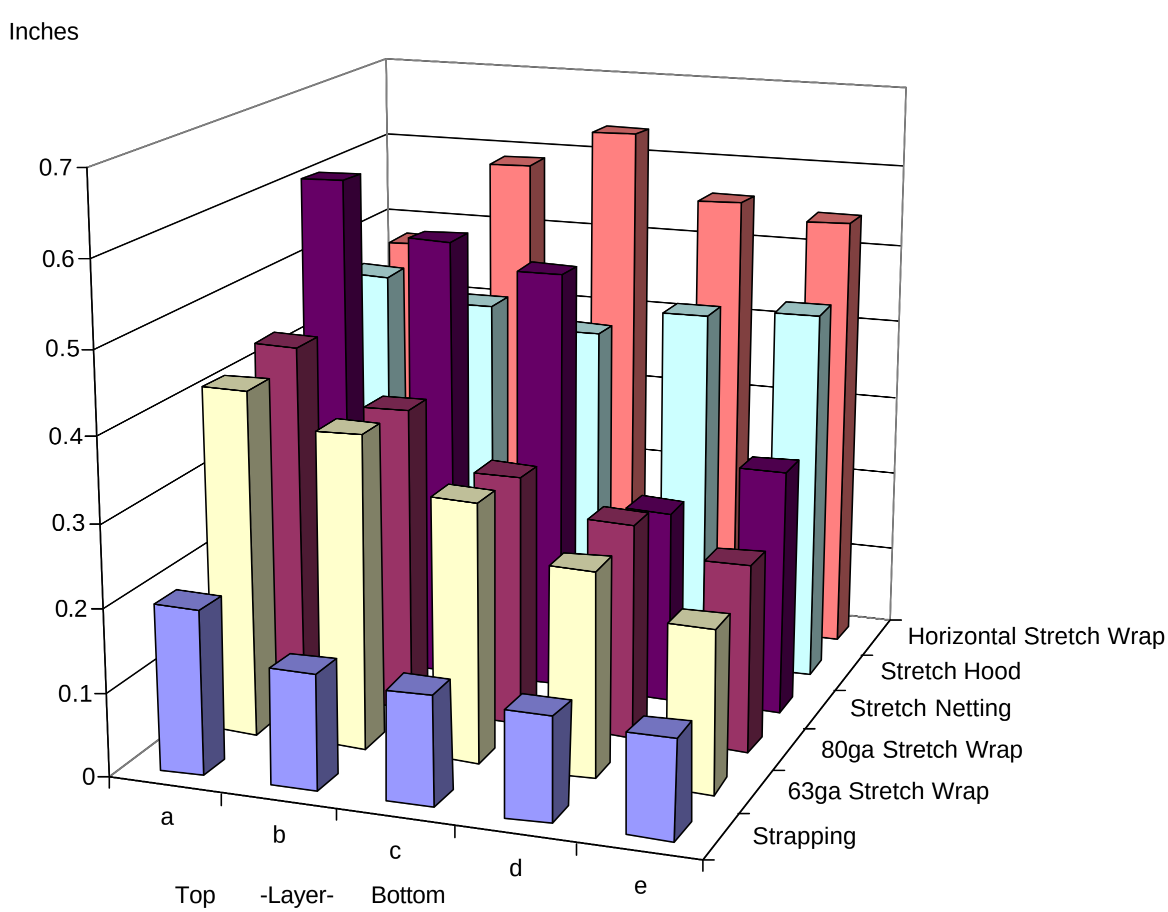
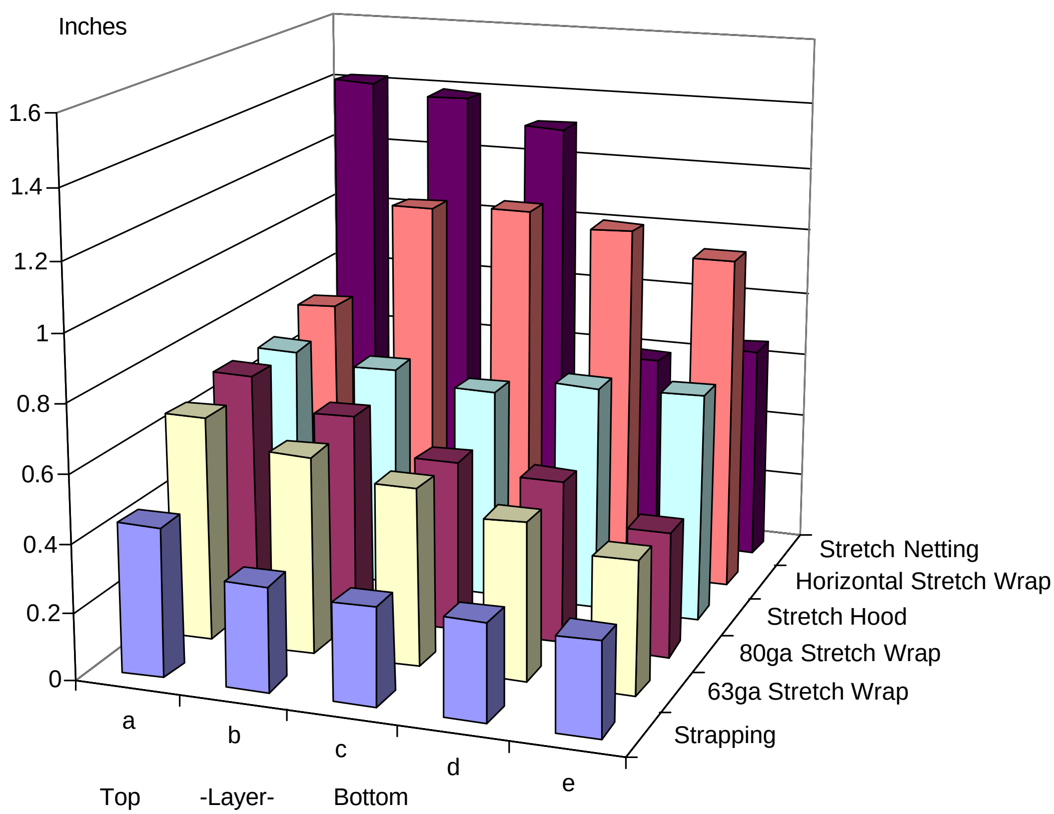


Figure 6.7 CAMD During Vibration Testing of Preliminary Stabilizers

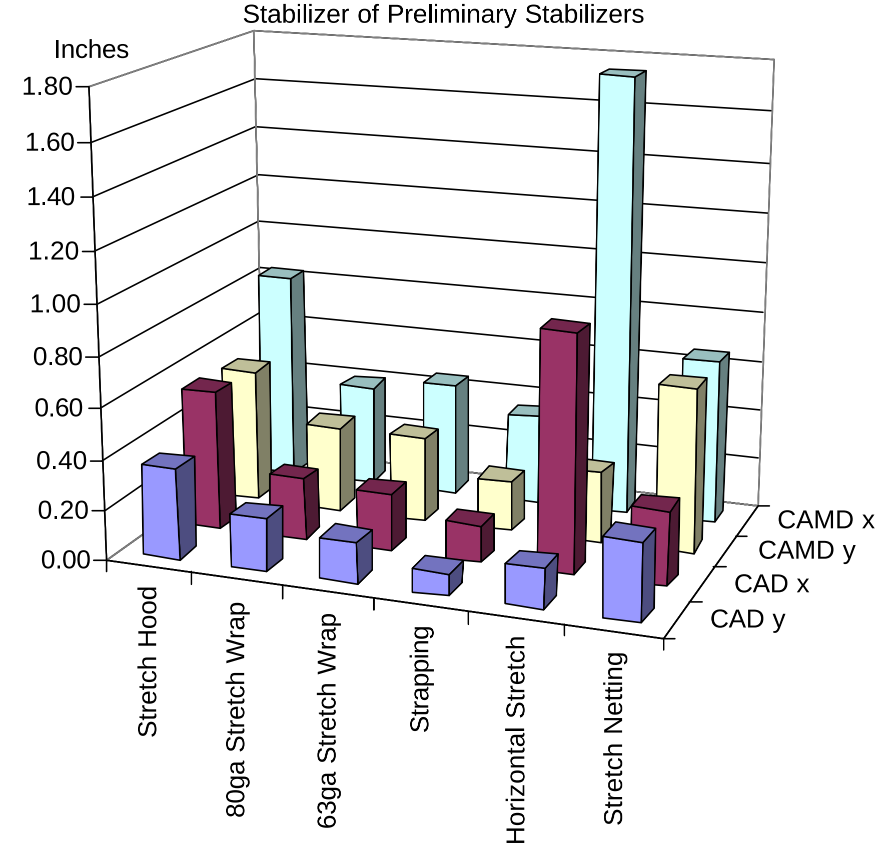


Overall, the displacements during vibration testing were larger for the preliminary stabilizers. The amount of displacement that occurred in CAD and CAMD for horizontal stretch wrap and stretch netting was 1.11" and 1.4" respectively.

Pallet-Container Displacement

Figure 6.8 compares horizontal stretch wrap and stretch netting with the stabilizers tested in Section 4.0. The amount of displacement which occurred in the stretch netted test unit was equivalent to that of the stretch hooded test units, about 0.3" and 0.61" for CAD and CAMD respectively. The displacement in the horizontally wrapped load was very directional. In direction "y," which was perpendicular to the direction of the wrap, the amount of displacement was equivalent to the other stretch wrapped test units at just under 0.4”. However, in direction “x,” which was parallel to the direction of wrap, there was displacement of over 1.7”. As Ievans determined, this much overhang is very detrimental to the integrity of the test unit (Ievans, 1974). This displacement discrepancy may have been caused by the lack of support of the stabilizer on the respective sides of the test unit.

Figure 6.8 Vibration Pallet Container-Displacement as a Function of Load Stabilizer of Preliminary Stabilizers



The discrepancy in directionality of the horizontal stretch wrap may have skewed the outcome of the average Container Displacement results. Due to the data reduction method used in container displacement, averages were taken between direction “x” and “y”. If only the average end results were reported, then the extreme differences in directionality would have been missed and an assumption would have been made that overall, horizontal stretch wrap was a poor load stabilizer. However, in the direction of wrap, this is far from true.

6.3.2 Impact Testing

Displacement that occurs in impact testing is typically bi-directional. However, since the test is designed to force the test unit to shift in one direction, the direction of impact, this direction was the only one analyzed. As discussed in Section 4.3.1, any negative displacement in the upper layers of the pallet may be associated with the load impacting the backstop of the testing apparatus. The pallet end impacted was noted for each test.

Container Displacement

Figures 6.9 and 6.10 compare the performance of horizontal stretch wrap and stretch netting, during impact testing, with the stabilizers tested in Section 4.0 through CAD and CAMD respectively. In CAD and CAMD, the horizontal stretch wrapped test unit performed as well as the stretch hooded test units, which was the best performer in Section 4.0. The stretch netted test unit was the worst performer by a significant order of magnitude over its closest competitor, 63ga stretch wrapped test units.

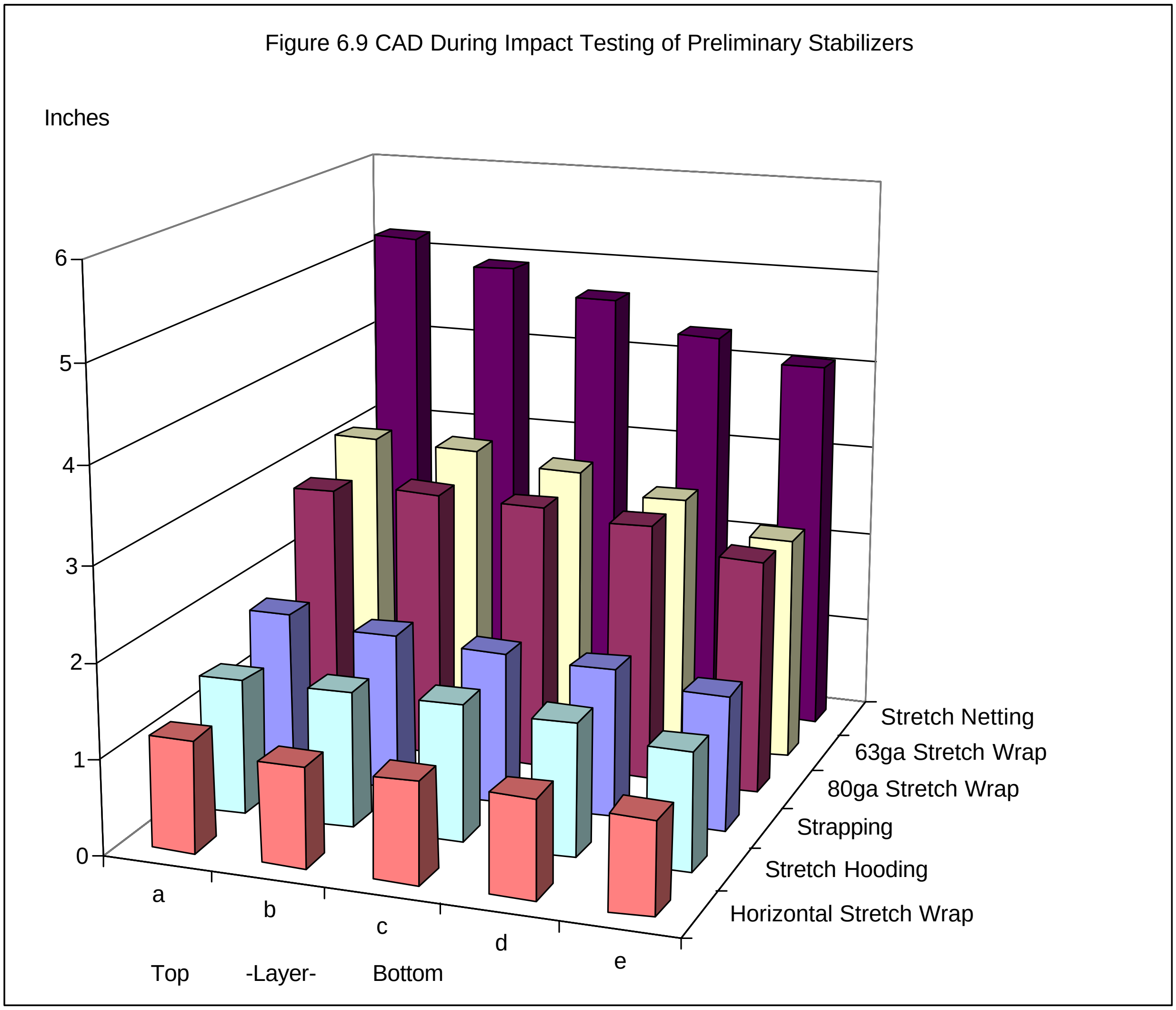
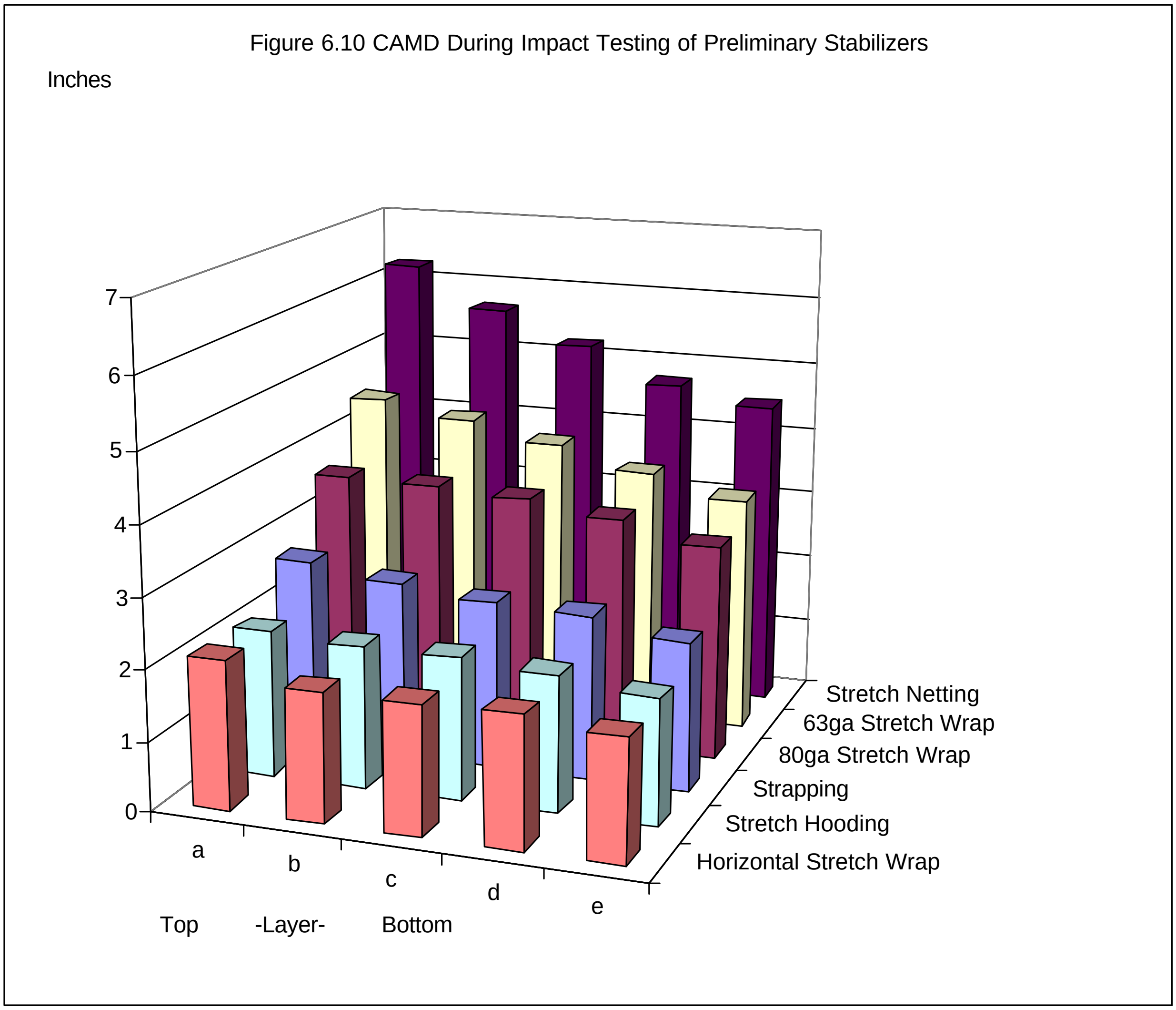


Figure 6.9 CAD During Impact Testing of Preliminary Stabilizers
Inches
6
5
4
3
2
1
0
a
b
c
d
e
Top
-Layer-
Bottom
Stretch Netting
63ga Stretch Wrap
80ga Stretch Wrap
Strapping
Stretch Hooding
Horizontal Stretch Wrap



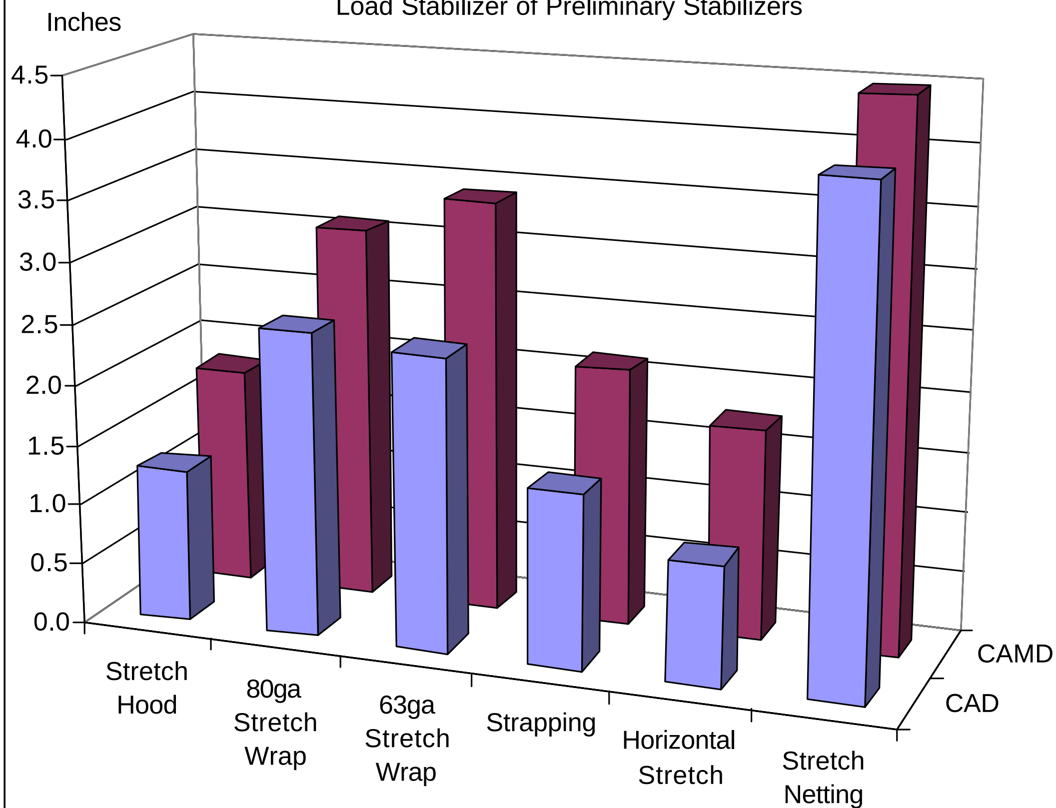
Overall, the displacements during impact testing were significant. The amount of displacement that occurred in CAD for the horizontally stretch wrapped test unit was only an inch, whereas the displacement that occurred in the stretch netted test unit was around 5”. Displacement in CAMD was around 2” and 6” for the horizontally stretch wrapped test unit and stretch netted test unit respectively.

Pallet-Container Displacement

Figure 6.11 compares horizontal stretch wrap and stretch netting to the stabilizers tested in Section 4.0. The amount of displacement which occurred in the horizontally stretch wrapped test unit was equivalent to the strapped test units in Section 4.0, around 1” and 1.7” for CAD and

CAMD respectively. The stretch netted test unit was the worst performer when compared to the stabilizers in Section 4.0. The amount of displacement was an order of magnitude larger, 1" greater, than the displacement that occurred in the 63ga stretch wrapped test units. This large amount of movement may have been caused by the lack of containment force exerted by the stretch netting. As Ievans determined, this much overhang is extremely detrimental to the integrity of the test unit. (Ievans, 1974)

Figure 6.11 Impact Pallet-Container Displacement as a Function of Load Stabilizer of Preliminary Stabilizers



6.4 SUMMARY AND CONCLUSIONS

6.4.1 Summary of Results

Summary tables of testing results are shown below. 100% effectiveness indicates the best performing stabilizer. The percentages are based of the best performing stabilizer as a benchmark.

Table 6.2 Vibration Testing Results of Preliminary Stabilizers

Container Displacement CAD	Relative Effectiveness	Container Displacement CMAD	Relative Effectiveness
Strapping	100%	Strapping	100%
63ga stretch wrap	47%	63ga stretch wrap	66%
80ga stretch wrap	45%	80ga stretch wrap	62%
Stretch hood	39%	Stretch hood	60%
Stretch netting	32%	Stretch netting	43%
Horizontal stretch wrap	30%	Horizontal stretch wrap	38%
Pallet Container Displacement CAD	**Relative Effectiveness**	**Pallet Container Displacement CAMD**	**Relative Effectiveness**
Strapping	100%	Strapping	100%
63ga stretch wrap	60%	80ga stretch wrap	75%
80ga stretch wrap	52%	63ga stretch wrap	71%
Stretch netting	39%	Stretch netting	42%
Stretch hood	26%	Stretch hood	41%
Horizontal stretch wrap	22%	Horizontal stretch wrap	27%
Amplitude	**Relative Effectiveness**		
Strapping	100%		
Stretch hood	99%		
63ga stretch wrap	97%		
Stretch netting	95%		
80ga stretch wrap	94%		
Horizontal stretch wrap	78%		

Table 6.3 Impact Testing Results of Preliminary Stabilizers			
Container Displacement CAD	Relative Effectiveness	Container Displacement CMAD	Relative Effectiveness
Horizontal stretch wrap	100%	Stretch hood	100%
Stretch hood	81%	Horizontal stretch wrap	99%
Strapping	66%	Strapping	78%
80ga stretch wrap	41%	80ga stretch wrap	58%
63ga stretch wrap	38%	63ga stretch wrap	47%
Stretch netting	23%	Stretch netting	34%
Pallet Container Displacement CAD	Relative Effectiveness	Pallet Container Displacement CAMD	Relative Effectiveness
Stretch hood	100%	Horizontal stretch wrap	100%
Strapping	88%	Stretch hood	97%
Stretch netting	88%	80ga stretch wrap	82%
Horizontal stretch wrap	52%	Strapping	57%
63ga stretch wrap	52%	63ga stretch wrap	51%
80ga stretch wrap	50%	Stretch netting	39%

6.4.2 Conclusions

The goal of this exercise was to measure and compare load shift and container displacement in test units that were stabilized with horizontal stretch wrap and stretch netting. Because only one test unit was used per ASTM test, the results are preliminary. More research should be conducted on these stabilizers before results are utilized in real world application. The results were:

Vibration Testing

- Container Displacement: Stretch netting and horizontal stretch wrap performed with similar results, both were poor performers in comparison with the other load stabilizers.
- Pallet Container Displacement: Stretch netting performed better than stretch hooding, but worse than the stretch wrapped test units. Horizontal stretch wrap was the worst average performer of all stabilizers tested. However, the large displacement discrepancy between direction “x” and “y’ should be noted.

- Transmissibility: Stretch netting performed better than the 80ga stretch wrapped test units, but worse than the 63ga stretch wrapped test units. Horizontal stretch wrap was the worst performer of all stabilizers tested.

Impact Testing

- Container Displacement: Horizontal stretch wrap performed better than stretch hooding, which was the best performer in Section 5. Stretch netting was the worst performer of all the stabilizers tested.
- Pallet Container Displacement: Horizontal stretch wrap performed in approximately the 75th percentile and stretch netting performed approximately in the 63rd percentile when averaging CAD and CAMD.

6.4.3 Discussion

Stretch Netting

Stretch netting did not have the containment force of the other stabilizers because of its inability to properly feed through the stretch wrapping applicator's carriage and its lack of stretch. However, in proper application, the stretch netting used would have likely achieved similar containment forces to the stabilizers in Section 4.

The containment force that was applied may have been enough to hold a unit load together when exposed to average vibration forces, but it was not enough to hold the load during larger impact forces.

Horizontal Stretch Wrap

Horizontal stretch wrap offered a large amount of vertical containment, something that none of the other stabilizers offered. The results from the preliminary tests indicated that in the direction of wrap, horizontal stretch wrap offered excellent protection in vibration and impact testing. Wrapping in both directions may improve the stabilizers performance.

However, because the wrapping pattern calls for stretch wrap to be in contact with the floor, the integrity of the stabilizer is in constant jeopardy of being cut off by careless material handlers that do not pick the load fully off the ground.

Horizontal stretch wrap was originally slated to be included in the primary testing of this experiment. Five test units were initially shipped to Lantech, where new test containers and test units were assembled. The test units were labeled appropriately, wrapped with their Lan-Ringer, and shipped back to The Center for Unit Load Design at Virginia Tech for testing. A photograph of one of the test units coming off the Lan-Ringer at Lantech is shown in Figure 6.12.

Figure 6.12 Photograph of a Horizontal Stretch Wrapped Test Unit Coming Off The Lang-Ringer at Lantech

The test units where shipped with an extra layer of stretch wrap, applied around all four sides (parallel to the floor), for additional support. They where shipped by a common LTL carrier. When the test units arrived at Virginia Tech, the excess layer of stretch wrap was removed from the test units. Upon inspection, the test units had experienced excessive damage to the horizontal wrap during shipping. It appeared that the loads had been dragged across the floor, cutting the wrap off the bottom of the pallet as seen in the photograph in Figure 6.13.

Figure 6.13 Photograph of a Damaged Horizontally Stretch Wrapped Test Unit

Testing was not completed on these loads due to the lack of stability the horizontal stretch wrap provided (units tested with horizontal stretch wrap were wrapped by hand as outlined in Section 6.2.2.1). Although this was detrimental to the original research plan, it acted as a test in and of itself. Five out of five of the test units shipped arrived with so much damage to the horizontal wrap, that the wrap was not able to stabilize the units.

Given this real world account, due consideration should be made when utilizing horizontal stretch wrap in an LTL environment.

7.0 PROOF OF CONCEPT

7.1 Introduction

The method used in this study to measure displacement in the test units was encumbered by human error, inherent in the process. In looking for a more efficient and accurate method to quantify displacement within a unit load, The Center for Unit Load Design at Virginia Tech turned to modern optical 3D scanning technology. Since using this technology to measure displacement in all of the test units in Sections 4 and 6 was cost prohibitive, two independent test units were selected, one per ASTM test, to determine the viability of this new technology.

7.2 Background

The process is capable of a digital spatial analysis of solid objects that would facilitate quantifying the displacement of a test unit. The 3D scanning picks up millions of different points that represent an image of the outside of the test unit. When these points are assembled in a CAD system, they are called a point cloud. This cloud is the 3D image of the test unit. The comparisons of the clouds, before and after testing, can determine displacements that occurred during testing to a tenth of a millimeter.

M. F. Inspect (www.mfinspec.com) scanned the test units and completed the point cloud analysis. For a full outline of the process see Section 7.4.

7.3 Material

Two pallets of Zephyrhills water bottles where used. Each case of water contained thirty-five half liter bottles, while the test unit contained sixty cases. Each test unit was stabilized using a stretch hood.

7.4 Method

After receiving the water pallets at The Center for Unit Load Design, a team from M.F. Inspect applied a coating of opaque aerosol to the exterior of both stretch hooded test units. A photograph of the test unit with opaque substance on the stretch hood is shown in Figure 7.1.

Figure 7.1 Photograph of the Test Unit with Opaque Substance on the Stretch Hood

M.F. Inspect then used ScanWork's portable 3D scanning system and Perceptron's 3D scanning technology coupled with Innovmetric software to scan, import, and view the point cloud. Vibration and impact testing was then conducted as outlined in Sections 3.3.1 and 3.3.2 respectively. When testing was completed, M.F. Inspect scanned the test units again.

At this point, the team returned to M.F Inspect headquarters to complete the point cloud comparisons and analysis of the cross sections which were specified.

7.5 Results

The images below were provided by M.F. Inspect, who also supplied a data CD Rom containing the point cloud data. They show a comparison of a before testing scan and an after testing scan. The resultant color displayed correlates to the scale on the right. This scale identifies the magnitude of movement the test unit experienced due to testing. Figure 7.2 identifies where cross sections of measurement were taken on the test unit that was vibration tested and Figures 7.3 through 7.13 are the respective cross sections. Figure 7.14 identifies where the cross sections of displacement were taken on the impacted test unit and Figures 7.15 through 7.25 are the respective cross sections.

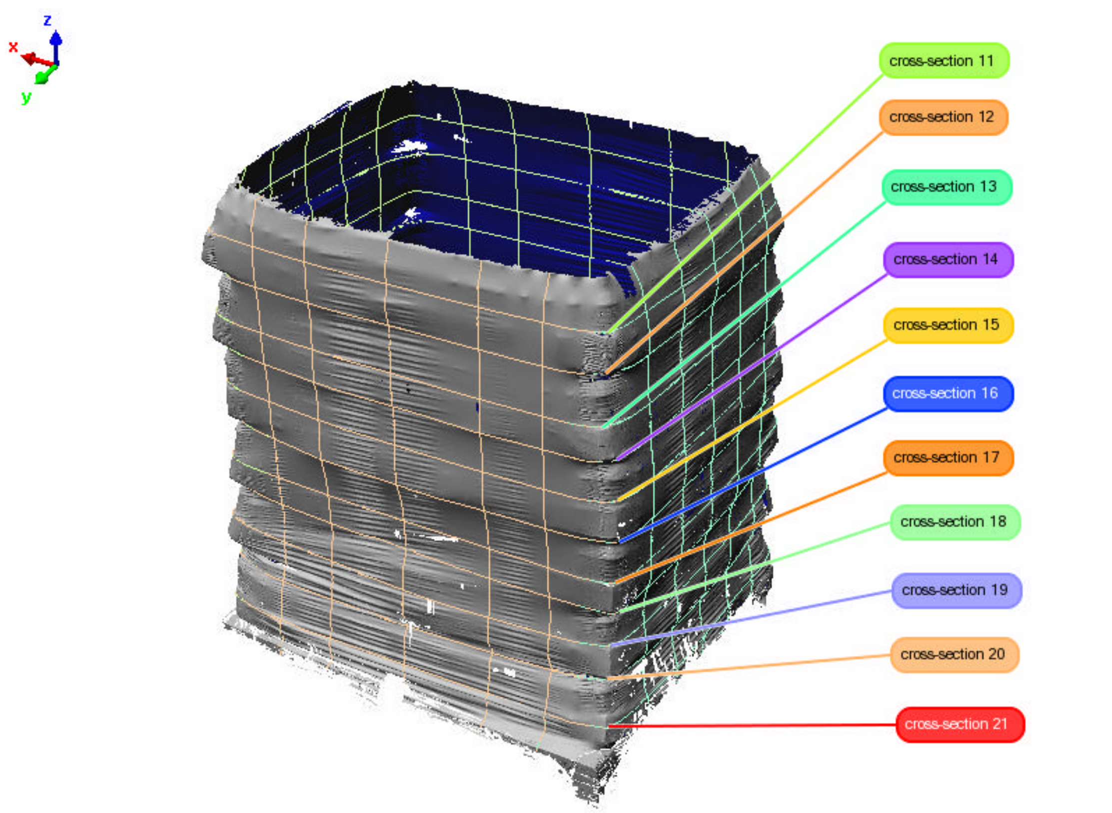


Figure 7.2 Identification of Where the Cross Sections Were Taken on the Vibrated Test Unit

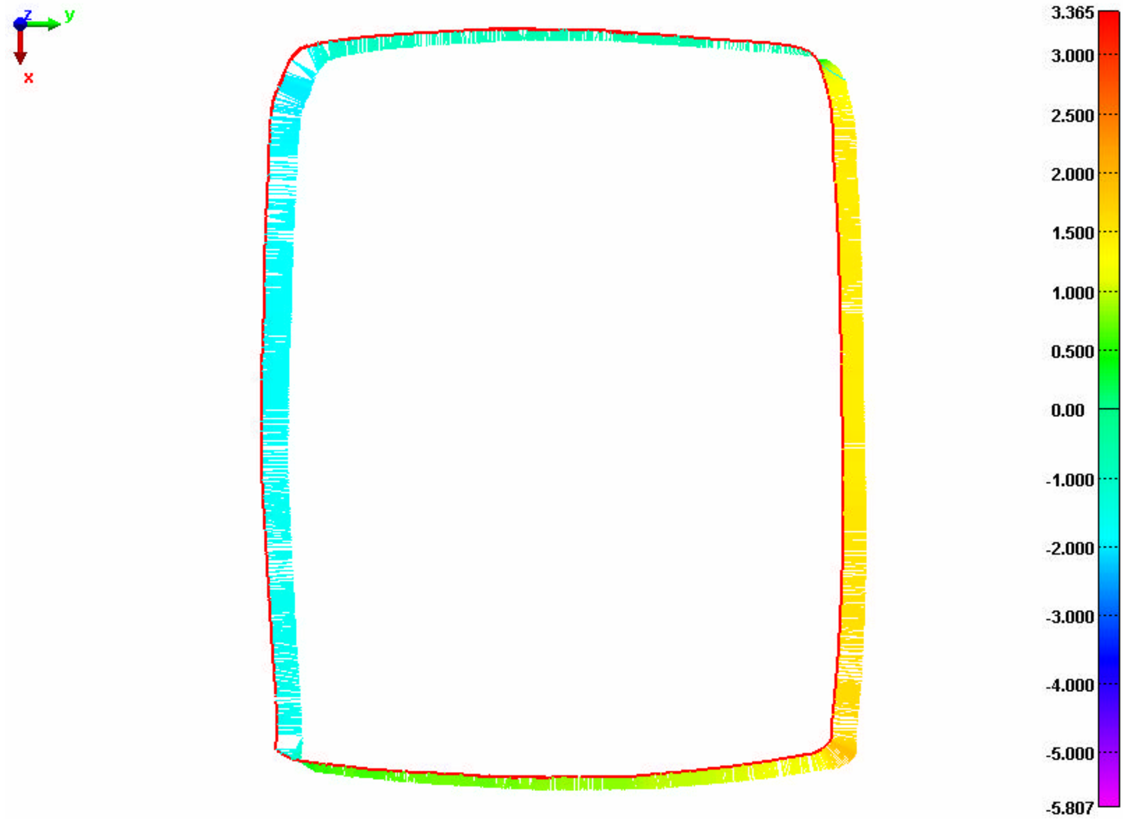


Figure 7.3 Cross Section #11

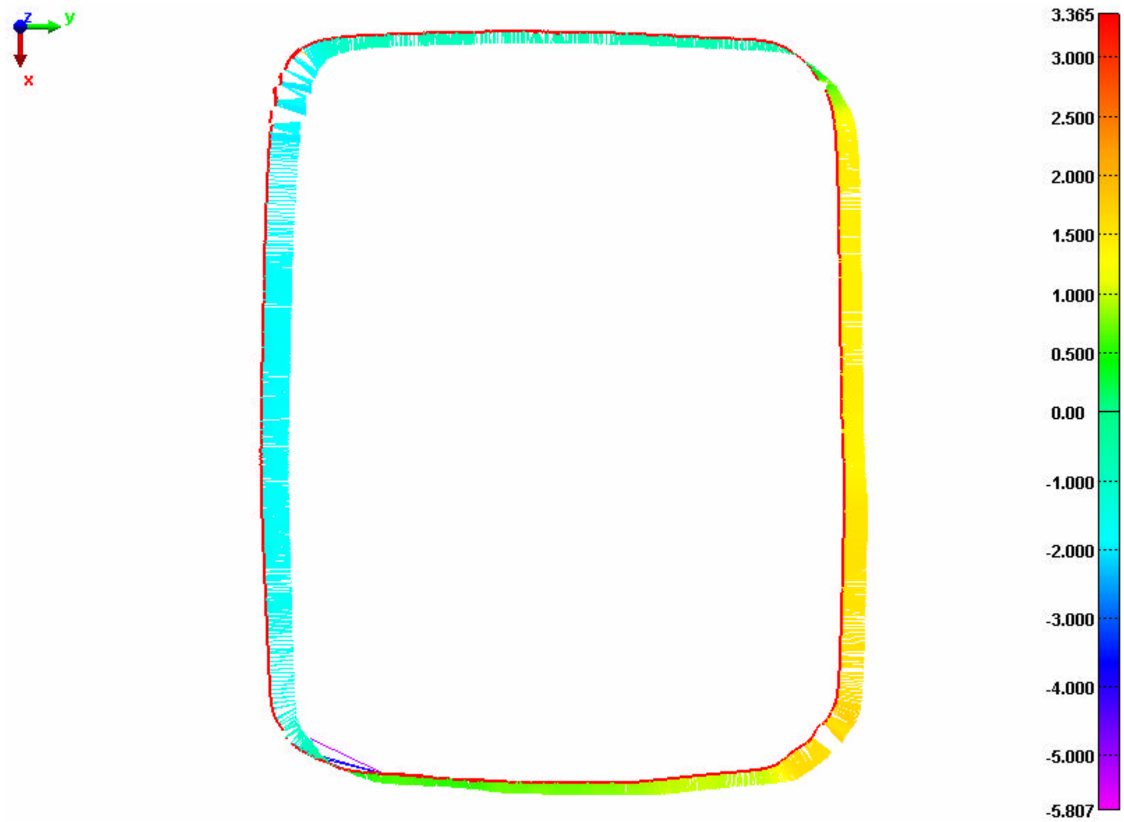


Figure 7.4 Cross Section #12

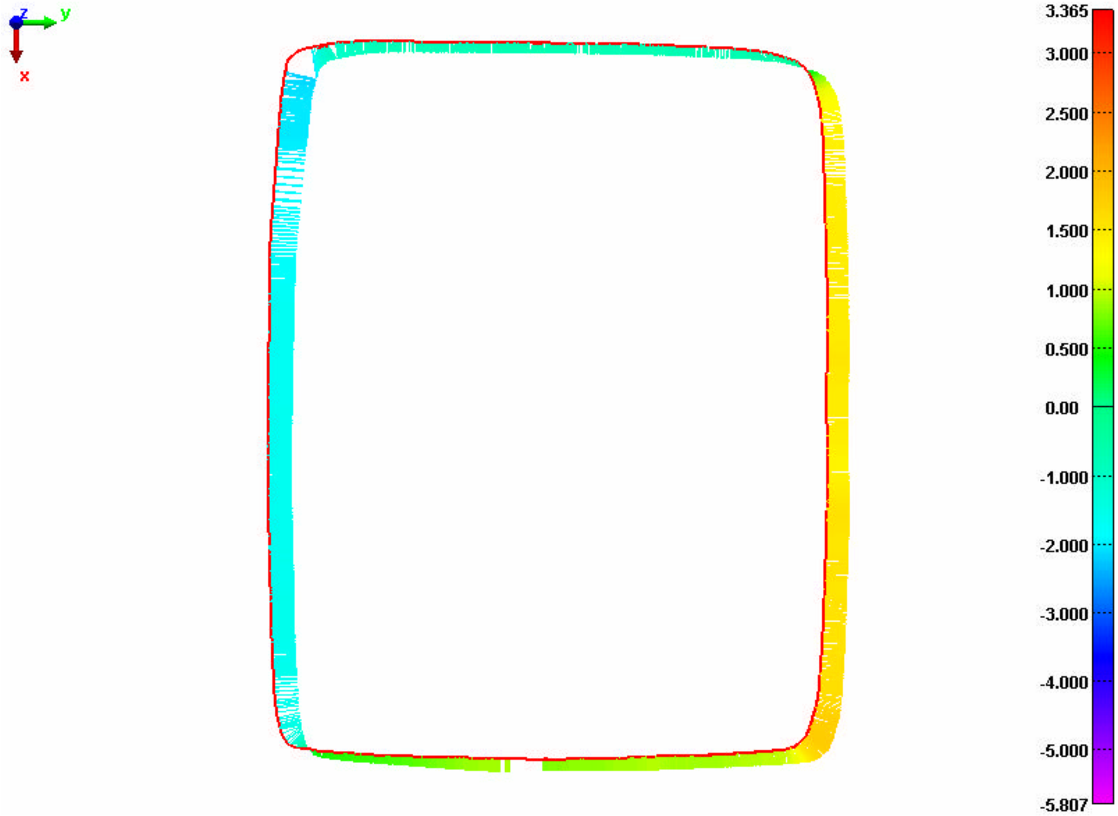


Figure 7.5 Cross Section #13

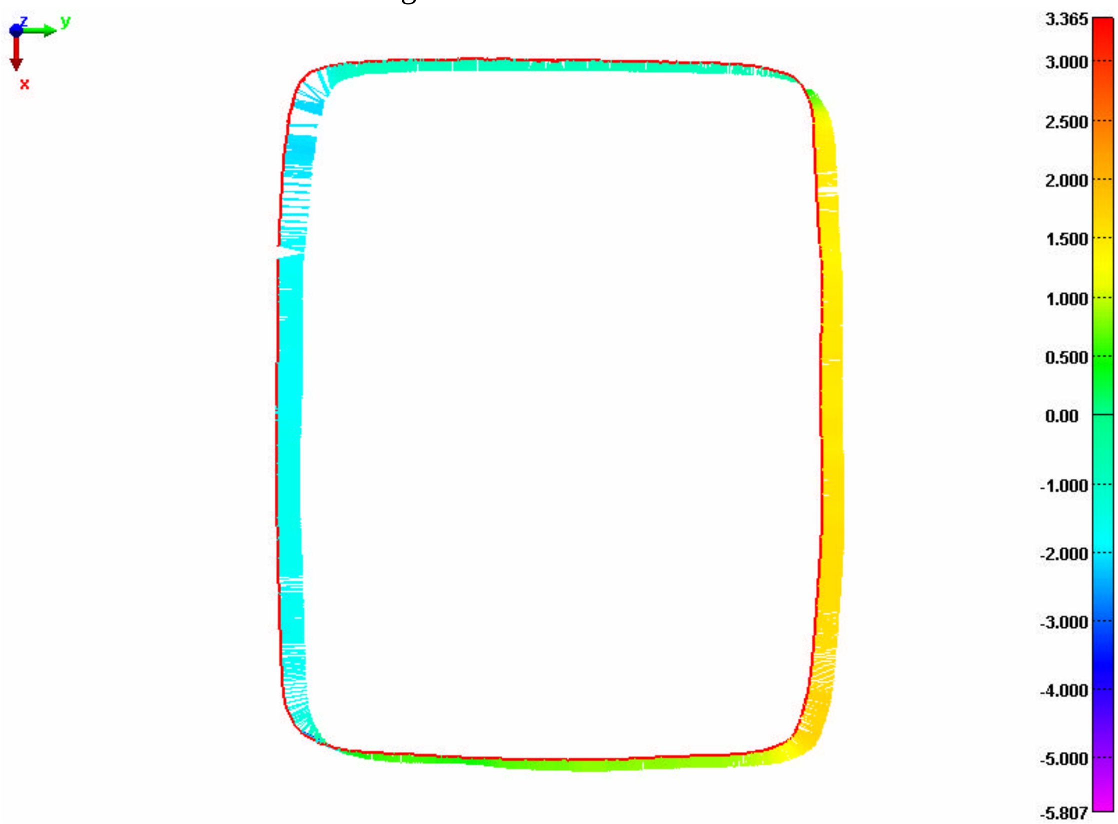


Figure 7.6 Cross Section #14

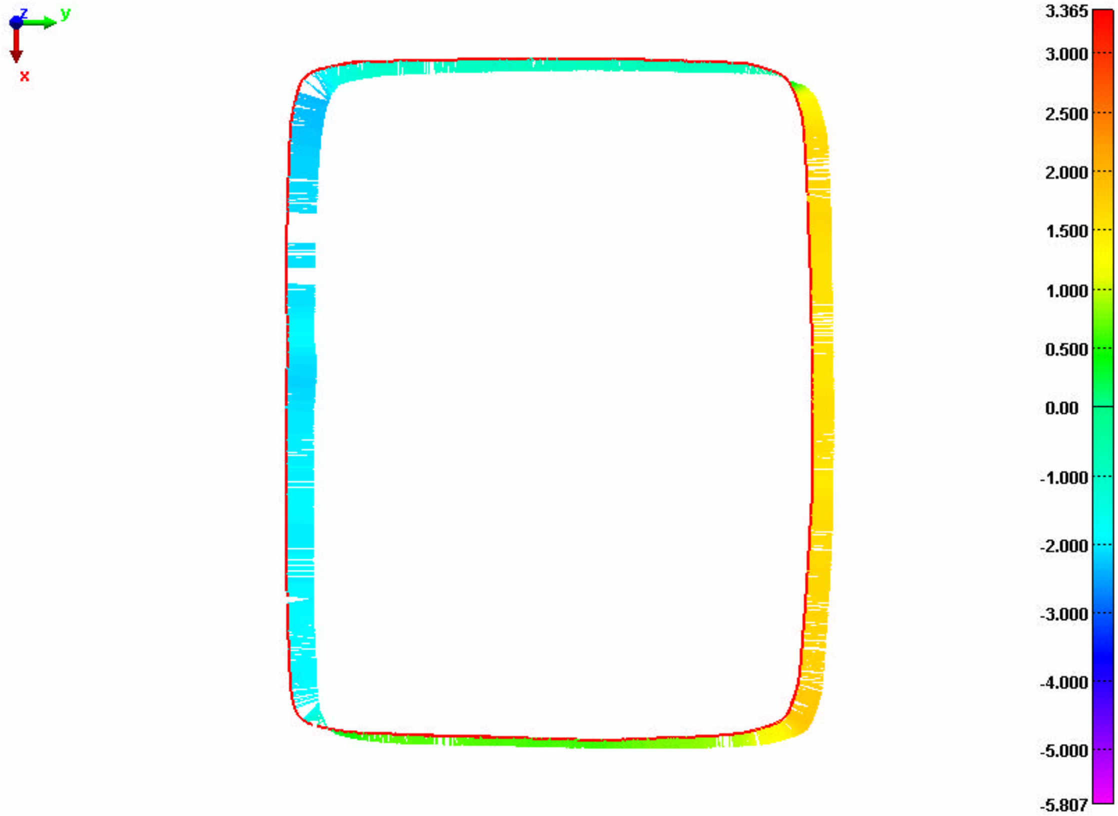


Figure 7.7 Cross Section #15

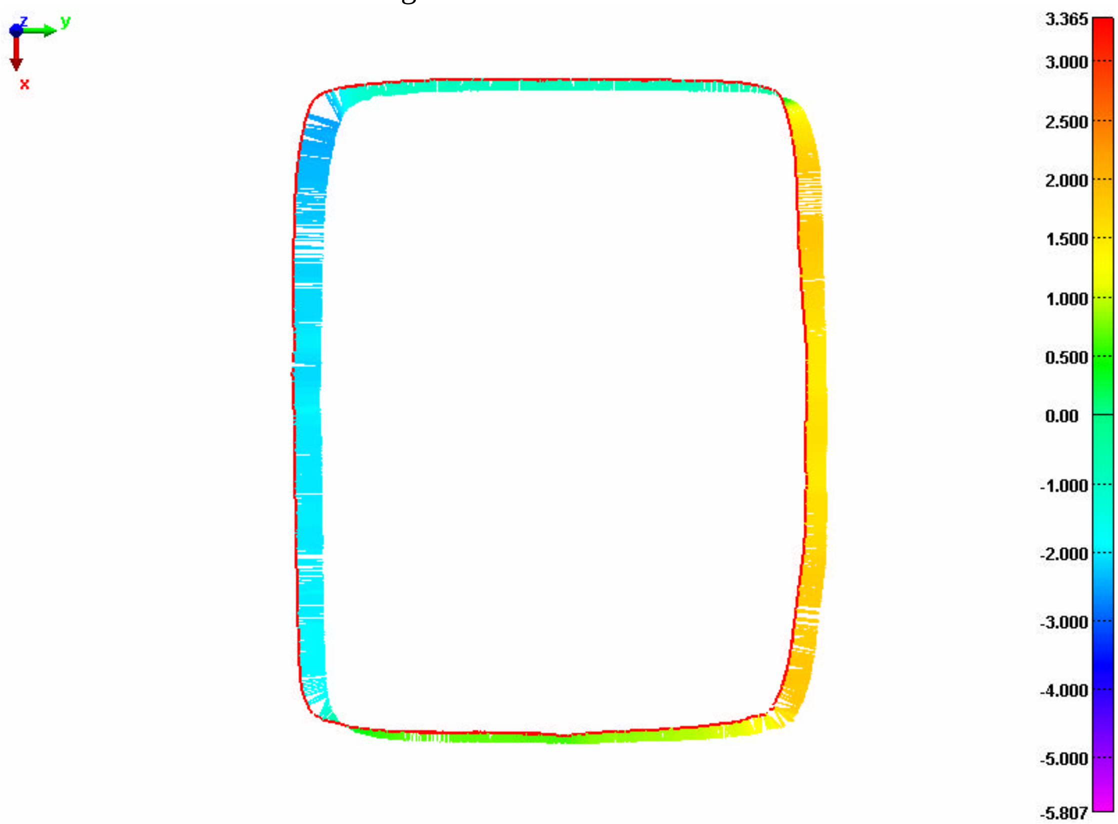


Figure 7.8 Cross Section #16

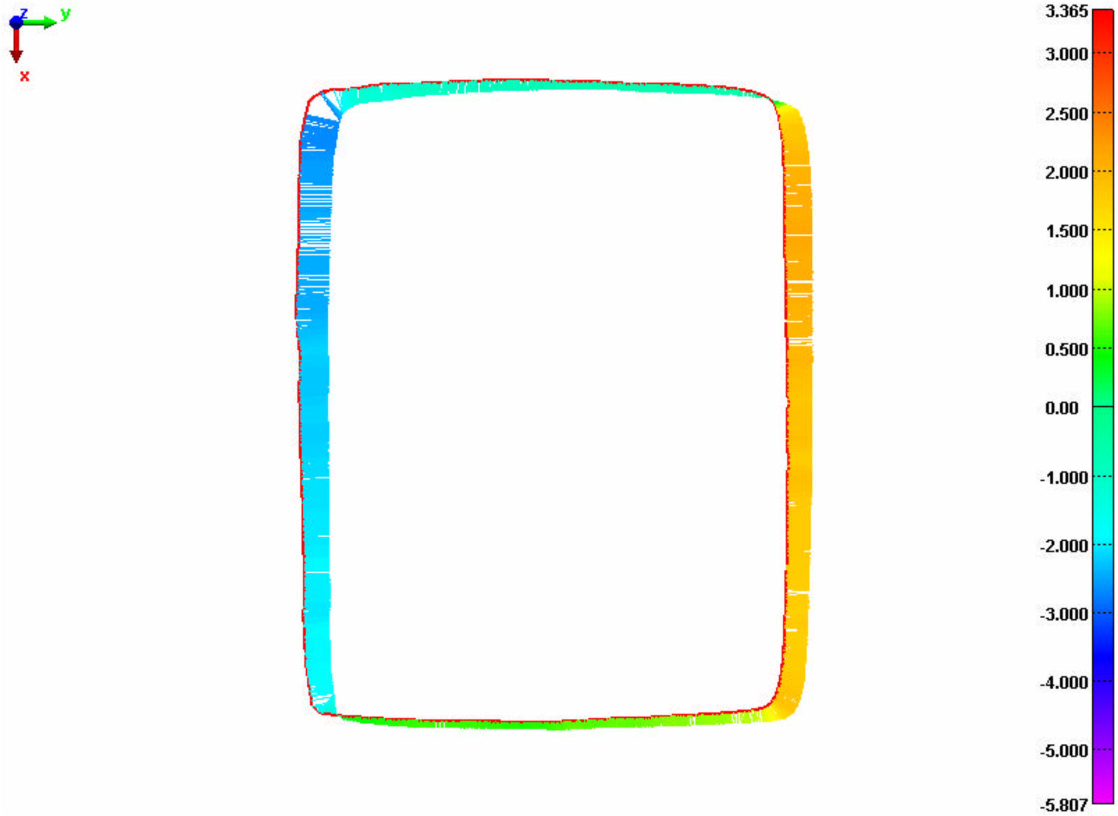


Figure 7.9 Cross Section #17

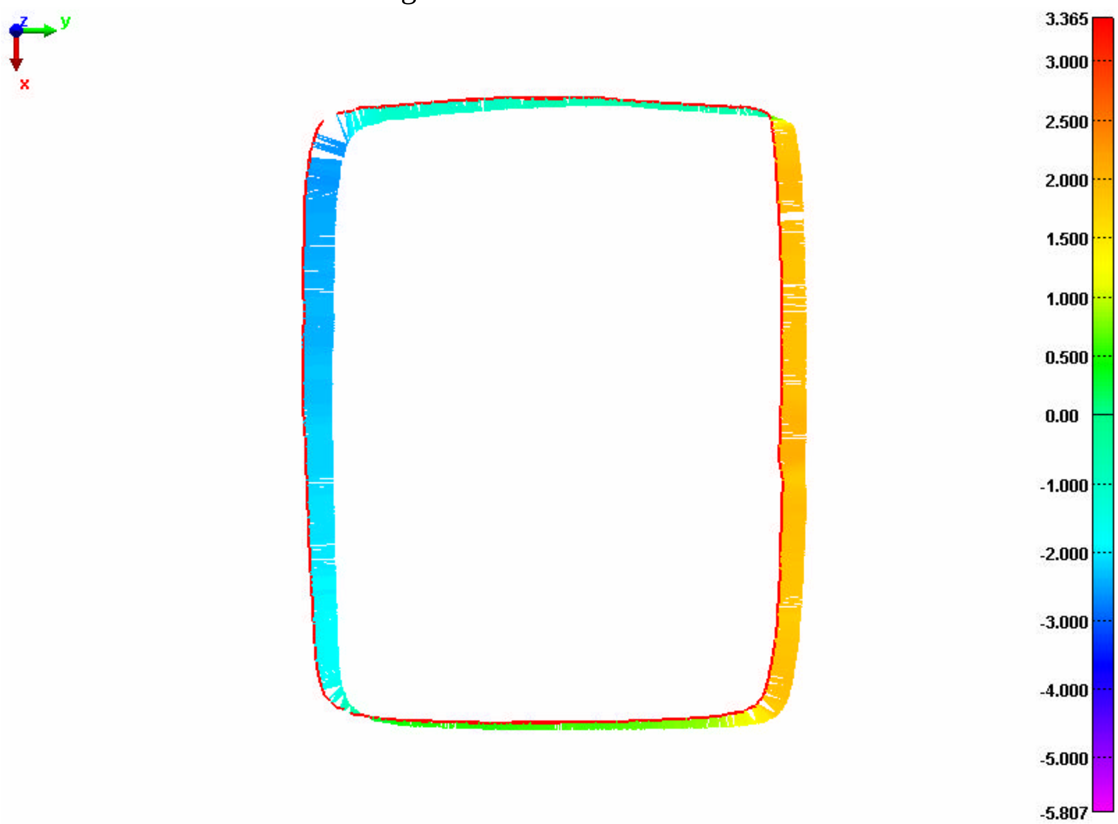


Figure 7.10 Cross Section #18

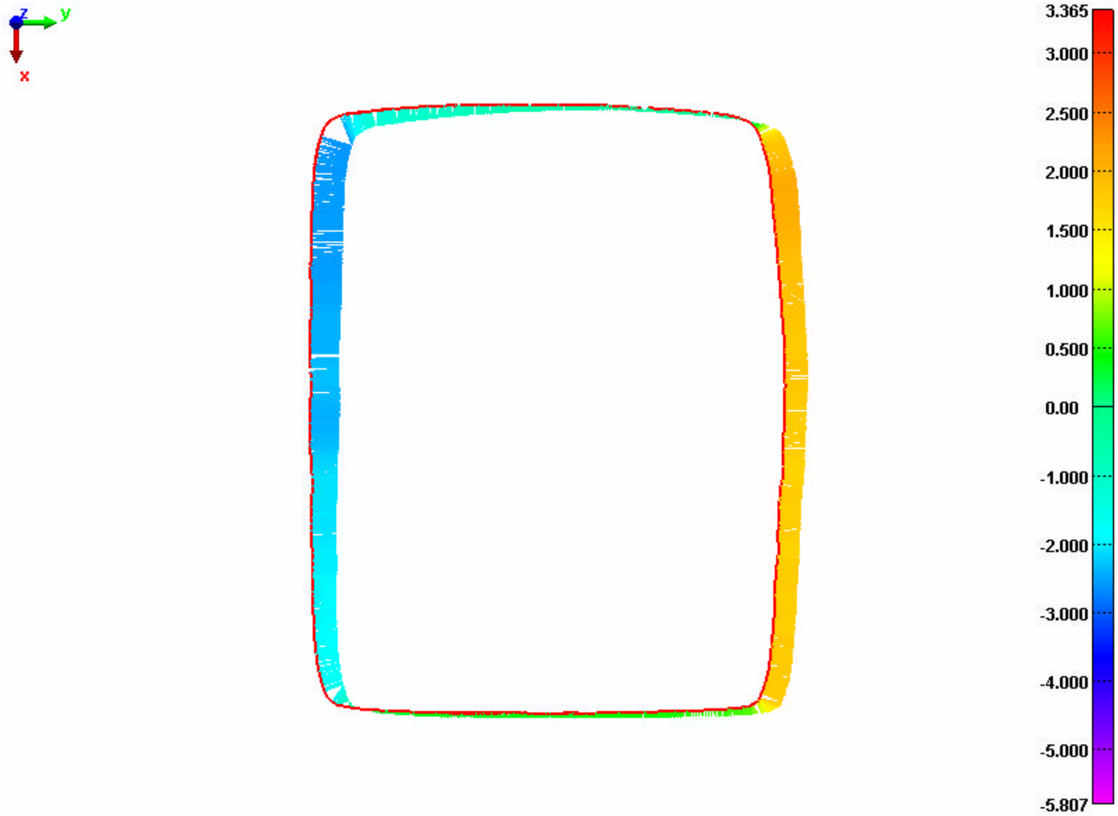


Figure 7.11 Cross Section #19

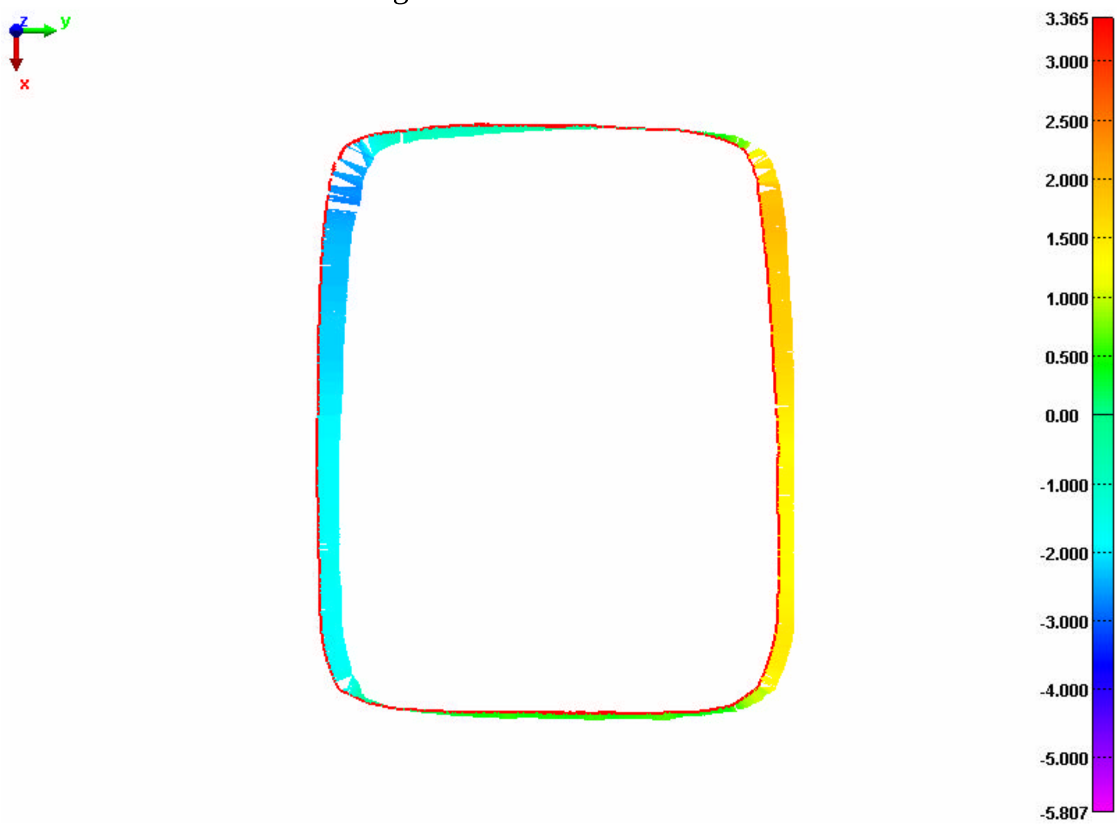


Figure 7.12 Cross Section #20

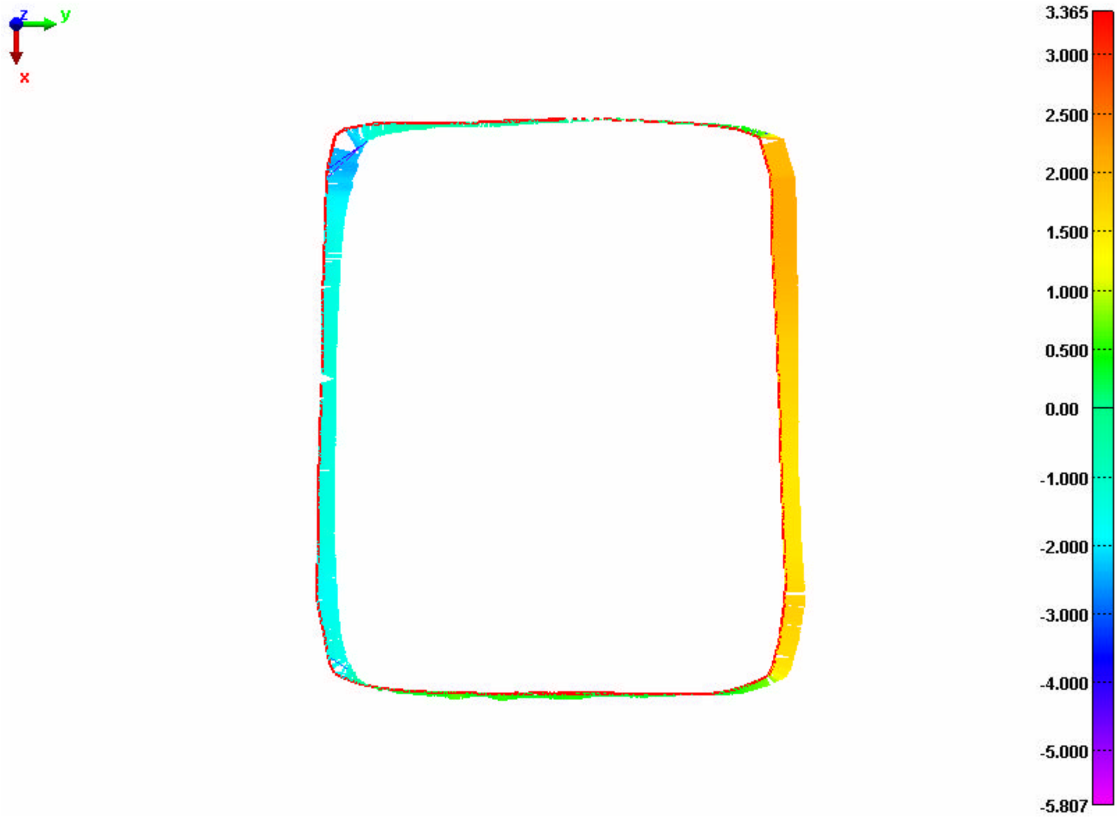


Figure 7.13 Cross Section #21

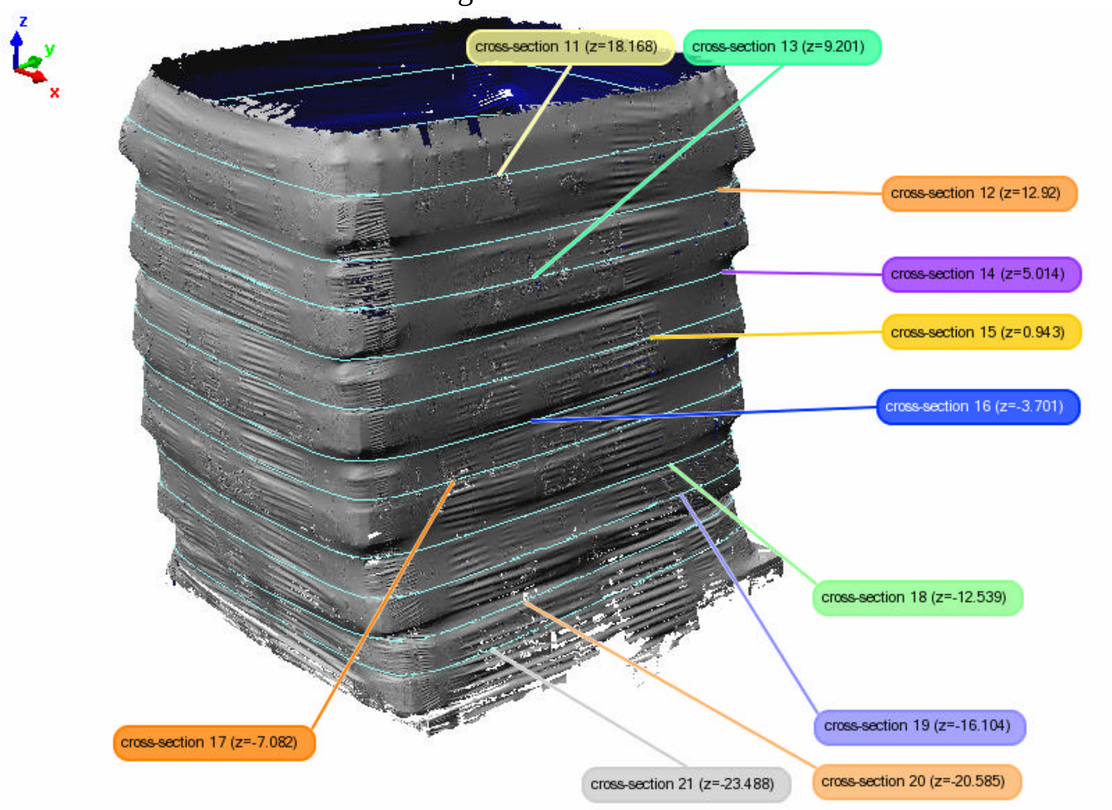


Figure 7.14 Identification of Where The Cross Sections Were Taken on the Impacted Test Pallet

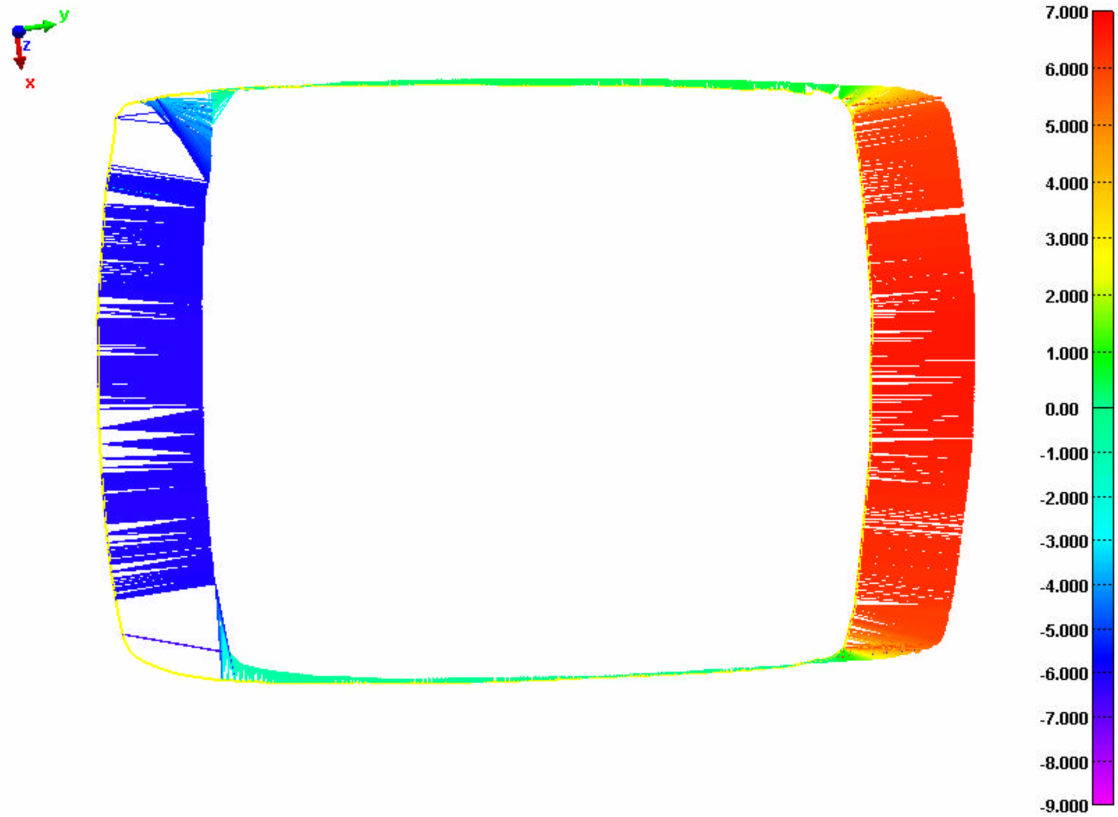


Figure 7.15 Cross Section #11

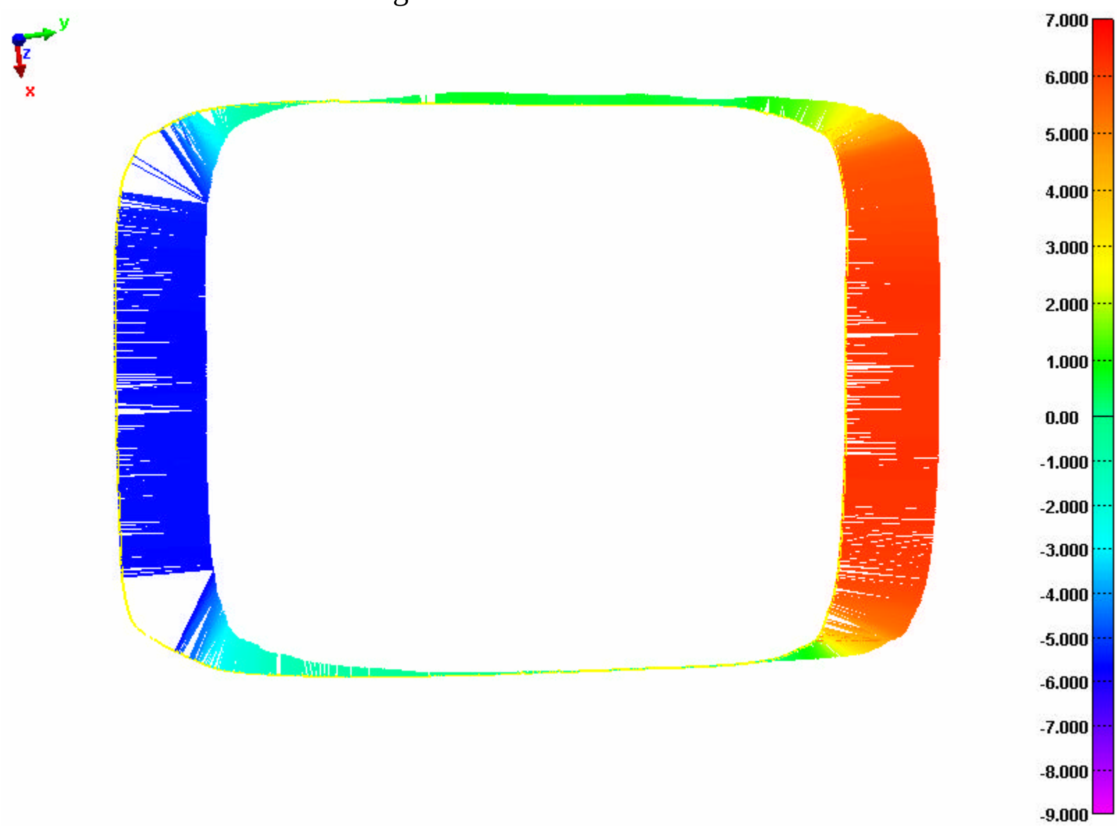


Figure 7.16 Cross Section #12

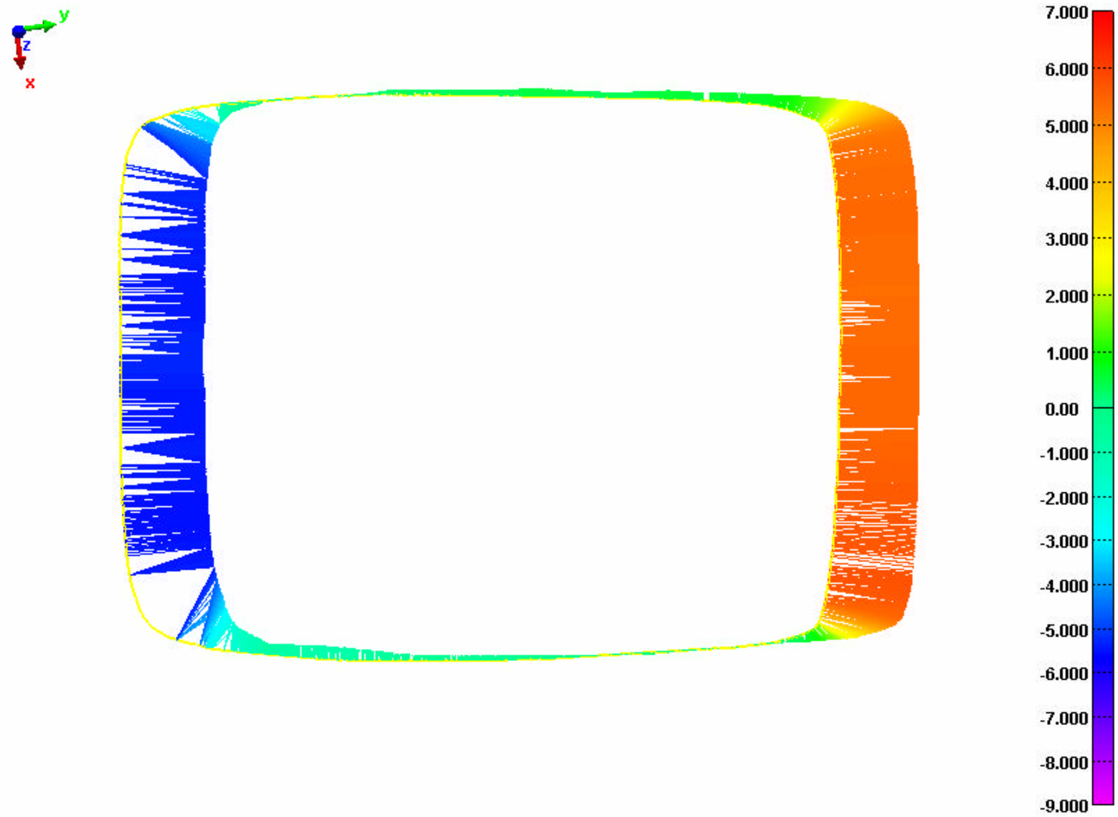


Figure 7.17 Cross Section #13

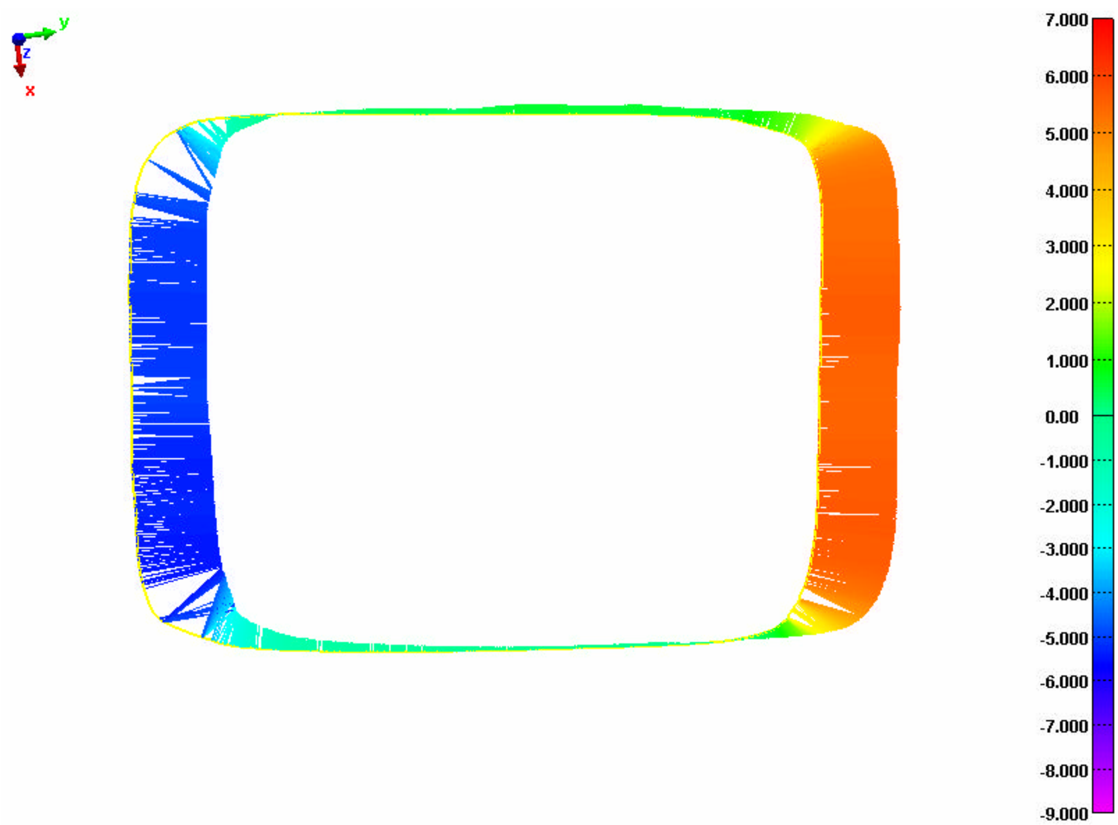


Figure 7.18 Cross Section #14

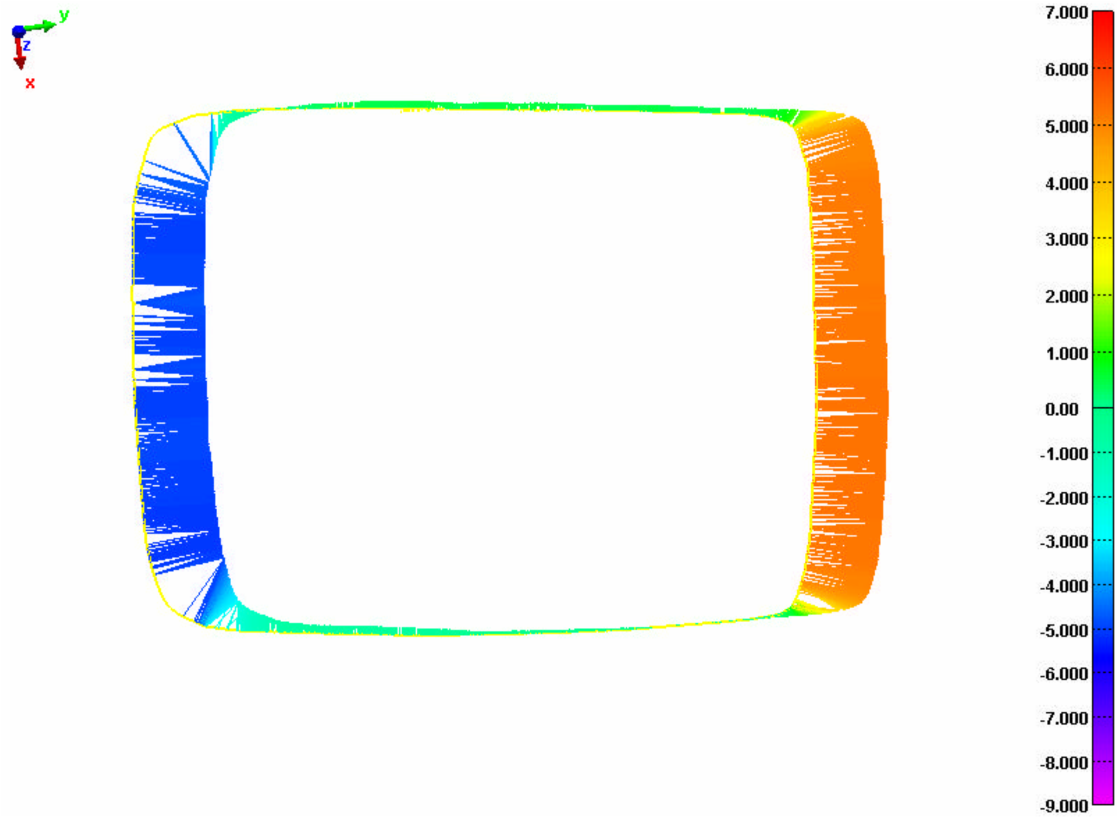


Figure 7.19 Cross Section #15

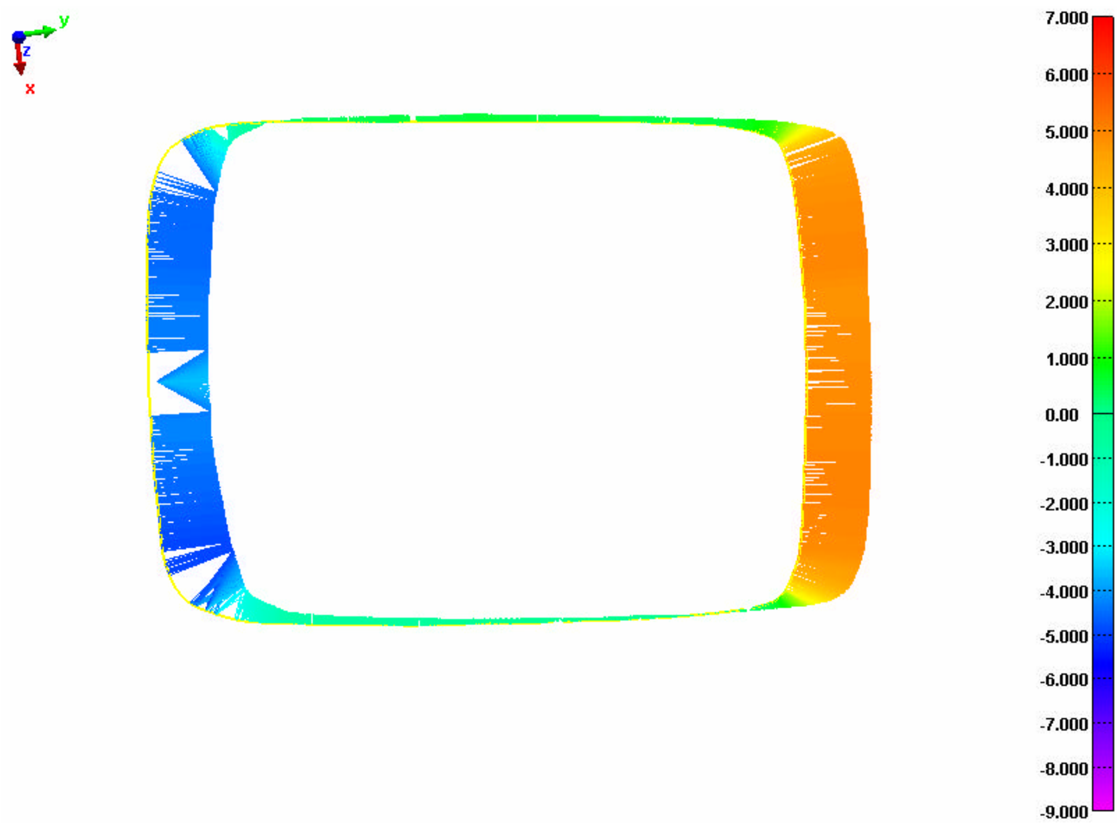


Figure 7.20 Cross Section #16

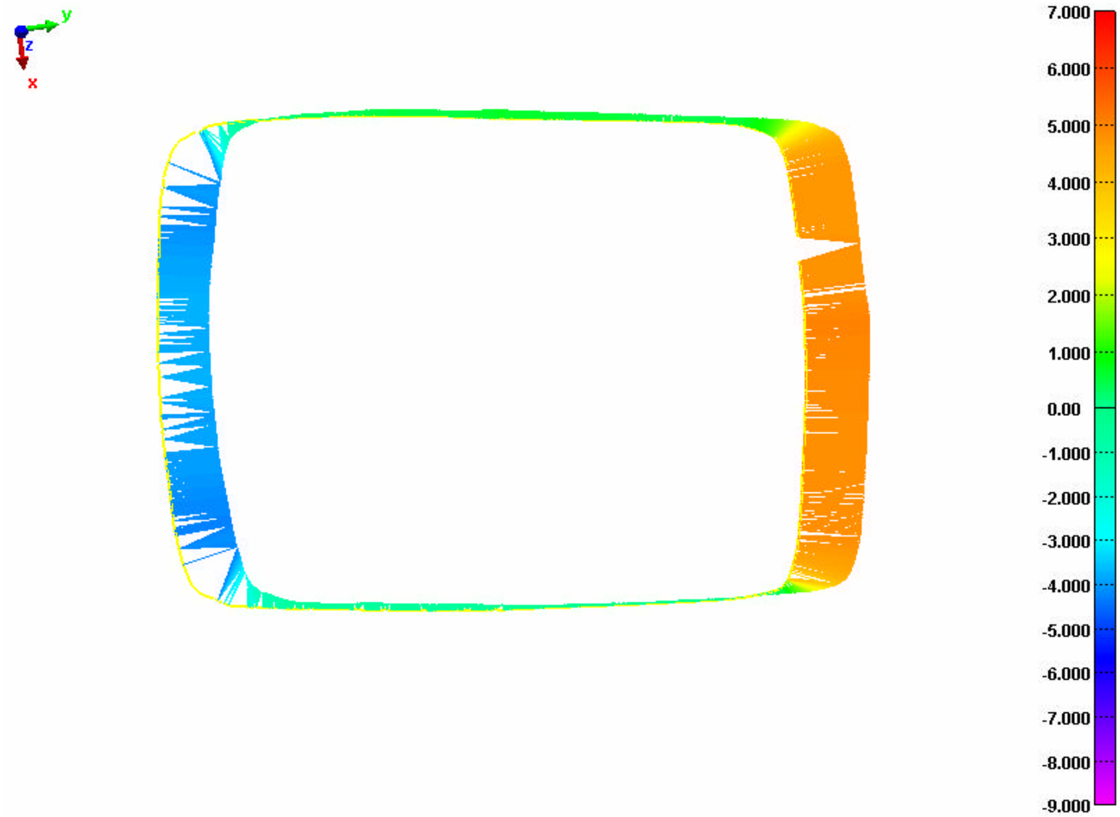


Figure 7.13 Cross Section #21

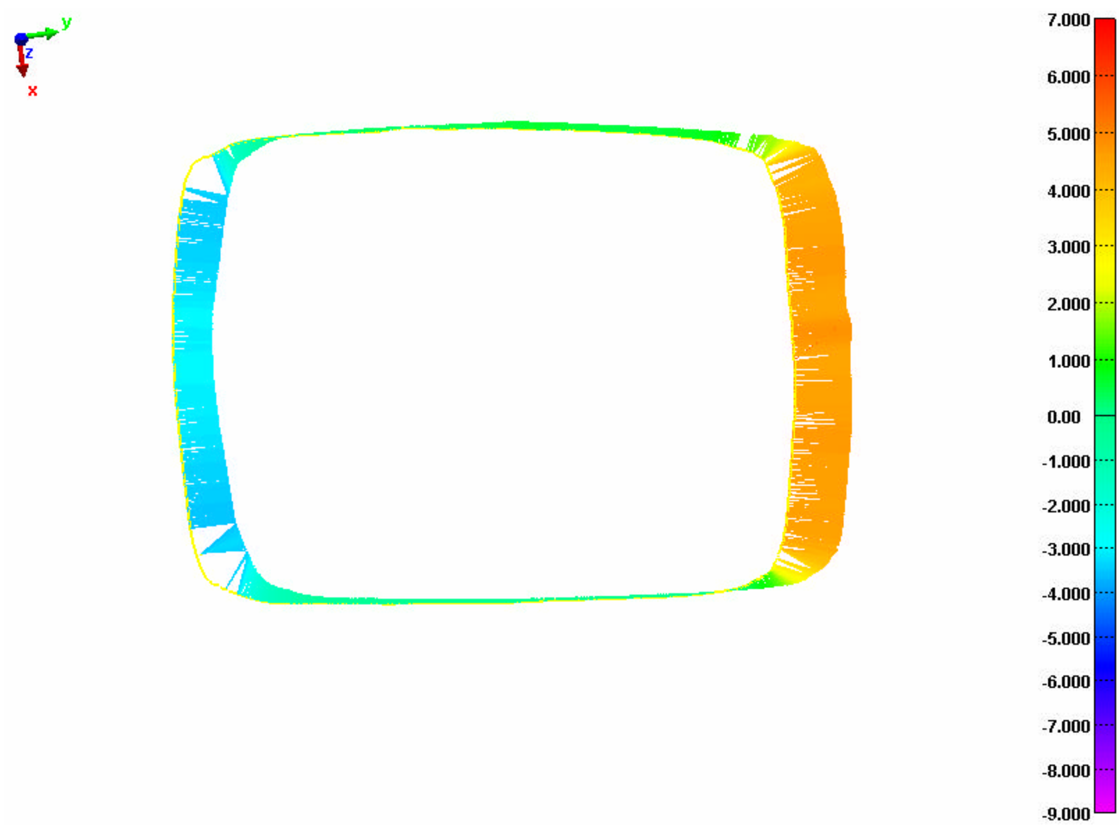


Figure 7.13 Cross Section #22

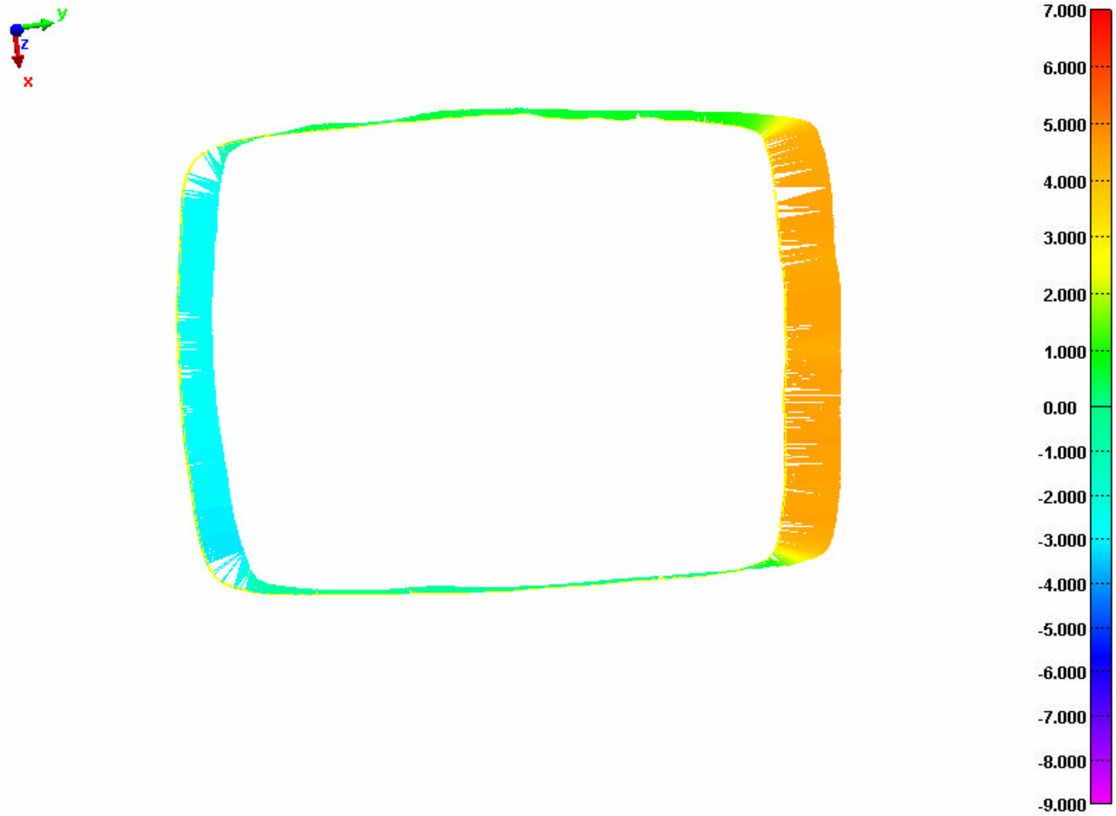
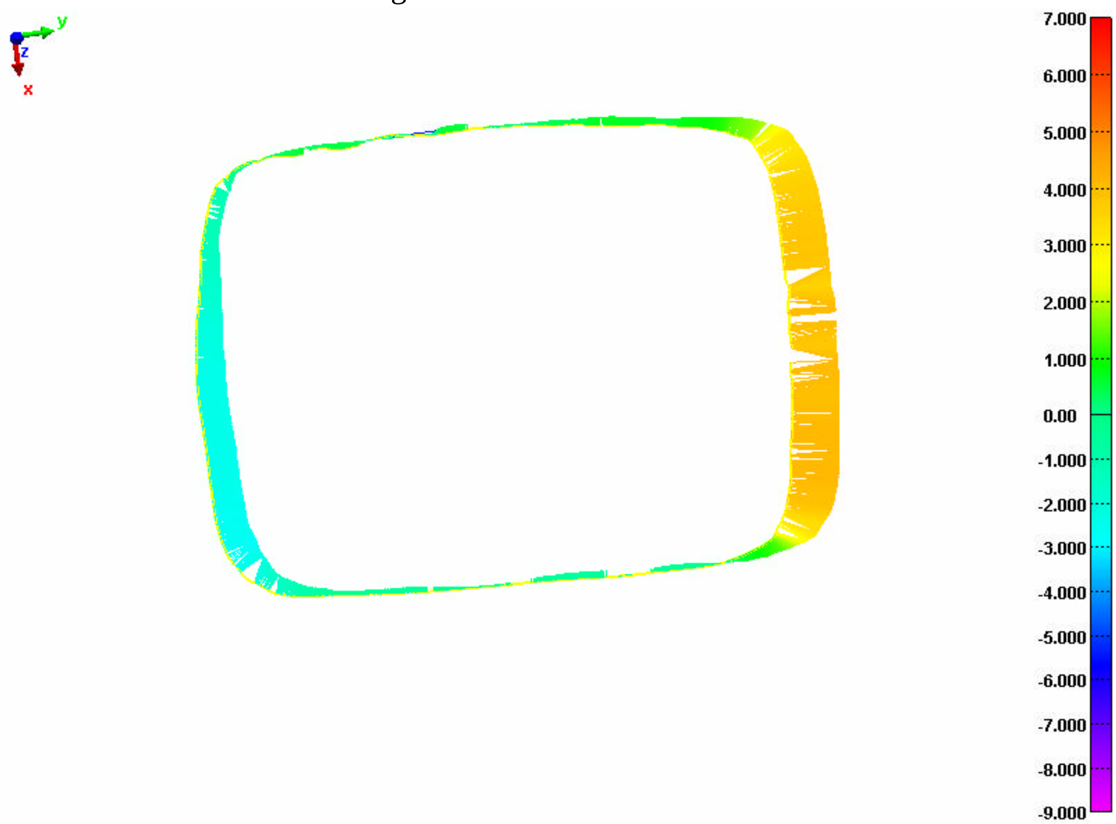


Figure 7.13 Cross Section #23



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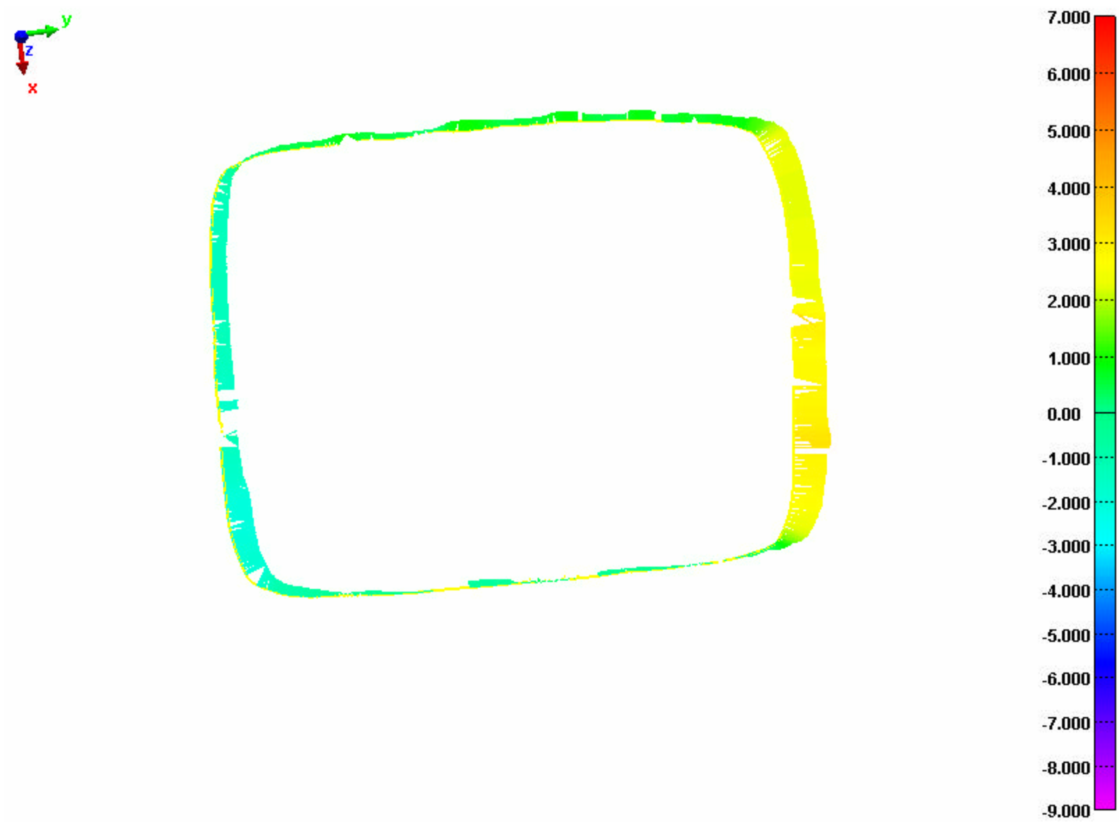

Figure 7.25 Cross Section #25

7.6 Discussion

The advantages and disadvantages of using this system are listed below.

Advantages:

- Accuracy to a thousandth of an inch.
- Ability to view displacement data from any desired cross section.
- Color outputs for graphic presentation.
- Ability to analyze the displacement that occurs in non rigid product (sacked or bagged product). The current method used in Section 4.0 does not have this capability.

Disadvantages

- Cost of time, material, opaque aerosol, technology, and use of outside vendor.
- Scanning process is time consuming.
- A well ventilated area is needed for application of the opaque coating.

The test units were much larger than what M.F. Inspect's clients typically have scanned. Their 4" travel scanning laser was too small for the job, allowing for only two pallets to be scanned twice in one day. In addition, when they returned to their home base, the files were too large to be handled by their computer system. The file had to be transferred to another computing facility for proper analysis. This caused considerable delays. A larger scanning device (with less accuracy) and a more advanced computing system would assist in making optical scanning of units loads more viable.

The data we received did not provide enough of an analytical improvement over the traditional method (Sections 4.0 and 6.0) to justify the cost of purchasing a system. The data collection method in Section 4.0 and the optical scanning method essentially provided the same results.

Overall, I was impressed with optical 3D scanning technology. Over time, as the cost of large scale scanning decreases and the sensitivity of the lasers improve, allowing for the elimination of the opaque coating, this technology is likely to provide a valuable and viable service to manufacturing and material handling industries.

8.0 CONCLUSIONS: INDUSTRY IMPLICATIONS

8.1 Summary and Implications

The objective of this research was to evaluate multiple load stabilization techniques using a standard test to compare their effectiveness. The traditional load stabilizers used in this study included 80ga stretch wrap, 63ga stretch wrap, and strapping. More recently, a method called stretch hooding has been introduced to the market, but research on its effectiveness has lagged behind sales. This experiment was aimed at comparing the effectiveness of stretch hooding with the more traditional stabilization techniques mentioned.

In vibration testing, strapping performed well ahead of the stretch wrapped test units. Stretch hooding was the worst performer when compared to the 80ga and 63ga stretch wrap and strapping (Section 4.0), and the third worse stabilizer when the preliminary stabilizers of stretch netting and horizontal stretch wrap were included (Section 6.0).

In impact testing, stretch hooding was the best performer, slightly better than strapping, followed by 80ga and 63ga stretch wrap. When horizontal stretch wrap and stretch netting were included, horizontal stretch wrap was the best performer and stretch netting the worst.

In vibration testing of the preliminary stabilizers, when looking at pallet-container displacement, horizontal stretch wrap performed evenly with the stretch wrapped test units, when wrapped perpendicular to stringers of the pallet and parallel to the direction of impact. Further testing of horizontal stretch wrap should be performed to determine the effect of vertical containment force on a load's stability.

As stated in section 3.4.1, industry has yet to determine which method of measuring unit load displacement, Cumulative Average Displacement (CAD) or the Cumulative Average Maximum Displacement (CAMD), is a more appropriate unit of measure. This research was not able to offer any insights into this question. However, in vibration testing with horizontal stretch wrap, the CAD and CAMD both resulted in data that resembled an arc, starting and ending at similar displacements but raising in the middle. If only the displacement of the top layer of CAD or CAMD was used, then the maximum displacement that occurred would not be accurately conveyed. CAD and CAMD should be calculated for all layers of containers within any unit load.

In addition, because the two directional displacements were averaged together in the situation above, the resultant numbers indicated that horizontal stretch wrap was a poor stabilizer. When in reality, it depends on the direction of wrap. CAD and CAMD should be calculated for both directions of movement to ensure that no data directionalities are missed.

When analyzing the results of this research, it should be noted that the stretch hooded loads were assembled in Florida (due to equipment availability) and shipped to Virginia Tech for testing. During transit, the test loads experienced some damage to the bottom layer of test containers. This damage might have had an effect on the vertical stabilization force the stretch hood applied to each load. This lessening of force may have allowed the loads to "walk" more during the small repetitive forces of vibration testing. The testing of virgin stretch hooded loads should be conducted to properly assess the effectiveness of stretch hooding during vibration testing.

The current economy is putting large cost reduction pressures on the shipping industry. One of the current trends is to switch from 80ga stretch wrap to 63ga stretch wrap to reduce cost. This typically results in the use of more 63ga stretch wrap to achieve a similar stability and containment force, which again may cause wrapping costs to increase. Instead of switching wraps, industry should consider changing the 80ga wrap pattern to one using less material. Fine tuning the 80ga wrap pattern may have greater potential for cost reductions.

Given the overall results, stretch hooding proved a viable alternative to traditional load stabilizers. However, more research should be conducted on the effectiveness of the stretch hood to confirm these findings. As the stretch hood market expands in North America, cost of the film and machinery will likely decline. If this is the case, stretch hooding has the potential to become a true market competitor, here to stay.

8.2 Research Recommendations

Recommendations for future research include:

- Ensure that a larger distance is left for the containers to shift in impact testing
- Note individual test container damage before and after testing
- Clearly outline the definition of failure of a unit load, possibly utilizing the 22 degree tip test to identify failure (ASTM D 1083 - Tip Test Procedure)
- Identify if there are any material handling personnel safety concerns that might induce failure
- Effectiveness of different stretch hood film thicknesses.
- Stretch hooding performance on loads without sharp corners.
- Box to box interactions when using different load stabilizers.
- Impact of different load stabilizers on different loads and weights.
- Effect of vertical containment force on unit loads
- Water proofing ability of different load stabilizers.
- Effect of containment force on load stabilizer selection.
- Measuring the number of corners torn during testing did not yield any useful information, but if the weather proofing of different load stabilizers is being tested, this could be a useful measure.

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ASTM D 3950 – 96 "Strapping, Nonmetallic (and Joining Methods)" ASTM 100 BARR Harbor Drive, West Conhohocken, PA 19428

ASTM D 4169 "Performance Testing of Shipping Containers and Systems" ASTM 100 BARR Harbor Drive, West Conhohocken, PA 19428

ASTM D 4649 "Standard Guide for Selection of Stretch Wrap Films" ASTM 100 BARR Harbor Drive, West Conhohocken, PA 19428

ASTM D 4649 "A1. Test Method or General Evaluation of Stretch Wrap Materials Under Non-Laboratory Conditions" ASTM 100 BARR Harbor Drive, West Conhohocken, PA 19428

ASTM D 4675 – 93 "Selection and Use of Flat Strapping Materials" ASTM 100 BARR Harbor Drive, West Conhohocken, PA 19428

ASTM D 5414 -95 "Evaluation of Horizontal Impact Performance of Load Unitizing Stretch Wrap Films" ASTM 100 BARR Harbor Drive, West Conhohocken, PA 19428

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APPENDIX A: RAW DATA
A1: Vibration Testing
Vibration: Stretch Hood

1. Displacement (Inches) Pallet 1 run 15

Before	**1**	**2**	**3**	**4**
a	- 3/64	1/4	- 1/32	0
b	1/64	- 3/32	1/64	0
c	- 1/32	3/32	- 1/16	15/64
d	0	1/64	- 1/4	- 3/64
e	9/32	- 1/16	- 1/8	1/2
After	**1**	**2**	**3**	**4**
a	- 1/16	15/32	0	1/32
b	1/32	- 5/32	1/16	3/32
c	3/32	1/32	- 1/64	- 11/32
d	3/64	- 1/16	- 1/8	- 3/16
e	1 1/4	- 1/8	- 3/8	1 3/4

Containment Force (Pounds)				
side	**1**	**2**	**3**	**4**
top	37.7	32.1	34.6	33.5
middle	26	29.4	32.5	32.7
bottom	12.8	23.5	20.8	23.5

Amplitude of top box	**Nat Freq.**	**RMS**	**Control Y**
0.23644	7.62939	0.78248	0.00583706

Corners Ripped Before	1top 2top 4bottom
Corners Ripped After	1top 2top 4bottom

1. Displacement (Inches) Pallet 2 run 16

Before	**1**	**2**	**3**	**4**
a	1/64	- 1/32	1/32	- 17/64
b	1/16	- 1/8	1/32	- 3/32
c	- 3/32	- 1/4	0	0
d	- 15/64	3/32	- 1/16	- 1/8
e	- 1/4	13/16	17/32	- 5/32
After	**1**	**2**	**3**	**4**
a	- 7/32	- 3/32	1/16	- 1/8
b	- 1/8	- 1/8	3/32	- 3/32
c	- 1/8	- 3/8	3/32	1/32
d	- 1/4	- 1/16	- 1/32	- 1/8
e	7/16	0	3/8	3/4

Containment Force (Pounds)				
side	**1**	**2**	**3**	**4**
top	32.8	28.8	37	31
middle	29.6	26.9	33.8	36.7
bottom	18.5	21.5	14.9	25

Amplitude of top box	**Nat Freq.**	**RMS**	**Control Y**

0.19499	7.62939	0.77707	0.00575

Corners Ripped Before	1top 4top 4bottom
Corners Ripped After	1top 2top 3top 3bottom 4top 4bottom

1. Displacement (Inches) Pallet 3 run 17

Before	**1**	**2**	**3**	**4**
a	- 3/32	5/64	- 3/16	- 1/32
b	- 3/64	1/32	5/32	- 1/16
c	3/64	3/16	- 1/4	- 1/16
d	1/32	3/16	- 1/32	- 1/32
e	1/4	1/64	13/16	7/16
After	**1**	**2**	**3**	**4**
a	- 5/64	0	- 9/32	- 1/64
b	- 1/32	- 1/32	9/32	3/32
c	1/16	1/8	- 7/32	1/32
d	3/64	3/32	1/32	- 1/32
e	15/16	9/32	9/16	1/2

Containment Force (Pounds)

side	**1**	**2**	**3**	**4**
top	22	30.5	32.1	30
middle	23.4	26.3	25.4	25
bottom	18.2	16.1	22.5	10.3

Amplitude of top box	**Nat Freq.**	**RMS**	**Control Y**
0.07089	7.94729	0.711589	0.00500776

Corners Ripped Before	1top 2top 3top 3bottom 4top
Corners Ripped After	1top 1bottom 2top 3top 3bottom 4top

1. Displacement (Inches) Pallet 4 run 18

Before	**1**	**2**	**3**	**4**
a	- 1/8	0	5/64	1/16
b	- 1/16	1/64	3/64	1/32
c	0	- 3/64	- 1/16	- 1/16
d	- 3/32	- 7/64	- 3/16	1/16
e	3/8	- 1/8	1/4	1/64
After	**1**	**2**	**3**	**4**
a	- 1/8	- 9/32	9/32	1/8
b	0	- 1/32	3/8	7/64
c	1/32	- 3/32	1/16	- 3/32
d	- 1/32	- 7/64	- 1/8	1/8
e	1 3/4	1/16	- 1/16	1/64

Containment Force (Pounds)

side	**1**	**2**	**3**	**4**
top	33.2	36.8	30.3	32.8
middle	33.7	25.3	27.5	31.3
bottom	22.5	19.9	18.6	9.3

Amplitude of top box	Nat Freq.	RMS	Control Y
0.18607	7.31150	0.65172	0.0055174

Corners Ripped Before	1top 1bottom 3bottom 4top 4bottom
Corners Ripped After	1top 1bottom 2bottom 2top 3top 3bottom 4top 4bottom

1. Displacement (Inches) Pallet 5 run 18

Before	1	2	3	4
a	- 1/8	- 1/4	1/32	1/16
b	1/16	- 3/8	9/32	- 1/32
c	3/64	- 13/32	1/4	5/32
d	- 9/32	- 7/32	1/64	1/32
e	- 3/16	- 1/16	- 11/64	- 5/16
After	**1**	**2**	**3**	**4**
a	3/32	- 1/32	- 3/32	1/64
b	1/8	- 1/16	1/4	- 1/8
c	1/8	- 9/32	- 7/32	1/16
d	- 3/16	- 9/64	- 1/16	0
e	- 9/16	0	9/32	- 9/32

Containment Force (Pounds)				
side	**1**	**2**	**3**	**4**
top	31	35.1	29.4	36.5
middle	31.4	25.5	28.7	33.4
bottom	22.1	15.1	21.6	15.4

Amplitude of top box	Nat Freq.	RMS	Control Y
0.10446	7.62939	0.714491	0.00420521

Corners Ripped Before	1top 2top 3top 3bottom 4top
Corners Ripped After	1top 2top 3top 3bottom 4top

Vibration: 80ga Stretch Wrap

2. Displacement (Inches) Pallet 1 run 20

Before	1	2	3	4	5	6	7	8
a	0	0	- 1/16	3/16	1/4	3/16	1/32	1/4
b	1/64	5/64	3/16	- 1/64	- 3/32	1/64	0	- 1/16
c	0	0	- 1/64	- 1/16	- 3/32	1/64	0	1/32
d	- 1/16	0	0	0	1/64	3/32	0	0
e	9/32	- 1/4	1/16	- 5/32	1/64	- 3/32	0	- 1/4
After	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	1/8	1/16	- 1/16	1/16	1/4	1/4	1/16	1/16
b	11/32	1/4	9/32	5/8	- 1/8	- 1/32	0	- 1/4
c	3/32	1/32	0	1/8	- 1/4	3/32	0	- 1/32
d	3/32	1/16	1/16	- 1/16	1/8	- 3/8	1/18	- 1/16
e	9/16	1/32	5/8	- 1/16	- 1/8	- 3/8	1/8	- 1/8

Containment Force (Pounds)				
side	**1**	**2**	**3**	**4**
1	26.30	28.10	23.00	23.10
2	26.70	27.50	27.90	34.30
3	40.80	27.50	23.00	29.50

Amplitude of top box	Nat Freq.	RMS	Control Y
0.14125	7.62939	0.850025	0.00581275

Corners Ripped Before	
Corners Ripped After	1d 1c 3b 4b 4c 4d

Start Corner	4

2. Displacement (Inches) Pallet 2 run 21

Before	1	2	3	4	5	6	7	8
a	- 1/4	1/32	1/8	3/32	1/8	- 1/32	- 1/8	7/64
b	1/32	3/32	7/32	1/16	- 1/32	1/16	- 1/16	- 5/32
c	0	1/64	1/32	1/8	- 1/32	- 1/16	- 3/16	1/16
d	1/32	- 1/16	- 1/32	1/8	1/16	- 1/64	- 1/16	- 1/16
e	1/4	- 3/32	- 1/16	- 7/16	- 1/32	- 3/32	- 1/8	- 7/16
After	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	1/64	0	- 3/32	5/32	7/32	- 1/16	9/32	- 3/32
b	3/16	1/8	7/32	7/32	- 1/16	- 1/16	- 1/32	0
c	1/32	3/64	1/4	1/4	3/32	- 1/64	1/16	1/8
d	3/32	- 1/8	0	1/8	1/16	0	- 3/32	- 3/32
e	1/2	- 1/8	1/4	- 1/8	1/32	- 1/4	- 1/4	- 3/4

Containment Force (Pounds)				
side	**1**	**2**	**3**	**4**
top	22.60	25.60	25.80	27.10
middle	26.50	30.00	32.90	27.80
bottom	27.00	31.40	31.80	36.30

Amplitude of top box	Nat Freq.	RMS	Control Y
0.07114	7.62939	0.765016	0.00492506

Corners Ripped Before	
Corners Ripped After	1c 2b 2c 2d 2e 3b 3c 3d 4c 4d

Start Corner	1

2. Displacement (Inches) Pallet 3 run 22

Before	1	2	3	4	5	6	7	8
a	- 5/16	1/16	- 5/32	1/32	1/16	1/8	- 1/32	- 1/8
b	- 1/16	1/16	- 1/32	1/8	0	0	0	7/32
c	- 1/16	3/64	0	5/32	1/32	1/32	- 5/16	- 1/32
d	0	0	1/8	- 3/32	- 1/32	0	- 1/8	1/16
e	11/32	3/32	1/16	- 3/32	1/4	- 1/16	1/4	- 1/2
After	1	2	3	4	5	6	7	8
a	- 15/32	1/8	- 5/16	- 3/64	1/16	3/32	0	0
b	- 3/32	1/16	1/16	7/16	1/64	7/32	3/32	1/2
c	- 3/64	9/32	- 1/16	5/16	- 1/32	- 1/8	- 1/4	3/16
d	- 1/8	9/32	- 3/8	- 1/16	- 3/16	- 1/16	1/4	1/8
e	29/32	- 1/8	3/16	- 1/16	5/8	1/16	9/16	- 1/4

Containment Force (Pounds)				
side	1	2	3	4
top	28.40	32.30	25.60	30.50
middle	22.00	31.90	29.10	23.60
bottom	31.40	34.20	28.50	36.60

Amplitude of top box	Nat Freq.	RMS	Control Y
0.08715	9.21885	0.725314	0.00584682

Corners Ripped Before	
Corners Ripped After	2b 2c 3b 3c

Start Corner	2

2. Displacement (Inches) Pallet 4 run 23

Before	1	2	3	4	5	6	7	8
a	- 1/32	1/16	1/16	0	0	1/16	1/16	1/16
b	1/32	- 1/32	1/8	3/32	3/32	- 1/32	- 1/32	0
c	1/64	- 3/64	0	1/32	1/32	- 1/32	1/16	- 1/16
d	0	- 1/32	- 3/32	- 1/8	1/32	0	- 1/16	- 1/8
e	1/32	- 1/16	7/32	- 1/16	0	- 1/4	1/4	- 1/8
After	1	2	3	4	5	6	7	8
a	1/16	1/16	3/16	1/32	9/32	1/16	3/16	1/8
b	- 1/32	1/16	- 1/4	3/16	1/8	0	- 3/16	- 1/8

c	1/4	0	1/16	1/32	1/16	- 1/8	0	1/8
d	- 1/16	- 1/32	3/32	5/16	1/32	0	1/32	- 3/16
e	1/8	- 1/16	1/2	0	1/4	- 1/8	1/32	- 3/8

Containment Force (Pounds)				
side	1	2	3	4
top	27.90	27.10	28.10	25.40
middle	25.90	24.90	26.40	27.60
bottom	33.30	30.00	28.30	28.50

Amplitude of top box	Nat Freq.	RMS	Control Y
0.07201	10.17250	0.723027	0.00706112

Corners Ripped Before	
Corners Ripped After	1c 4c 4d

Start Corner	4

2. Displacement (Inches) Pallet 5 run 24

Before	1	2	3	4	5	6	7	8
a	0	- 1/4	- 5/16	0	- 3/16	- 3/32	- 3/16	1/4
b	- 1/8	7/32	0	3/16	- 3/16	1/32	0	0
c	- 7/32	0	0	3/32	- 1/8	3/32	0	- 1/8
d	3/32	1/32	0	1/16	9/32	0	0	0
e	3/8	- 3/8	9/32	- 3/8	1/8	9/32	1/4	- 3/32
After	1	2	3	4	5	6	7	8
a	5/32	- 7/32	- 5/32	1/4	- 5/16	- 1/16	3/8	1/8
b	- 1/8	1/2	5/32	13/32	- 3/16	1/8	- 1/4	- 1/16
c	- 1/8	3/16	1/16	1/4	- 3/16	1/8	- 3/64	- 5/32
d	1/8	- 1/8	- 1/8	3/16	5/16	0	3/64	1/8
e	3/4	5/32	7/16	- 9/16	1/4	- 3/8	1/2	- 1/16

Containment Force (Pounds)				
side	1	2	3	4
top	25.50	26.10	35.20	28.10
middle	32.60	27.90	27.60	25.80
bottom	31.40	25.50	28.90	31.00

Amplitude of top box	Nat Freq.	RMS	Control Y
0.09575	10.49040	0.772351	0.00662043

Corners Ripped Before	
Corners Ripped After	4bottom

Start Corner	4

<u>Vibration: 63ga Stretch Wrap</u>

3. Displacement (Inches) — Pallet 1 — run 25

Before	1	2	3	4	5	6	7	8
a	3/16	0	0	1/16	0	9/32	1/64	3/64
b	0	- 1/16	0	1/64	- 1/32	0	1/32	1/32
c	- 1/64	1/32	0	0	0	0	0	0
d	1/64	0	0	0	- 1/32	- 1/8	0	0
e	1/32	0	0	- 3/32	1/8	1/34	0	0
After	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	5/32	0	7/64	- 1/32	- 1/32	5/16	1/32	1/8
b	1/16	0	1/8	- 3/32	3/16	3/8	5/32	0
c	1/8	5/16	0	0	- 3/64	- 1/16	- 5/32	3/16
d	5/32	3/16	1/8	- 1/32	- 3/64	1/32	1/16	- 1/8
e	5/8	- 1/8	0	- 3/8	1/16	- 3/8	5/16	1/16

Containment Force (Pounds)

side	1	2	3	4
top	28.50	22.00	27.30	19.90
middle	23.40	22.70	30.20	24.00
bottom	28.20	14.20	29.00	21.40

Load displacement

Amplitude of top box	Nat Freq.	RMS	Control Y
0.07957	10.17250	0.761805	0.0065045

Corners Ripped Before	
Corners Ripped After	1a 1b 1c 3a 3b

Start Corner	4

3. Displacement (Inches) — Pallet 2 — run 26

Before	1	2	3	4	5	6	7	8
a	1/64	3/32	0	0	3/32	0	0	3/64
b	3/64	0	0	3/64	0	3/32	0	0
c	1/32	0	0	0	3/64	0	0	1/16
d	1/64	- 1/32	0	0	1/16	0	0	0
e	1/4	- 3/16	0	1/64	1/64	0	0	- 1/16
After	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	1/8	3/32	1/32	1/32	- 3/64	1/4	1/32	- 1/16
b	1/32	3/16	1/4	5/64	1/8	- 9/32	3/16	3/16
c	7/32	1/32	- 1/32	- 5/32	1/8	1/4	1/16	3/32
d	3/32	1/64	- 5/32	1/32	- 1/16	- 1/16	1/8	- 1/32
e	3/8	- 1/8	3/16	- 1/8	3/32	- 3/16	3/16	- 7/32

Containment Force (Pounds)

side	1	2	3	4
top	15.90	26.30	24.30	13.70
middle	18.40	23.50	24.20	21.00
bottom	21.60	27.30	13.70	22.50

Amplitude of top box	Nat Freq.	RMS	Control Y
0.08242	10.17250	0.706117	0.00697117

Corners Ripped Before	
Corners Ripped After	4b 4c 4d 4e

Start Corner	4

3. Displacement (Inches) Pallet 3 run 27

Before	1	2	3	4	5	6	7	8
a	0	3/16	0	1/32	- 1/16	0	- 1/32	1/32
b	- 1/16	1/16	0	1/16	- 1/8	3/16	- 1/16	0
c	- 1/32	0	0	0	- 1/16	- 1/32	0	0
d	0	1/32	0	0	1/32	0	0	0
e	0	0	0	0	5/64	- 3/16	- 1/32	1/32
After	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	1/16	7/16	3/16	- 5/16	- 7/32	3/32	1/16	7/32
b	1/32	5/16	0	5/32	1/64	3/16	5/32	5/32
c	- 3/32	7/64	3/16	0	- 5/32	- 1/16	1/32	1/32
d	3/16	3/16	1/4	- 1/32	1/32	0	3/32	1/4
e	3/8	1/4	1/16	0	0	- 15/16	1/4	1/16

Containment Force (Pounds)				
side	1	2	3	4
top	23.40	17.30	20.80	22.50
middle	28.30	21.90	28.40	20.40
bottom	20.10	18.10	16.70	11.60

Amplitude of top box	Nat Freq.	RMS	Control Y
0.05449	10.49040		0.00642492

Corners Ripped Before	
Corners Ripped After	3b

Start Corner	1

3. Displacement (Inches) Pallet 4 run 28

Before	1	2	3	4	5	6	7	8
a	- 1/16	0	- 1/16	3/64	0	1/8	1/8	0
b	0	0	1/32	- 1/32	0	3/32	3/32	3/64
c	0	0	- 1/16	0	0	0	- 5/64	1/32
d	0	0	0	0	0	0	0	0
e	1/32	3/32	1/32	0	1/32	0	3/32	0
After	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	- 3/64	- 3/32	- 5/64	3/16	1/8	3/32	9/64	- 1/64
b	3/32	- 3/32	3/16	3/32	- 1/16	3/64	3/32	5/32

c	3/16	3/32	3/64	1/4	3/16	- 3/16	- 1/16	3/16
d	1/8	- 3/64	- 1/16	0	3/32	1/64	0	5/64
e	5/32	- 3/16	1/64	0	1/8	- 1/32	3/8	0

Containment Force (Pounds)				
side	**1**	**2**	**3**	**4**
top	16.80	22.20	15.20	20.90
middle	27.60	27.70	28.40	27.90
bottom	21.40	26.80	14.10	19.50

Amplitude of top box	**Nat Freq.**	**RMS**	**Control Y**
0.08370	10.17250	0.789841	0.00617906

Corners Ripped Before	
Corners Ripped After	1c 1e 4a 4b 4c 4d 4e

Start Corner	1

3. Displacement (Inches) Pallet 5 run 29

Before	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	- 1/64	1/8	1/32	1/16	1/32	0	1/64	1/32
b	0	0	3/32	1/64	0	- 1/32	0	0
c	0	0	1/32	3/64	- 3/32	0	- 1/8	1/32
d	0	0	1/32	- 1/16	0	0	- 1/16	1/32
e	1/8	- 3/64	3/16	- 1/8	1/16	- 1/8	- 1/16	0
After	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	- 5/64	5/32	3/64	3/32	5/64	- 3/32	- 1/64	1/8
b	- 3/32	1/32	- 1/16	1/16	3/64	3/32	1/8	3/16
c	1/4	9/64	3/64	1/16	- 3/64	3/64	- 1/16	9/32
d	3/32	1/16	0	5/32	7/32	3/64	- 3/16	9/32
e	1/2	1/32	13/16	0	1/2	- 3/64	1/4	- 3/16

Containment Force (Pounds)				
side	**1**	**2**	**3**	**4**
top	13.80	22.30	16.90	18.70
middle	20.40	29.10	24.20	26.00
bottom	13.20	20.10	14.30	25.50

Amplitude of top box	**Nat Freq.**	**RMS**	**Control Y**
0.10171	9.53674	0.783977	0.00682678

Corners Ripped Before	
Corners Ripped After	2d 2e 3d

Start Corner	4

Vibration: Strapping

4. Displacement (Inches) Pallet 1 Run 30

Movement After Test								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	1/32	- 1/64	- 1/32	- 1/8	1/32	- 5/32	11/64	- 1/8
b	1/32	0	- 1/64	0	0	- 1/32	1/64	- 3/64
c	- 1/64	0	- 1/16	0	0	0	1/64	0
d	- 1/64	0	1/64	1/64	0	0	1/64	- 3/64
e	- 3/64	1/16	- 1/32	0	- 5/64	- 1/16	3/16	7/32

Containment Force (Pounds)								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Before	28.90	28.10	30.40	26.40	27.10	30.70	31.20	26.10
After	23.60	14.80	24.60	20.00	32.20	24.80	20.90	22.40

Amplitude of top box	Nat Freq.	RMS	Control Y
0.058679	10.80830	0.752648	0.00633628

4. Displacement (Inches) Pallet 2 Run 31

Movement After Test								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	0	- 13/32	1/8	- 1/16	7/32	1/16	1/4	0
b	0	- 3/64	0	3/64	3/64	0	3/64	1/64
c	- 1/64	0	- 1/64	1/64	1/16	- 3/32	1/16	3/64
d	1/8	3/64	- 1/64	0	0	1/16	1/16	3/64
e	- 1/16	- 3/64	5/32	3/32	- 1/32	1/64	- 1/32	- 1/16

Containment Force (Pounds)								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Before	28.10	29.00	29.10	31.70	15.80	26.10	36.40	35.50
After	18.20	19.60	23.30	25.50	12.50	14.10	22.90	21.90

Amplitude of top box	Nat Freq.	RMS	Control Y
0.075004	9.53674	0.726079	0.00587509

4. Displacement (Inches) Pallet 3 Run 32

Movement After Test								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	3/64	- 11/32	1/16	1/321	1/8	- 7/32	- 1/32	- 3/32
b	0	0	1/32	0	0	- 1/64	- 1/64	- 1/32
c	0	0	3/64	- 1/64	0	0	1/32	3/64
d	- 1/64	5/64	1/32	- 1/32	- 5/64	9/64	5/32	- 1/64
e	- 1/8	- 3/32	- 1/32	- 1/32	3/16	0	3/64	1/4

Containment Force (Pounds)								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Before	22.00	26.00	29.70	29.80	27.90	34.90	34.80	31.50
After	21.00	24.80	21.60	17.50	20.30	23.90	20.30	19.70

Amplitude of top box	Nat Freq.	RMS	Control Y

0.0479171	11.44410	0.674944	0.00617386

4. Displacement (Inches) Pallet 4 Run 33

Movement After Test								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	1/8	1/8	9/64	1/16	13/32	- 1/8	- 1/4	- 1/64
b	1/64	- 1/32	3/64	3/32	3/64	0	0	0
c	1/64	1/64	0	0	0	0	0	0
d	0	0	0	0	0	1/8	- 1/64	0
e	- 1/32	- 3/64	- 1/64	3/16	1/32	1/64	- 1/32	0

Containment Force (Pounds)								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Before	26.80	30.70	30.80	34.10	26.40	23.20	28.40	34.20
After	23.00	22.20	23.40	28.80	20.90	15.90	21.80	23.60

Amplitude of top box	Nat Freq.	RMS	Control Y
0.0634408	9.53674	0.706759	0.00766827

Note: top load displacement of corner protector was 2.5 off edges 1-8 and 2-3. the straps shifted 4 inches.

4. Displacement (Inches) Pallet 5 Run 34

Movement After Test								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	1/16	- 1/16	1/64	- 1/8	3/64	- 11/64	- 1/16	1/64
b	0	- 1/16	3/64	9/64	0	0	5/32	1/64
c	0	0	3/64	- 1/64	1/64	0	- 1/32	1/64
d	- 3/64	3/64	0	1/32	0	3/64	- 1/32	0
e	3/8	1 13/32	1/16	3/16	- 3/16	1/32	- 3/32	- 1/32

Containment Force (Pounds)								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Before	22.00	29.00	24.20	32.20	22.00	23.30	32.30	29.30
After	16.00	23.90	19.10	23.20	18.40	16.40	18.80	14.80

Amplitude of top box	Nat Freq.	RMS	Control Y
0.03445	9.53674	0.714852	0.00651442

A2: Impact Testing

Impact: Stretch Hood

1. Displacement (Inches) pallet 6

Before	1	2	3	4
a	1/16	1/8	3/32	1/4
b	- 3/32	0	- 1/16	1/8
c	- 1/16	- 3/64	1/64	1/8
d	5/32	1/64	5/32	1/16
e	5/16	1/2	9/32	7/16
After	**1**	**2**	**3**	**4**
a	7/64	11/32	0	1/4
b	- 3/32	3/64	- 5/64	1/8
c	7/64	- 1/16	1/32	3/16
d	1/64	- 1/8	- 5/32	3/8
e	7/32	-1 3/16	15/32	2 1/2

Containment Force (Pounds)				
Tension	**1**	**2**	**3**	**4**
top	35.10	35.20	36.10	35.80
middle	30.10	29.30	28.90	24.90
bottom	22.60	12.20	20.00	12.50

Corners Ripped Before	1top 2top 4top
Corners Ripped After	1top 1bottom 2top 2bottom 3bottom 4top 4bottom

Impact side	1

1. Displacement (Inches) pallet 7

Before	1	2	3	4
a	3/32	- 3/32	3/64	0
b	- 1/16	1/16	- 5/64	1/16
c	- 1/32	- 1/8	1/32	- 1/64
d	- 1/32	- 3/32	- 1/16	- 1/16
e	0	5/32	0	3/32
After	**1**	**2**	**3**	**4**
a	1/8	1/16	1/32	0
b	- 1/16	3/64	- 1/8	3/32
c	- 1/32	- 1/32	3/32	1/16
d	- 3/32	- 3/32	0	1/8
e	0	- 9/16	9/32	1 9/16

Containment Force (Pounds)				
Tension	**1**	**2**	**3**	**4**
top	36.90	39.10	39.60	43.00
middle	31.50	23.20	33.10	26.20
bottom	24.00	17.80	16.50	15.20

Corners Ripped Before	2top 3top 4top
Corners Ripped After	1bottom 2top 2bottom 3top 3bottom 4top 4bottom

Impact side	1

1. Displacement (Inches) pallet 8

Before	1	2	3	4
a	1/4	1/16	1/16	1/16
b	0	1/64	1/16	- 1/32
c	1/16	- 1/8	0	- 3/32
d	- 1/16	1/16	0	1/32
e	- 5/8	3/8	0	0
After	**1**	**2**	**3**	**4**
a	3/16	- 1/64	3/64	7/32
b	- 1/64	3/64	- 1/32	0
c	0	- 1/64	- 3/16	0
d	- 3/32	- 1/64	3/8	1/2
e	- 1/2	- 3/4	3/16	5/16

Containment Force (Pounds)				
Tension	**1**	**2**	**3**	**4**
top	33.80	33.60	35.40	39.70
middle	26.00	20.70	26.90	25.50
bottom	24.30	12.30	19.80	21.80

Corners Ripped Before	3top 4top
Corners Ripped After	1top 1bottom 2bottom 3top 3bottom 4top 4bottom

Impact side	1

1. Displacement (Inches) pallet 9

Before	1	2	3	4
a	0	- 1/32	- 1/8	3/64
b	1/16	0	- 3/64	3/32
c	- 1/32	0	1/8	1/64
d	0	1/16	- 1/64	1/16
e	- 1/32	- 3/32	- 1/16	3/32
After	**1**	**2**	**3**	**4**
a	1/32	- 1/8	- 3/32	- 1/16
b	1/16	0	0	1/64
c	0	- 11/32	13/64	3/64
d	0	0	3/32	5/32
e	- 3/16	2 3/16	- 9/32	7/8

Containment Force (Pounds)				
Tension	**1**	**2**	**3**	**4**
top	35.20	34.00	40.80	26.20
middle	26.60	30.50	22.60	29.10
bottom	17.70	22.00	15.80	23.20

Corners Ripped Before	1top
Corners Ripped After	1top 1bottom 2bottom 3bottom 4bottom

Impact side	1

1. Displacement (Inches) pallet 10

Before	1	2	3	5	4
a	0	1/32	0	1/16	5/32
b	3/32	- 3/64	1/32	1/16	1/64
c	- 1/8	0	0	1/8	1/16
d	1/16	- 1/16	1/32	3/32	1/16
e	5/32	0	- 3/16	0	3/32
After	**1**	**2**	**3**	**5**	**4**
a	1/64	3/16	1/32	3/32	5/16
b	1/16	- 5/64	1/64	- 1/16	3/32
c	- 1/8	1/16	1/8	1/16	1/16
d	1/16	1/16	1/64	- 1/8	- 1/64
e	15/16	2 1/4	- 1/4	- 1/2	-1 3/16

Containment Force (Pounds)				
Tension	**1**	**2**	**3**	**4**
top	32.80	37.70	30.20	40.90
middle	26.70	29.20	27.40	23.10
bottom	25.60	19.40	26.10	13.90

Corners Ripped Before	3top 5top
Corners Ripped After	1bottom 2bottom 3top 3bottom 4bottom 5 top 5bottom

Impact side	1

Impact: 80ga Stretch Wrap

2. Displacement (Inches) pallet 6

Before	1	2	3	4	5	6	7	8
a	- 1/64	3/64	- 1/16	7/32	- 1/64	1/32	- 1/16	- 1/32
b	- 1/64	- 1/64	- 3/32	- 3/16	- 1/64	- 1/32	5/32	5/64
c	0	- 1/64	5/32	- 1/16	0	0	1/64	1/32
d	- 1/64	0	- 1/32	3/32	0	- 1/64	1/16	- 1/32
e	1/32	- 1/16	1/8	- 1/8	1/32	- 1/64	1/8	0
After	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	1/4	3/32	- 5/32	1/4	1/16	- 1/8	- 1/16	0
b	1/32	- 3/32	- 11/32	- 1/4	1/4	- 1/32	7/32	3/16
c	- 1/4	- 7/16	5/64	- 7/32	3/16	3/32	0	- 1/8
d	- 5/32	- 11/32	- 1/16	3/16	9/16	1/4	5/64	1/8
e	-3 9/16	-4 5/32	- 3/8	- 3/8	3 3/4	3 3/8	3/32	1/16

Containment Force (Pounds)				
side	**1**	**2**	**3**	**4**
top	20.6	21.4	16.8	25.3
middle	24.1	23.5	27.1	26.5
bottom	26.9	33.5	27.5	31.7

Start Corner	1
Impact side	4

Corners Ripped Before	
Corners Ripped After	2c 2d 3b 3d 1bottom 2bottom 3bottom 4bottom

2. Displacement (Inches) pallet 7

Before	1	2	3	4	5	6	7	8
a	- 1/8	0	0	- 3/64	- 3/32	0	- 3/32	- 1/64
b	0	1/32	- 7/64	- 3/64	- 3/64	1/16	- 1/16	1/32
c	0	0	1/16	0	- 1/64	- 1/32	0	1/64
d	0	0	1/64	- 1/32	0	- 1/32	- 3/32	3/64
e	1/8	- 1/8	1/32	- 1/16	1/32	- 5/64	7/32	- 1/4
After	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	3/16	3/32	- 1/32	0	- 7/32	- 3/19	1/64	1/8
b	11/32	1/8	- 1/8	1/16	7/32	- 5/32	- 1/16	3/32
c	- 9/32	- 3/8	- 1/16	1/64	1/4	1/64	- 3/32	- 1/16
d	- 1/4	- 9/32	1/32	- 3/32	5/64	1/4	- 5/32	1/8
e	-3 1/8	-4 3/4	0	- 1/8	4 1/2	4 1/16	1/2	- 3/16

Containment Force (Pounds)				
side	**1**	**2**	**3**	**4**
top	22.7	26.5	25	26.1
middle	30.2	33.2	26.5	33.2
bottom	32.9	32.3	28.9	35

Start Corner	4
Impact side	4

Corners Ripped Before	
Corners Ripped After	2c 3b 3d 1bottom 2bottom 3bottom 4bottom

2. Displacement (Inches) pallet 8

Before	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	1/64	3/32	0	3/32	1/16	- 3/64	- 1/8	0
b	1/64	1/32	1/32	0	1/32	1/64	1/16	1/64
c	0	0	1/16	0	0	1/64	0	5/64
d	1/64	- 1/16	- 3/64	3/64	1/64	0	- 3/64	0
e	1/16	- 1/64	- 1/32	0	0	- 1/32	3/32	- 3/32
After	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	- 3/64	3/16	5/32	5/32	7/64	1/16	- 3/325	1/32
b	3/64	1/32	- 3/64	3/32	5/64	- 3/32	1/64	0
c	7/64	7/64	3/16	1/4	9/64	11/64	1/8	3/32
d	- 1/32	- 33/64	- 1/16	1/16	5/32	0	- 5/64	11/64
e	-1 13/16	-1 1/4	- 1/16	0	1 3/16	1 11/32	5/16	- 1/8

Containment Force (Pounds)				
side	**1**	**2**	**3**	**4**
top	22.5	25.2	24.3	29.8
middle	26	25.1	22.3	35.4
bottom	26	36.1	28.9	34.9

Start Corner	2
Impact side	4

Corners Ripped Before	
Corners Ripped After	3d 3bottom 4b 4bottom

2. Displacement (Inches) pallet 9

Before	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	- 7/64	1/16	- 3/32	1/16	1/64	1/64	3/32	3/16
b	- 1/32	- 1/32	- 1/8	0	0	1/16	- 3/16	- 5/32
c	0	1/32	1/16	5/32	1/32	0	- 3/32	3/32
d	0	0	- 1/32	- 3/32	0	0	1/8	0
e	3/16	0	0	- 1/32	1/16	- 3/32	5/32	- 1/8
After	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	1/32	7/32	- 3/16	- 1/16	9/32	- 5/64	5/32	1/4
b	- 5/64	- 11/32	- 3/32	1/16	1/4	0	- 1/32	- 1/16
c	- 1/32	5/64	- 1/32	- 3/64	3/16	0	- 3/32	3/32
d	- 19/32	- 43/64	1/16	0	3/8	- 1/32	7/32	1/32
e	-1 1/16	- 7/8	5/16	0	3 7/8	3 3/8	3/8	7/16

Containment Force (Pounds)				
side	**1**	**2**	**3**	**4**
top	25.1	23.9	20.9	20.8
middle	24.4	27.7	30.4	29
bottom	24.8	37.8	20.7	27.7

Start Corner	4

Impact side	4

Corners Ripped Before	
Corners Ripped After	2d 3b 3bottom 4bottom

2. Displacement (Inches) pallet 10

Before	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	3/64	0	1/4	5/32	1/32	- 1/32	1/16	7/64
b	- 5/64	1/16	3/32	5/64	1/32	- 1/64	- 5/64	- 9/64
c	1/16	0	3/32	1/8	0	1/64	- 1/8	11/64
d	0	- 1/16	1/16	- 1/16	- 1/32	0	1/16	3/32
e	1/16	- 1/16	0	- 1/32	0	- 5/64	5/64	- 5/32
After	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	1/8	0	- 1/4	1/8	- 1/32	- 1/4	3/64	5/32
b	- 1/8	- 3/16	3/32	1/8	5/32	- 1/8	- 1/16	3/64
c	3/32	3/32	1/8	7/32	- 1/64	- 3/64	- 5/32	- 1/4
d	1/32	- 11/32	3/32	- 3/32	3/8	3/32	1/16	- 1/8
e	- 31/32	- 15/16	- 1/8	1/16	1	1	9/32	- 7/32

Containment Force (Pounds)				
side	**1**	**2**	**3**	**4**
top	20.4	33.4	21.2	28.1
middle	26.3	27.4	25.6	26.3
bottom	30.5	35.2	30.5	35.3

Start Corner	4
Impact side	4

Corners Ripped Before	
Corners Ripped After	1bottom 2bottom 4c 4bottom

Impact: 63ga Stretch Wrap

3. Displacement (Inches) pallet 6

Before	1	2	3	4	5	6	7	8
a	- 1/32	0	0	0	0	0	- 1/16	3/64
b	0	0	0	0	0	0	0	0
c	0	0	0	0	0	0	0	0
d	0	0	0	0	0	0	0	0
e	0	0	0	0	0	0	1/64	0
After	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	- 1/8	1/32	- 13/64	3/32	3/64	3/16	- 3/32	1/64
b	- 3/16	- 7/32	- 9/32	- 1/16	1/16	5/32	1/16	- 1/32
c	- 3/32	3/8	1/64	5/32	- 1/16	1/16	- 1/32	1/32
d	- 3/32	1/16	- 5/64	7/32	3/8	9/64	1/32	- 1/32
e	-2 21/32	- 9/16	0	- 1/16	5/8	2 29/32	0	- 5/8

Containment Force (Pounds)				
side	1	2	3	4
top	12.4	16.7	13.8	21.8
middle	18.7	25.1	20.6	28.2
bottom	21.4	28.9	15.4	26.1

Start Corner	3
Impact side	4

Corners Ripped Before	
Corners Ripped After	1bottom 2bottom 3bottom 4bottom

3. Displacement (Inches) pallet 7

Before	1	2	3	4	5	6	7	8
a	0	7/64	- 1/32	1/16	0	1/8	3/16	1/32
b	- 1/32	0	0	0	1/64	0	1/32	- 1/16
c	0	0	1/32	0	1/64	- 1/32	1/32	0
d	0	0	1/32	0	0	0	- 1/32	0
e	0	0	0	0	0	0	1/32	- 1/32
After	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	1/4	3/8	- 3/32	- 1/64	- 7/16	- 1/32	7/64	3/32
b	7/16	7/64	1/64	1/16	- 3/16	- 5/16	- 1/32	- 1/16
c	5/16	1/4	1/32	5/64	- 9/32	- 5/32	1/32	- 1/64
d	7/32	5/32	1/16	1/64	- 1/16	- 13/16	- 1/16	1/32
e	3/8	2 13/16	1/4	1/8	-2 1/2	- 1/4	1/16	- 1/8

Containment Force (Pounds)				
side	1	2	3	4
top	13.5	23.1	13.8	20
middle	18.7	24.3	18	23.6
bottom	14.2	20.3	14.7	20.3

Start Corner	4
Impact side	4

Corners Ripped Before	
Corners Ripped After	1bottom 2bottom 3bottom 4bottom

3. Displacement (Inches) pallet 8

Before	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	- 1/8	0	- 1/16	1/16	- 1/16	1/16	3/64	- 1/16
b	- 1/64	- 1/8	0	1/32	- 1/64	0	1/8	0
c	1/16	0	- 3/64	1/32	0	0	0	3/64
d	0	0	0	0	0	0	0	3/32
e	0	0	5/32	- 1/16	3/64	- 1/64	0	1/64
After	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	- 1/8	- 3/16	- 5/32	1/32	- 1/8	- 1/32	1/64	- 1/16
b	- 7/32	- 11/16	5/32	1/4	11/32	- 1/32	1/64	0
c	- 1/4	- 3/8	- 1/32	1/4	21/32	13/32	- 1/16	1/32
d	- 11/16	- 3/8	1/32	- 1/32	5/16	15/32	- 3/32	7/32
e	-2 3/4	-3 5/8	0	- 1/4	2 3/4	2 13/16	0	- 1/8

Containment Force (Pounds)				
side	**1**	**2**	**3**	**4**
top	19.5	21.8	15.5	18.1
middle	16.6	23.9	17.5	24.1
bottom	13.3	20.7	20	19.1

Start Corner	2
Impact side	4

Corners Ripped Before	
Corners Ripped After	1bottom 2bottom 3bottom 4a 4bottom

3. Displacement (Inches) pallet 9

Before	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	0	- 7/32	1/16	- 1/64	- 1/64	- 5/32	1/16	- 3/32
b	0	0	- 1/32	- 1/32	0	- 1/64	- 1/32	0
c	0	0	- 1/16	- 1/32	0	0	0	1/16
d	1/64	0	0	0	0	0	3/64	- 3/64
e	1/32	0	1/32	0	1/16	- 3/32	1/8	- 5/32
After	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	1/32	1/8	1/8	- 1/16	13/32	1/4	0	- 3/16
b	3/32	1/4	- 1/16	0	15/32	5/32	- 3/32	0
c	1/64	3/64	- 3/8	- 7/32	9/32	3/64	- 1/32	9/64
d	- 1/16	-1	- 9/32	0	11/32	1/8	3/32	- 7/64
e	-3 1/4	- 7/8	0	- 1/4	4 3/8	4	1/16	- 1/4

Containment Force (Pounds)				
side	**1**	**2**	**3**	**4**
top	12.4	14.5	13.6	22.3
middle	17.2	27	18.9	21.2
bottom	21.8	38.6	20.6	23.1

Start Corner	2
Impact side	4

Corners Ripped Before	
Corners Ripped After	1bottom 2bottom 3bottom 4bottom

3. Displacement (Inches) pallet 10

Before	1	2	3	4	5	6	7	8
a	1/16	- 1/64	- 1/16	- 1/16	- 3/32	1/32	- 1/32	3/32
b	- 1/32	0	3/32	3/64	- 5/64	1/32	1/16	1/32
c	0	0	- 1/64	0	1/64	0	- 1/64	1/16
d	1/64	0	1/64	3/64	0	0	0	1/16
e	1/64	- 1/32	1/8	- 3/32	1/16	0	0	0
After	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	5/8	3/64	- 3/32	- 1/16	- 7/32	- 11/32	- 1/16	1/16
b	7/32	- 1/32	1/32	5/32	- 1/16	- 7/32	5/32	1/16
c	- 1/8	- 9/16	3/64	7/32	3/4	7/32	- 3/64	1/8
d	- 9/32	- 7/16	- 1/16	1/8	13/32	1/4	- 3/32	3/32
e	-2 5/8	-3 7/16	0	- 3/8	3 1/4	2 1/16	1/4	- 1/4

Containment Force (Pounds)				
side	1	2	3	4
top	18.1	19.1	18.1	16.7
middle	18.6	22.2	17.6	22.3
bottom	20.6	18.3	21.7	21.7

Start Corner	4
Impact side	4

Corners Ripped Before	
Corners Ripped After	1a 1bottom 2bottom 3bottom 4a 4bottom

Impact: Strapping

4. Displacement (Inches) Pallet 6

Movement After Test								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	1/16	3/32	3/32	- 1/16	- 1/8	0	1/64	- 1/16
b	1/32	1/64	0	0	1/64	1/64	0	0
c	0	1/16	3/64	0	0	- 1/64	- 1/64	0
d	3/32	1/16	0	0	- 3/16	- 1/8	0	- 1/16
e	25/32	1 5/8	- 1/8	0	1 5/16	-1 1/16	- 1/16	1/8

Containment Force (Pounds)								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Before	28.40	22.20	27.10	29.40	27.40	30.80	33.10	25.50
After	17.50	17.60	26.00	34.40	26.10	19.40	30.50	22.10

Impact Side	**2**

4. Displacement (Inches) Pallet 7

Movement After Test								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	7/16	5/16	1/64	- 9/32	- 1/8	- 3/8	- 3/64	3/64
b	3/8	3/64	0	- 5/64	0	- 1/32	0	5/64
c	1/64	3/32	0	1/64	1/16	0	0	1/16
d	1/16	15/32	0	- 1/64	- 1/16	- 1/16	- 1/64	0
e	5/16	2 7/16	0	- 3/16	-1 3/4	- 13/32	- 1/16	1/16

Containment Force (Pounds)								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Before	25.10	20.40	27.00	25.60	23.00	31.60	26.90	29.80
After	13.30	12.80	41.00	27.00	17.90	22.10	27.20	40.80

Impact Side	**2**

4. Displacement (Inches) Pallet 8

Movement After Test								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	- 5/64	- 1/32	1/8	- 1/8	29/64	- 9/32	0	- 9/32
b	7/64	- 1/64	3/64	1/64	0	- 15/32	0	0
c	1/16	1/64	0	- 3/64	- 3/32	- 3/64	1/16	0
d	1/16	1/64	1/64	1/64	- 5/32	- 13/16	3/16	3/64
e	11/16	1 25/32	1/16	- 1/16	-2 19/32	-2 3/8	1/32	3/8

Containment Force (Pounds)								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Before	19.90	22.90	29.30	28.90	29.60	31.10	36.40	27.00
After	19.10	15.70	0.70	40.70	16.40	20.60	24.90	24.30

Impact Side	**2**

4. Displacement (Inches) Pallet 9

Movement After Test								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	5/8	1/32	3/64	0	- 3/16	- 1/16	1/32	- 1/16
b	3/16	1/32	- 1/16	- 1/64	0	- 1/64	1/32	1/64
c	3/64	1/64	- 1/32	- 1/16	- 5/64	- 1/8	1/16	- 1/64
d	1/8	1/32	0	- 1/16	- 1/32	- 1/16	1/64	0
e	1	1 15/16	0	- 1/4	-1 5/8	- 25/32	- 3/32	1/4

Containment Force (Pounds)								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Before	21.50	23.50	28.90	31.70	29.20	27.40	32.20	29.90
After	15.10	13.70	23.80	27.70	28.80	20.30	24.50	25.00

Impact Side	**2**

4. Displacement (Inches) Pallet 10

Movement After Test								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
a	0	3/32	1/8	- 3/32	- 1/16	- 1/32	1/16	- 1/64
b	- 1/64	5/32	1/32	- 1/32	1/16	1/64	0	- 1/64
c	1/64	1/16	3/32	0	0	- 1/16	0	- 1/64
d	7/64	1/32	0	0	0	- 5/16	3/32	- 1/32
e	7/8	1 15/16	- 1/32	3/32	-2 1/16	-1 3/8	- 1/8	- 1/8

Containment Force (Pounds)								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Before	26.90	24.70	31.60	25.00	29.60	35.10	24.60	34.80
After	17.40	15.80	30.40	26.20	19.10	21.20	28.80	25.50

Impact Side	**2**

APPENDIX B: PALLET SPECIFICATION

PALLET DESIGN SYSTEM Version 4.0

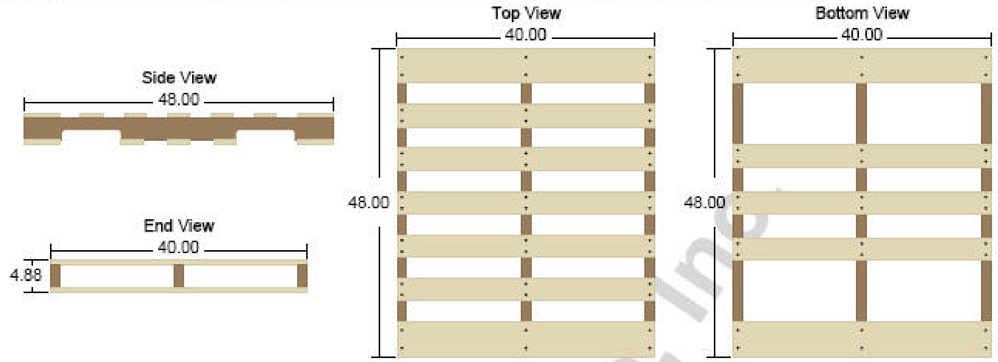
Pallet Specification Sheet

All dimensions in inches

Customer:

Prepared by:
The Pallet Alliance Inc.
100 Europa Dr., Suite 450
Chapel Hill, NC, 27517
PDS License: 321 Date: March 15, 2007

Pallet ID: Sofwood GMA
Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Multiple-Use, New Manufacture



Components

Top Deck:
Style: Deckboard Type: New Lumber

Number	Thickness	Width	Length
5	0.688	3.500	40.00
2	0.688	5.500	40.00

Volume: 5.4 bd ft

Bottom Deck:
Style: Deckboard Type: New Lumber

Number	Thickness	Width	Length
3	0.688	3.500	40.00
2	0.688	5.500	40.00

Volume: 4.1 bd ft

Stringers:
Type: New Lumber

Number	Width	Height	Length
3	1.500	3.500	48.00

Partial 4-way Entry Notch:
Depth: 1.500 Length: 9.00 Location: 6.00 Radius: 0.75
Volume: 5.3 bd ft

Materials

Fasteners:

Fastener ID:	2.0 x .113
Fastener Type:	Helically Threaded Nail
Fastener Length:	2.00
Thread Length:	1.25
Thread Diameter:	0.126
Wire Diameter:	0.113
Head Diameter:	0.280
Helixes:	9.0
Flutes:	5
Thread Angle:	60
MIBANT Angle:	36
FWI:	89
FSI:	68
Total Number:	72

New Lumber:
Lumber ID: Southern Softwood

Species Class	Grade
Southern Yellow Pine	Utility &BTR

Moisture Content (at manufacture and assembly): Green

Total New Lumber Volume: 14.8 bd ft

Custom Notes and Information:

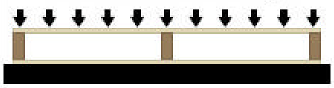
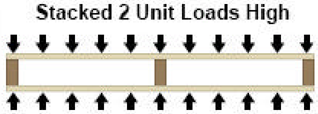
PALLET DESIGN SYSTEM Version 4.0
Pallet Structural Analysis

Customer:

Prepared by:
The Pallet Alliance Inc.
PDS License: 321 Date: March 15, 2007

Pallet ID: Sofwood GMA
Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Multiple-Use, New Manufacture

Unit Load Type: Uniformly Distributed - Full Pallet Coverage
Unit Load Weight Variability: Low
Service Environment: Dry Environment (EMC <= 19%)

Support Condition	Safe Maximum Load	Deflection at Maximum Load	User Specified Deflection Limit	Maximum Load for Deflection Limit	Critical Member
Stacked 1 Unit Load High 	5060 lbs.	0.18 in.	----	----	Top Deckboard
Stacked 2 Unit Loads High 	3163 lbs. (each pallet)	0.18 in.	----	----	Top Deckboard

Lateral Collapse Resistance

Low | Medium | Good | Excellent

H/V = 1.73

Pallet Design System (PDS)
Developed by:
National Wooden Pallet and Container Association (NWPCA)
In cooperation with:
Pallet and Container Research Laboratory, Virginia Tech Department of Wood Science and Forest Products;
U.S.D.A. Forest Service and Forest Products Laboratory; APA - The Engineered Wood Association;
Software Technologies Laboratory, Virginia Tech Department of Industrial and Systems Engineering

PALLET DESIGN SYSTEM Version 4.0

Pallet Physical Property Analysis

Customer:

Prepared by:
The Pallet Alliance Inc.
PDS License: 321 Date: March 15, 2007

Pallet ID: Sofwood GMA
Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Multiple-Use, New Manufacture

	At Manufacture	At 25% MC	At 19% MC	At 15% MC	At 12% MC
Average Pallet Weight	49 lbs.	41 lbs.	39 lbs.	38 lbs.	37 lbs.

Dimensional Change due to Wood Drying

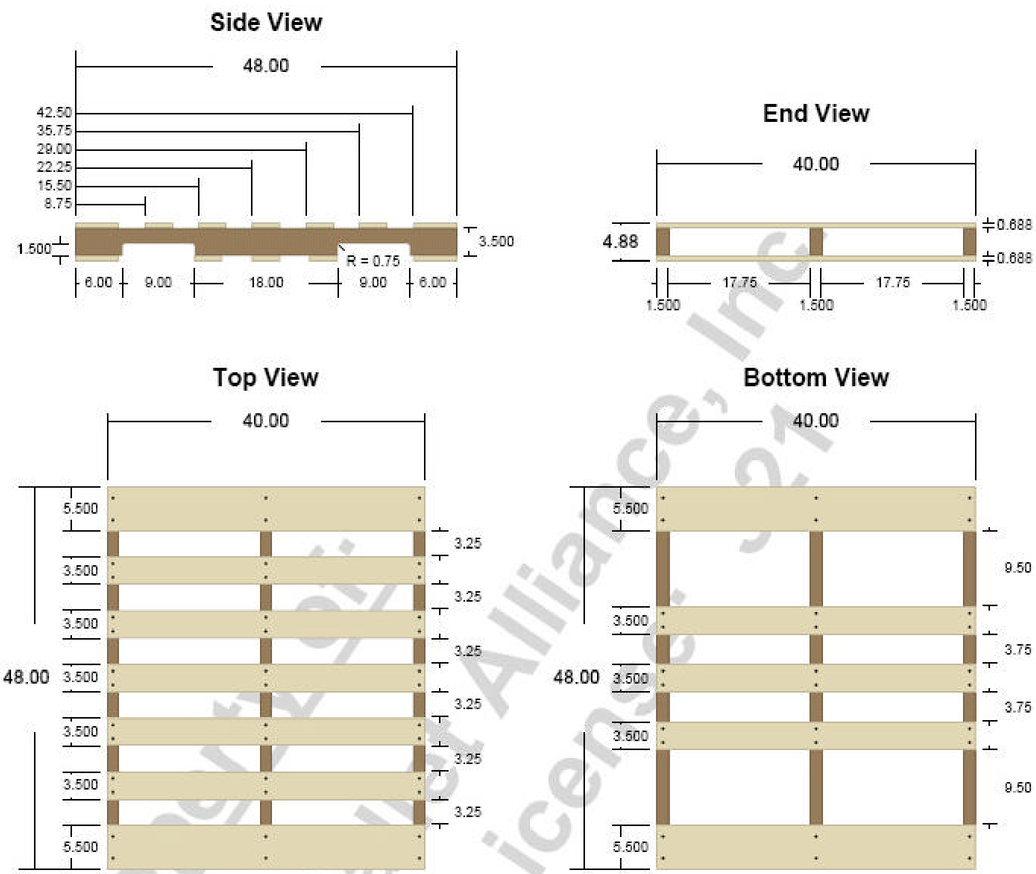
Component	Original Dimension	Shrinkage from Manufacture to 19% MC	Shrinkage from Manufacture to 15% MC
Top Deckboards	0.688 in. Thickness 3.500 in. Width 5.500 in. Width	0.014 in. (+/- 0.003 in.) 0.069 in. (+/- 0.015 in.) 0.109 in. (+/- 0.024 in.)	0.020 in. (+/- 0.004 in.) 0.100 in. (+/- 0.022 in.) 0.157 in. (+/- 0.034 in.)
Stringers	3.500 in. Height 1.500 in. Width	0.069 in. (+/- 0.015 in.) 0.030 in. (+/- 0.007 in.)	0.100 in. (+/- 0.022 in.) 0.043 in. (+/- 0.009 in.)
Bottom Deckboards	0.688 in. Thickness 3.500 in. Width 5.500 in. Width	0.014 in. (+/- 0.003 in.) 0.069 in. (+/- 0.015 in.) 0.109 in. (+/- 0.024 in.)	0.020 in. (+/- 0.004 in.) 0.100 in. (+/- 0.022 in.) 0.157 in. (+/- 0.034 in.)

PALLET DESIGN SYSTEM Version 4.0

2-D Pallet Drawings

All dimensions in inches

Pallet ID: Sofwood GMA
Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Multiple-Use, New Manufacture



Customer:

Prepared by:
The Pallet Alliance Inc.
100 Europa Dr., Suite 450
Chapel Hill, NC, 27517

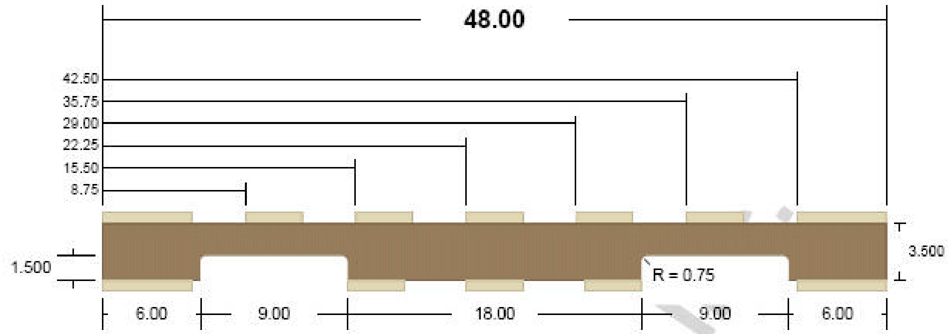
PALLET DESIGN SYSTEM Version 4.0

Pallet Drawing - Side and End View

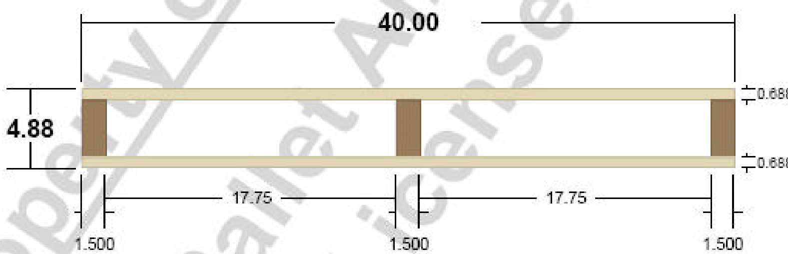
All dimensions in inches

Pallet ID: Sofwood GMA
Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Multiple-Use, New Manufacture

Side View



End View



Customer:

Prepared by:
The Pallet Alliance Inc.
100 Europa Dr., Suite 450
Chapel Hill, NC, 27517

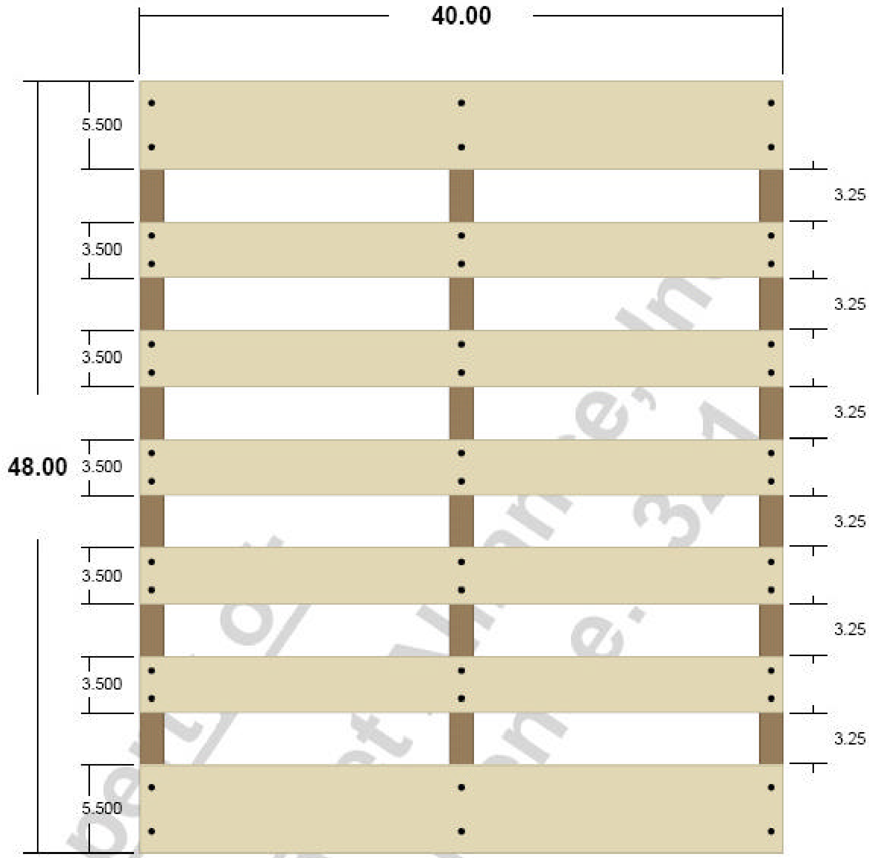
PALLET DESIGN SYSTEM Version 4.0

Pallet Drawing - Top View

All dimensions in inches

Pallet ID: Sofwood GMA
Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Multiple-Use, New Manufacture

Top View



Customer:

Prepared by:
The Pallet Alliance Inc.
100 Europa Dr., Suite 450
Chapel Hill, NC, 27517

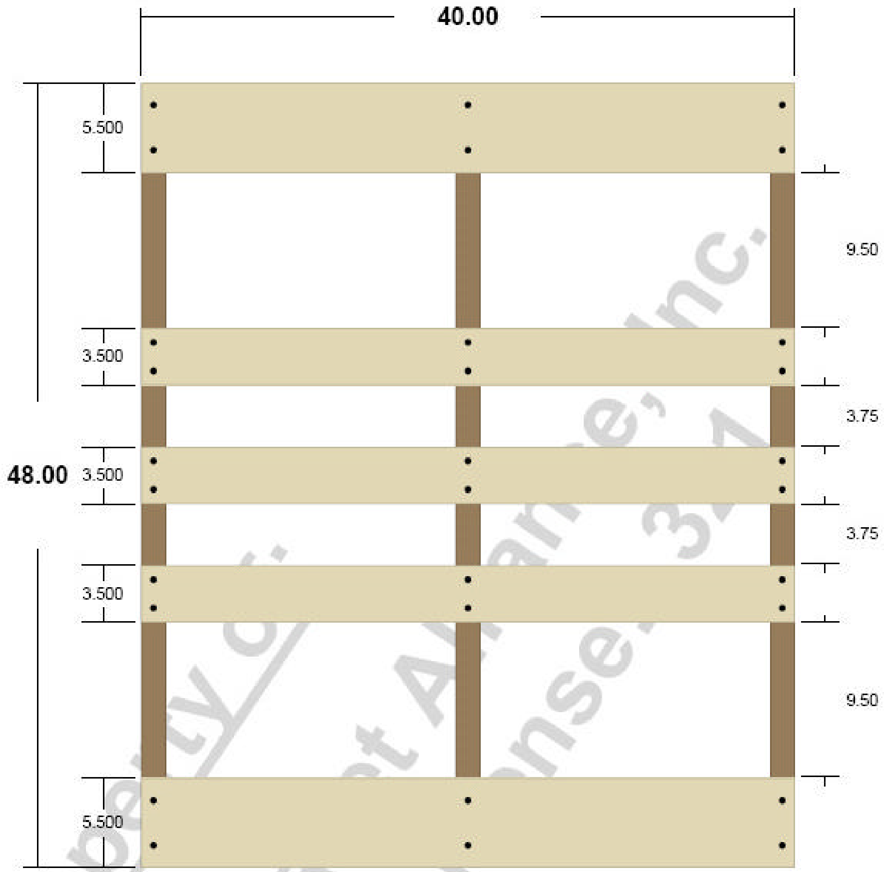
PALLET DESIGN SYSTEM Version 4.0

Pallet Drawing - Bottom View All dimensions in inches

Pallet ID: Sofwood GMA

Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Multiple-Use, New Manufacture

Bottom View



Customer:

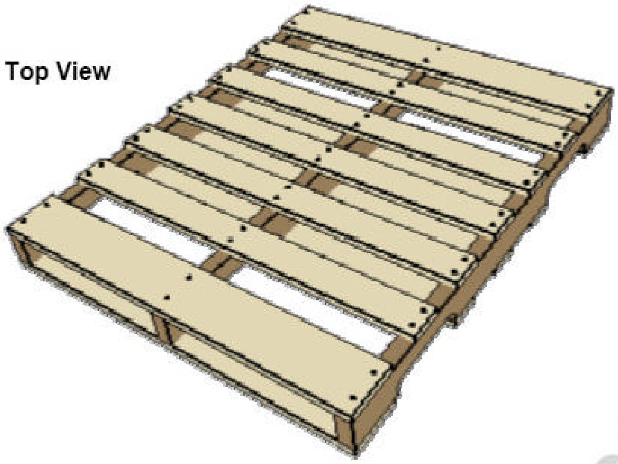
Prepared by:
The Pallet Alliance Inc.
100 Europa Dr., Suite 450
Chapel Hill, NC, 27517

PALLET DESIGN SYSTEM Version 4.0

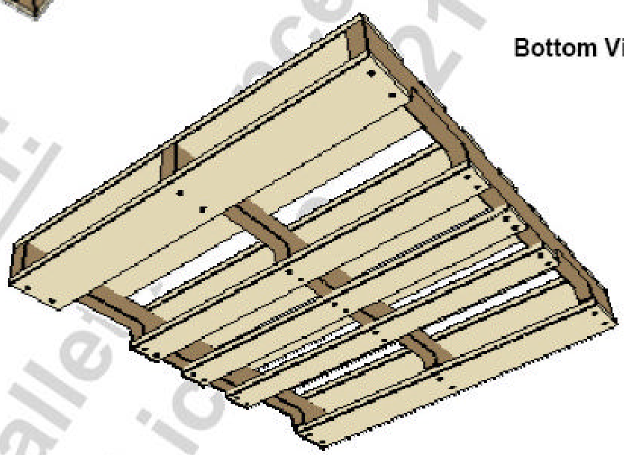
3-D Pallet Drawings

Pallet ID: Sofwood GMA
Classification: 48.00 x 40.00, Stringer-Class, Double-Face Non-Reversible, Partial 4-Way, Multiple-Use, New Manufacture

Top View



Bottom View



Customer:

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100 Europa Dr., Suite 450
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