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AN EXPLORATORY INVESTIGATION OF THE
TRANSMISSIBILITY OF THREE TYPES OF WOODEN
PALLETS

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Bhupinder Kumar

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Gary Burgess
Major Professor's Signature

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AN EXPLORATORY INVESTIGATION OF THE TRANSMISSIBILITY OF THREE TYPES OF WOODEN PALLETS

By

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ABSTRACT

AN EXPLORATORY INVESTIGATION OF THE TRANSMISSIBILITY OF THREE TYPES OF WOODEN PALLETS

By

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Pallets are commonly used for shipment of food and beverage products from manufacturing plants for selling, handling, transporting and storing purposes. Vibration sensitive products often get damaged during transportation due to excessive vibration of the unit load. Pallet materials and design play a vital role in reducing the vibration levels during transportation. As the stiffness of the pallet increases, vibration transmissibility levels tend to decrease.

In this study, a novel type of pallet called the "Dowel" pallet was tested. This pallet uses a wooden dowel fastening system instead of conventional nails. It also has stiffer deck boards. These Dowel pallets were compared to currently used G.M.A pallets in terms of transmissibility and Grms using ASTM D-999 and ASTM D-4728. Four types of unit load configurations were studied: Apple juice, Baked beans, Maple syrup cases and Diet coke. The results were compared at 1-10 Hz and 1-100 Hz. All configurations showed a decrease in vibration transmissibility when Dowel pallets were used. Based on the results, the packaging materials and transportation costs may be able to be reduced.

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CHAPTER 1: INTRODUCTION

The food and beverage industries produce products in mass quantity for distribution to local and remote locations. They ship these products from their manufacturing plants to their customers in shipping containers and on pallets for selling, handling, transporting and storing purposes. The handling system needs to be speedy for timely delivery of these high volume products. After World War II, the practices used by the military were adopted by industries to facilitate the supply chain. One of the developments in material handling during that time was the introduction of palletization [1]. Since then, pallets are used in various industries as the platform for the packaged products in unit loads. Today the main types of pallets used are made from wood, plastic, metal and corrugated board. They are being used for handling packaged products to make supply chain economical and rapid. The most common pallets used by the grocery industry are wooden pallets which have deck boards, stringers and fastening systems (nails). The deck boards are the top-most supporting base for packages and the stringers support the top deck boards. Bottom deck boards are used to give a flat platform.

The growing trend is to use palletized handling versus break-bulk manual handling of single package. This saves time and cost during cross-docking and loading/unloading processes in today's transportation environment. Unitizing the load also helps in eliminating shock damage to individual packages during manual handling. The major hazards during transportation of the packaged product in unit loads are mechanical [2]. Vibration damage is a primary concern with the transportation system in today's unitized load distribution environment. Mechanical vibrations and shocks which cause damage to products can be controlled using good structural design and materials.

Pallets play a vital role in transmitting dynamic forces during distribution. The other factors are truck/rail suspension systems, condition of the road and truck speed during transportation. The purpose of packaging is to protect products from these dynamic forces during transportation.

Pallets play an important role to reduce the damage caused by the transportation vibration and shocks, especially if they are made of stiffer wood and a tighter fastening system [3]. During transportation, the acceleration and vibrations produced by the truck transmits through the pallet to the products. Vibration transmissibility is a phenomenon which describes how forces are amplified in a unit load during distribution. It is expected that a more rigid platform would reduce vibration amplification and damage [3]. Therefore by decreasing the vibration transmissibility, it may be possible to reduce the protection required of the shipping containers in the unit load. Singh [4] found that by minimizing the vibration transmissibility for a pineapple unit load, vibration damage, such as brushing and abrasion was reduced during transportation.

In the past year major retailers like Wal-Mart have initiated sustainability initiatives over a five year period. One way to achieve this is by reducing overall packaging used by 5%. Primary packaging is where the enclosed product is in direct contact with product. Secondary packaging is outer packaging which encloses primary packaging to protect it from distribution hazards. It is clear that if this new pallet system provides a reduction in damage by attenuating vibration levels, the amount of secondary packaging being used will be reduced by a significant amount and may meet these sustainability targets.

Study Objective

This research investigates a pallet design which has stiffer wood deck boards and a new fastening system that minimizes loosening of the pallet during use. New pallets, fully loaded, were subjected to the distribution vibration testing and compared to Grocery Manufacturing Association (GMA) and Commonwealth Handling Equipment Pool (CHEP) pallets. Four kinds of loads were compared: Apple Juice, Baked Beans, Maple Syrup cases and Diet Coke. Tests were conducted in accordance with standards published by the American Society for Testing and Materials (ASTM).

By comparing transmissibility and resonance of loads on these three pallet types, the results can be used as justification for reducing the secondary packaging for shipping the unit loads. Pallets with lower vibration transmissibility may therefore improve packaging sustainability.

References:

1) LeBlanc Rick and Stewart Richardson, *Pallets- A North American Perspective*, (Ontario: PACTS Management Inc., 2003), 1-12.

2) Timothy G. Weigel, "Modeling the Dynamic Interactions between Wood Pallets and Corrugated Containers during Resonance" (Ph.D. diss., Virginia Polytechnic Institute and State University, 2001), 1-16.

3) Weigel T.G and M.S. White "The Effect of Pallet Connection Stiffness, Deck Stiffness and Static Load Level on the Resonant Response of Pallet Decks to Vibration Frequencies Occurring in the Distribution Environment," *Packaging Technology and Science* 12 (1999): 47-55.

4) Chonhenchob Vanee, Damrongpol Kamhangwong and S. Paul Singh. "Comparison of Reusable and Single-use Plastic and Paper Shipping Containers for Distribution of Fresh Pineapples," *Packaging Technology and Science* 21 (2008): 73-83.

CHAPTER 2: BACKGROUND AND LITERATURE REVIEW

2.1. Introduction

Packaging can be defined as a process which includes preparing products for distribution, marketing, storage and end use. The basic function of a package is to protect and preserve products. In the 20th century, marketing functions have been developed to fulfill consumer demands. Now packaging has evolved to be a science and technology which includes functions like communication, ease of use, child resistance, senior friendliness, aesthetic appeal, environment friendliness as well as protecting products during and after distribution. The whole packaging trade includes raw material acquisition, converting, packaging, suppliers and end users [1].

A system perspective should be kept in mind when packaging is developed. Products should be transported in a manner so that they reach their destination unharmed. The level of packaging required depends on hazards such as handling, shock, compression, environmental conditions and vibration during transportation. Break bulk package shipping is more prone to impacts and is more costly to handle. Unit load systems are better for transportation and handling of mass quantities of packaged products. Three types of unit load systems are generally used: slip sheets, clamp handling units, and pallet loads. Pallets are used more because of the ease of moving them with forklifts and the fact that they are universally accepted [1].

This literature review begins with the history of the pallet industry in the U.S. and how the structural designs have changed. The types of pallets and the grocery industry pooling systems are described. The fundamentals of vibration and dynamic forces during the distribution are reviewed. Chapter 2 ends with a review of previous research on pallets and unit loads, and shows how these studies contributed to packaging improvements for achieving undamaged shipment of products.

2.2. History of Pallets

A pallet is a rigid platform which gives a base to packaged products for storing, handling and transporting as unit loads. Unit loads consolidate products for easy storage and transportation. Pallets are the most effective way to handle unit loads and ship them from one place to another. Palletized loads are stabilized by using stretch or shrink wrap and strapping. A pallet comes in many dimensions but the most commonly used one is 48"x 40" in the United States grocery industry. This is commonly referred to as the Grocery Manufacturing Association (GMA) Standard pallet [3].

Palletizing has gone through different stages in the 20th century. Introduction of forklifts during World War II made it possible to move palletized loads around the world. Pallets were introduced early in World War II when supplies were distributed by ship, air and rail on skids. A skid is a raised platform of wood for holding equipment. Skids could be made manually and locally. But a problem with skids was that irregular-shaped products tend to tip. The tipping problem was resolved with the introduction of the double-decked pallet [2].

The first pallets had only two side stringers (Figure 2.1) because the early lift trucks had only a single platform to lift the unitized loads. Later, the middle stringer and bottom deck were introduced (Figures 2.2, 2.3) which answered issues related to weight distribution, product damage and lateral collapsing. By using a forklift and pallet, three day's work was reduced to four hours, as stated in a railway trade magazine in 1931. A study done by Office of the Quartermaster General in 1941 showed that using forklifts

Different Wood Pallet Configurations during development Stages

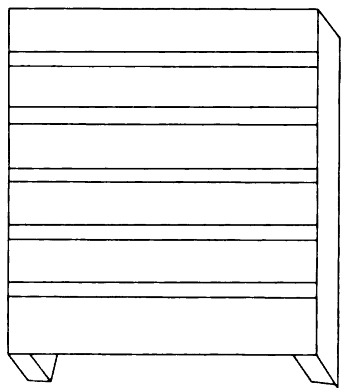


Figure 2.1: Pallet without Middle Stringer and Bottom Deck

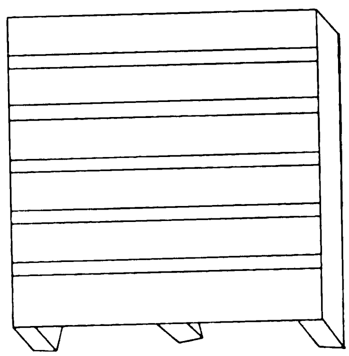


Figure 2.2: Pallet with middle stringer but without Bottom Deck

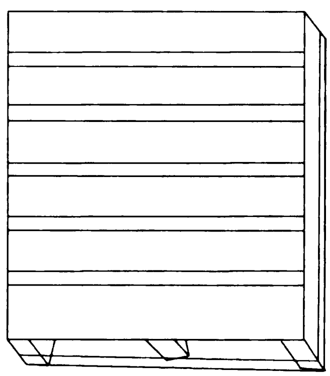


Figure 2.3: Pallet with Middle Stringer and Bottom Deck

and pallets in the military was the most effective material handling practice. This research showed more need for forklifts and pallets in the military, and as a result material handling equipment was developed and manufactured for the military sector. These new processes of material handling made it possible for the US military to distribute materials to forces quickly to two war fronts. This helped the US to win the war [2].

Pallets used during World War II were not standardized for size, because at that time, the bigger concern was unitizing materials and on time delivery. In 1942, studies conducted for standardizing pallet sizes found that 32" x 40" size was best for fitting trucks, railcars and ships. But after this standardization other dimension pallets were still in the supply chain. This caused problems during receiving and loading because someone had to adjust the fork lift opening. The Office of the Quartermaster General found that it was critical to have a consistent pallet dimension. Norman Chaners, working on critical dimensions and designs of pallets focusing on fast handling and efficiency during cross docking in busy shipping environment, invented four-way entry pallets which are now known as block pallets. He also helped to standardize the grocery pallet dimension to 48"x40" which is now used [2].

After World War II most of the food and automotive industries started using unitized loads and forklifts in warehouses for distributing their products. The pallet equipment used during World War II that were left in Australia were taken by the government, which ultimately gave birth to the Commonwealth Handling Equipment Pool (CHEP) Company, whose main work was repairing broken pallets and renting them to industry. CHEP is now the leading international pallet rental. In the US, the Grocery

Manufacturers of America (GMA) started pallet exchange programs and standardized the pallets size of 48"x40" in 1960 [2].

2.3. Pallet Types

While most of the industry uses wooden pallets, there are other materials which are used to make pallets. Plastic, metal and corrugated fiberboard are some materials used for pallets. Each of these materials has advantages and disadvantages.

2.3.1. Wood Pallets

The earliest pallets were made from wood. Wood pallets are constructed using the top and bottom deck boards secured with nails to stringers or blocks. Today in the U.S, 90-95% of pallets are made from wood. For many years the United States Grocery supply chain has used solid wood pallets [8]. Wood pallets can be multiple or single use, depending on the application and the material used [3]. Depending on the end use, hardwood or softwood may be selected. Hardwood pallets can be reused more times and are stronger in comparison to soft wood pallets. They cost in the range of 4-25, depends on design, application and material used. In 2003 typical wood pallet cost still dominated compared to other materials as shown in Figure 2.4 [2].

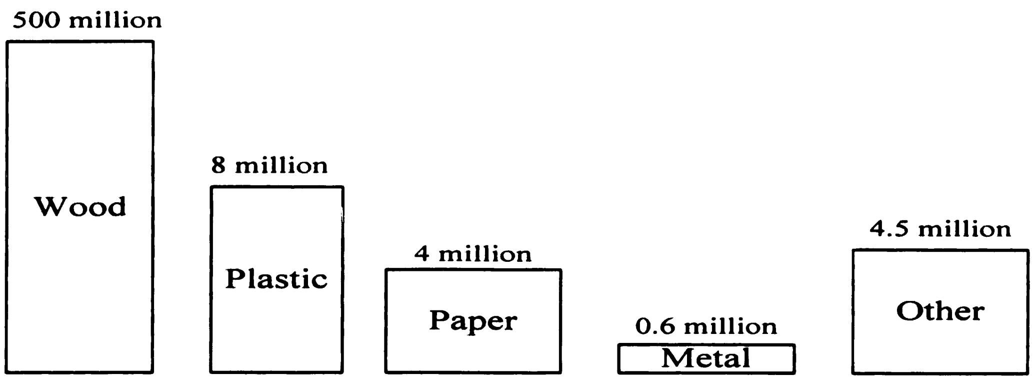


Figure 2.4: Pallet Manufacturing in US in 2003 (Reference: LeBanc 2003, p. 69)

Principally there are two types of wood pallets in industry: stringer and block styles.

2.3.1.1. Stringer

The stringer type is the most common. The stringers can be notched from the sides, making them four way entry for forklifts and pallet jacks. In 1999 it was found that 80 percent of pallets were of the stringer type [2]. Further classification of stringer pallets according to design and to facilitate handling are partial four way entry and reversible pallets. A reversible pallet has alike top and bottom deckboards.

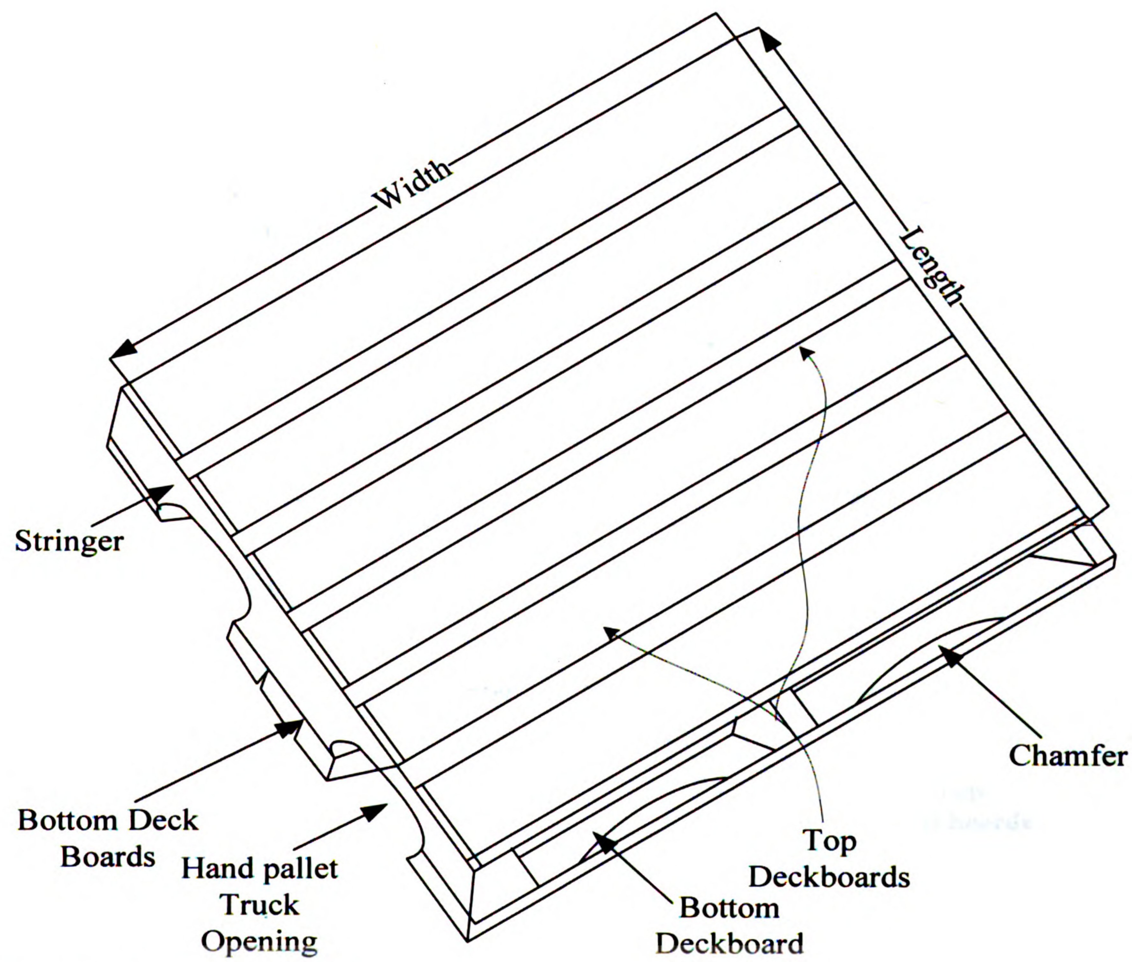


Figure 2.5: Stringer Pallet

2.3.1.2. Block

Block type pallets are full four way entry pallets. They are used mostly by rental pallet companies because these pallets are usually made up of hardwood for multiple use and allow pallet jacks to enter from four sides. Block pallets are classified as four way entry pallets, eight way entry pallets, and reversible pallets according to design and to facilitate handling.

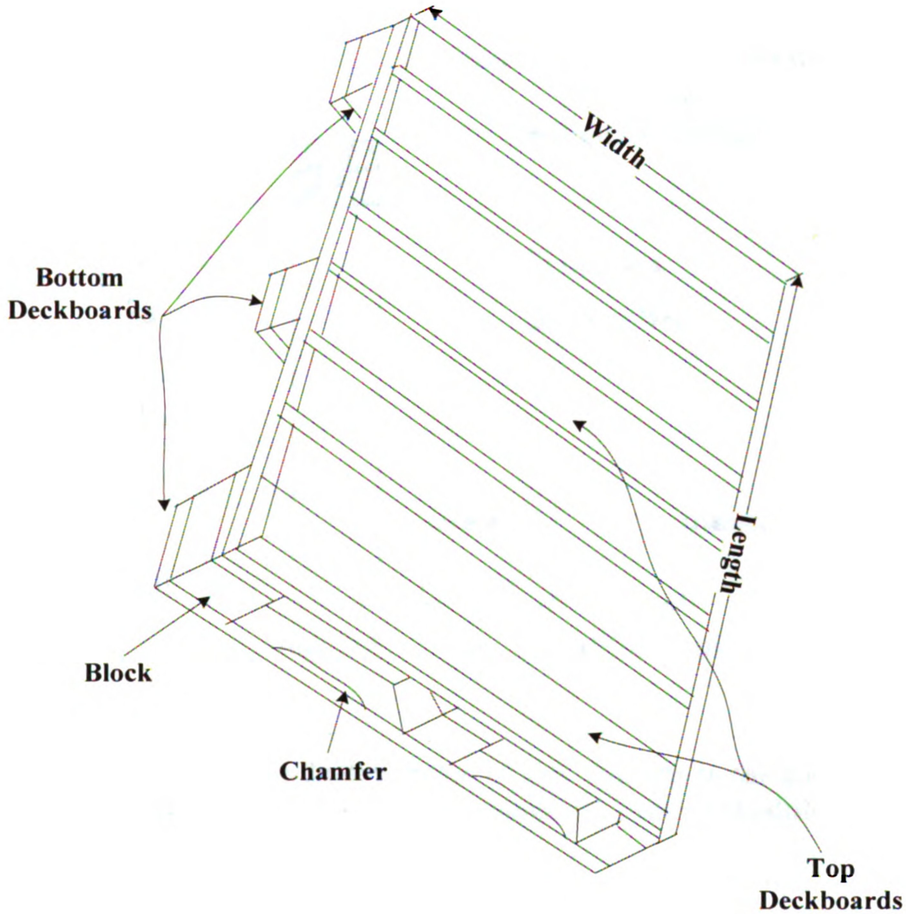


Figure 2.6: Block Pallet

The major concern for the wooden pallet industry is international regulations which can affect manufacturing and use of them in the supply chain. The total size of the wood pallet pool in USA is more than 4 billion [8]. The European Union now requires wood pallets to be bark-free and treated (heat or chemical) before importing shipments of products on them. These treatments increase the cost and make other materials like plastic competitive to the wood pallet manufacturing industry. This makes more use of alternative material pallets in exporting products to the European Union (see Figure. 2.7)

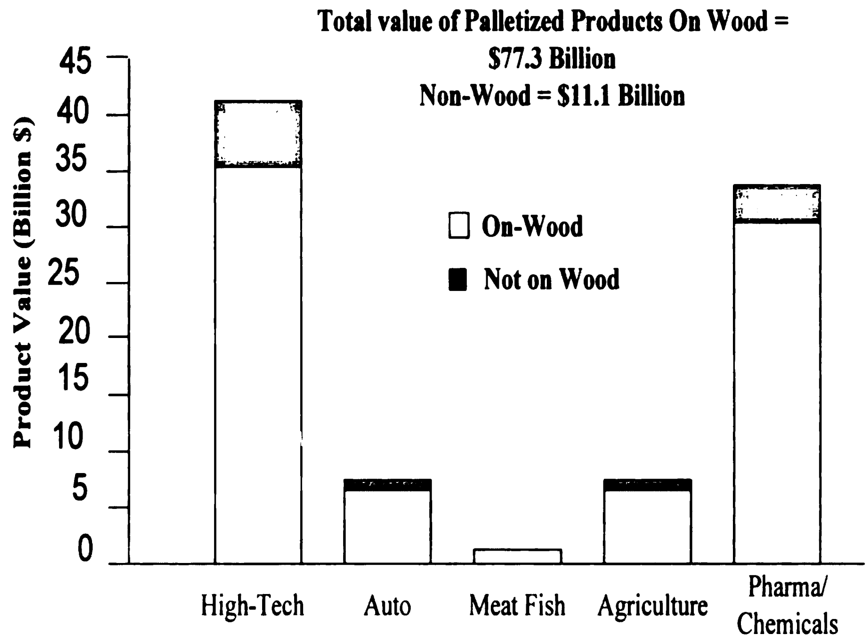


Figure 2.7: Product value by industry sector of U.S. exports to the European Union (source: U.S. Department of Commerce, Harmonized Trade Schedule, 2004 data) [9].

Medical device and pharmaceutical manufacturing companies attempting to deal with fewer regulations started using alternative material pallets for exporting, but still the wood pallets will continue to stay in the market because of their low cost, strength, and their environmentally friendly nature.

2.3.2. Plastic Pallets

There is no doubt that the use of wood pallets in supply chains will continue, but there is increasing use of alternatives because of some limitations of wood are weight, pest infestation, bark impurities, humidity related issues. One of the alternative materials is plastic. Plastic pallets can be made of recycled plastic or virgin plastic resins. A recent study shows that plastic pallets are the best alternative to wood pallets in closed loops and in the industries where the main concern is material flow. These pallets are long-lasting, not prone to insects, moisture resistant, light weight and clean. They are easily sanitized, which is why they are often used in the medical device and food industries. These pallets are generally four way entry for forklifts and can be double faced or single faced. Due to FDA and USDA approval and high impact resistance, they are widely accepted [9].

There are various processes and polymers which can be used for manufacturing plastic pallets. Due to the high cost of the virgin plastic resins, most of companies use recycled plastic resins for manufacturing plastic pallets. They can be made by injection molding or thermoforming. Injection molding uses melted polymer resins and then forces through a die to get the desired shape. In thermoforming, a plastic sheet is preheated and brought it into contact with the mold.

Recycled plastic lumber (RPL) can be used to make plastic pallets which are similar to wood stringer pallets. The main material used for the RPL is high density polyethylene. The Virginia Polytechnic Institute and State University found that the stiffness and flexural strength of these pallets are 10-20 % more than that of wood pallets [4].

The main disadvantage of plastic pallets is their deflection. When the load weight is high or the load is stored for a long time, the deflected parts jam forklifts, and make it difficult to lift. Plastic pallets are less stiff then wood pallets and cost more. They cost in the range of $ 20.00-$ 80.00[6].

2.3.3. Metal Pallet

Metal pallets are durable, fire resistant, do not have moisture-related issues, are stiffer and have no pest related issues. Steel and aluminum pallets are used in closed loop applications and are accepted by the FDA and USDA for use in the food, pharmaceutical, and medical device industries. These pallets cost far more than other types of pallets and are generally used when handling heavy equipment loads [5]. Metal pallets are expensive. The cost for a pallet is around $30-$350 [6].

2.3.4. Corrugated Fiberboard Pallet.

Fiberboard pallets have the advantage of being lighter compared to wood. Increasing fuel prices make them a viable alternative to wood, with comparative performance. They are economical for one-way shipping. They are inexpensive. The cost per pallet ranges from $3.00-$7.00 [7]. Fiberboard pallets can be affected by humidity, and so are not recommended for long time or outside storage [7].

2.4. Pallet Rentals.

As standardization increases, pallet rental systems have developed. In grocery distribution, rental companies collects empty pallets from retailers, receive them back to repair, and then deliver them to manufacturers to be refilled. The major benefits of a rental pool are standard size, quality in distribution, reuse and price standardization. CHEP has been a leader in the field of rental pallets since the 1950s. Other pallet companies like National Pallet Leasing System, Inc. operate in North America with around 40 supply companies which participate in pooling. But CHEP is the largest and longest established. It has around 106 pallet supply depots [6].

2.5. Transmissibility

During distribution, every package experiences dynamic forces due to the movement of the trailer floor. Every package/product reacts differently to this vibration according to its center of gravity, size, weight, stiffness and the base on which it is shipped. Awareness of the reaction of the product to these vibration levels leads to a better design of the package and distribution system. Products, packages and pallet loads are "spring-mass systems". This means that they behave like the model shown in Figure 2.8.

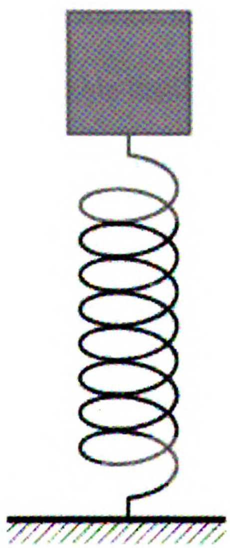


Figure 2.8: Spring Mass System.

In a drop onto the floor, they tend to vibrate during and after the impact at a characteristic frequency called its natural frequency. When placed on the floor of truck trailer, which tends to vibrate at its own natural frequency during travel, these spring-mass systems can experience amplified motion. When the natural frequency of the product, package or pallet load matches the natural frequency of the truck trailer floor, a condition known as resonance occurs. At resonance, the movement of the product, package or pallet load is greatest. This can easily lead to damage. Most trailers tend to vibrate between 2 and 8 Hz. 1 Hz. is one cycle per second. One cycle is one complete up and down motion of the floor. Railcars have about the same natural frequency range. So if a product, package or pallet load has a natural frequency in the 2-8 Hz range, there is a strong possibility that resonance will occur.

To study the effects of vibration, packages and pallet loads are tested on a vibration table. The table can be made to move up and down at any frequency and the amplitude of motion can also be varied. An accelerometer placed on top of the package or pallet load can be used to measure the vibration level in g's. A "g" is the acceleration due to gravity. An accelerometer placed on table itself measures the "input" acceleration. The ratio of the output acceleration (package or pallet load) to input acceleration (table) is the "transmissibility". This ratio is also called the magnification factor. The transmissibility will depend on the table frequency. It will be largest at resonance. In theory, for a single spring-mass system with natural frequency f_n on a vibration table that is vibrating at frequency f_f,

$$\textbf{Magnification Factor} = 1/(1-(ff/fn)\ )^2 = \textbf{(Package g's) / (Table g's)}$$

A plot of magnification factor versus frequency ratio f_f / f_n is shown in Figure 2.9.

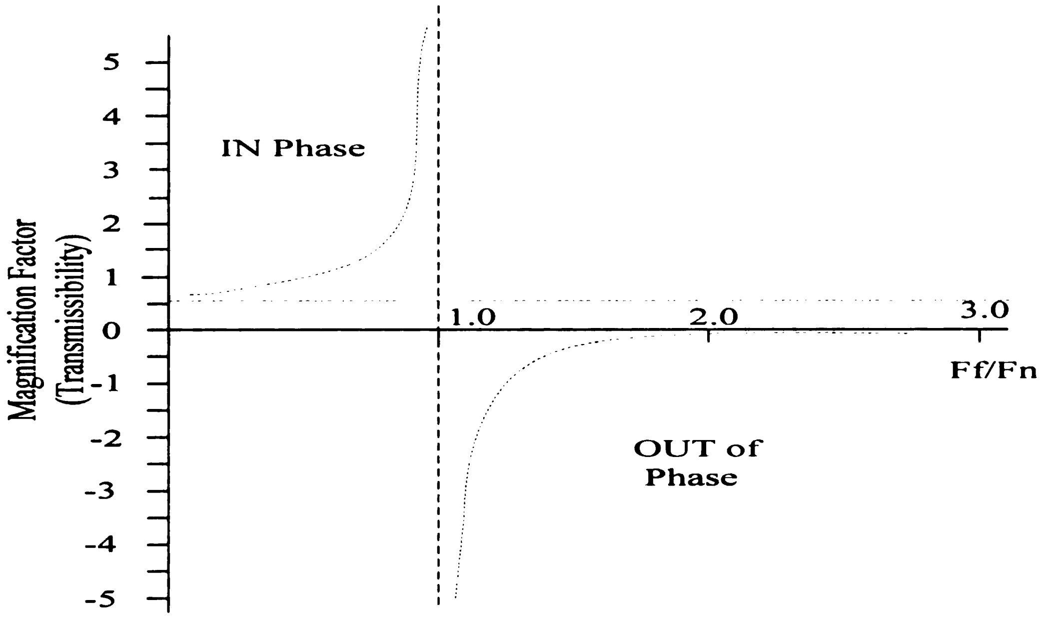


Figure 2.9: Transmissibility

Many researchers have shown that high transmissibility during transportation of unit loads can damage the product. For controlling resonance, packaging plays an important role. Stiff support systems like pallets raise f_n and lower the transmissibility.

Bundit Jarimopas [11] studied vibration levels in commercial truck shipments on roads in Thailand. The results of study shows that different truck suspension systems, roads, locations and the speeds can produce vibration levels that damage fruits. G.L Barchi [12] studied the distribution environment for loquats. He used PSD plots to drive a vibration table so that different packages could be studied in the lab. Almost 80-100% were damaged in the existing package. The use of vibration absorbing sheets reduced the damage to 20-40 %.Singh S.P [13] discovered that the primary package is the key component in reducing transmissibility during transportation. Bruising of strawberries was reduced when the primary packaging changed. Magnification factors at resonance

(6.5-10 Hz) of old stacked containers decreased from 4.9 to 3.3 at resonance (7-9 Hz) for a new package.

Timothy Weigel [14] found that transmissibility can be reduced if the deck boards of pallets are made stiffer and joints are made rigid. When the load weight increases, transmissibility increases. Fixed joint pallets show 16% less transmissibility than pinned joint ones. The stiffer the deck boards, the smaller the transmissibility at resonance. He concluded that pallet design and materials are critical in today's distribution environment for protecting the product. The transmissibility of the system depends on the weight of the unit load on the pallet and the stiffness of the pallet. Controlling these two factors during transportation could reduce the hazard to the package.

References:

1) Soroka.Walter, *Fundamentals of Packaging Technology* (Virginia: Institute of Packaging Professionals, 1995), 389-400.

2) LeBlanc Rick and Stewart Richardson, *Pallets-A North American Perspective* (Ontario: PACTS Management Inc., 2003), 1-12.

3) Twede Diana and Susan E.M. Selke, *Cartons, Crates and Corrugated Board: Handbook of Paper and Wood Packaging Technology*, (Pennsylvania: DEStech Publications Inc., 2005) 155-168.

4) Hamner Peter and Marshall White, "Is Recycled Plastic Lumber a Viable Alternative for Pallets," PALLET ENTERPRISE, November 2006, http://www.palletenterprise.com/articledatabase/view.asp?articleID=2086 (accessed March 23, 2010).

5) Brindley Chaille, "Alternative Pallet Materials 101," PALLET ENTERPRISE, November 2006, http://www.palletenterprise.com/articledatabase/view.asp?articleID=2080 (accessed Feb 22, 2010).

6) Grewal Gary Singh, "Performance Comparison of Plastic and Wood Pallets for Static and Dynamic Tests" (MS Thesis, Michigan State University, 1994), 1-14.

7) Anderson Marvin, "Recyclable, Heavy Duty, light weight, Moisture Resistant, Corrugated Fiberboard Pallet," (US Patent 5941177, 1999), 8-24.

8) Ray Charles D., John J. Janowiak, Judd H. Michael, and Hrabrin Bachev, "Economic and Environmental Impact Assessment of Proposed Bark-Free Requirements for Wood Pallets in International Trade," *Journal of Forest Products Business Research* 4(2007): 1-25.

9) Twede Diana, Diane Mollenkopf, and Cristina Guzman-Siller, "A Market–Driven Investigation of pallet Trends in Grocery Chains" *Journal of Food Distribution Research*, 38 (2007): 161-169.

10) Brandenburg Richard K. and Julian June-Ling Lee, *Fundamentals of Packaging Dynamics* (MTS System Corporation, 1985), 45.

11) Jarimopas Bundit, S. Paul Singh and Wasan Saengnil, "Measurement and Analysis of Truck Transport Vibration levels and Damage to packaged Tangerines during Transit," *Packaging Technology and Science* 18 (2005): 179-188.

12) Barchi G.L, A. Berardinelli, A. Guarnieri, L Ragni and C. Totaro Fila, "PH-Postharvest Technology: Damage to Loquats by Vibration-simulating Intra-State Transport," *Biosystems Engineering* 82 (2002): 305-312.

13) Singh, S. P., "New package system for fresh berries," *Packaging Technology and Science* 5 (1992): 3-10.

14) Weigel T.G and M.S. White, "The effect of pallet connection stiffness, deck stiffness and static load level on the resonant response of pallet decks to vibration frequencies occurring in the distribution environment," *Packaging Technology and Science* 12 (1999): 47-55.

CHAPTER 3: MATERIALS, TEST EQUIPMENT AND METHODS

In this study, three different pallets were subjected to vibration. Two of these pallets are currently used in the industry. They are CHEP (GMA-2) and GMA-1 pallets. These two are compared to the new "Dowel Pallet". Four types of packages were used to build pallet loads. These included cased goods, carbonated beverage cans in cartons, packaged processed food, and juice in cans.

3.1. Pallet Types

3.1.1. Dowel Pallet This is a block type pallet. The pallet dimensions are 48"x40"x 5½" and it weighs 49 lbs. This pallet is made of hardwood and has a wooden dowel fastening system. The dowels replace the nails in a typical pallet. The dowels can be seen in Figure 3.1. This is a four way entry pallet and is non reversible.

Figure 3.1: Dowel Pallet

3.1.2. G.M.A. Pallet-1 This is shown in Figure 3.2. It is a stringer type pallet. The pallet dimensions are 48"x40"x4 ¾" and it weighs 48 lbs. This pallet is made of hardwood and uses nails as the fastening system for the stringers and the top/bottom deck boards. It is a two way entry pallet for pallet jacks and four way for fork trucks. This is non reversible.

Figure 3.2: G.M.A-1 Pallet.

3.1.3 GMA Pallet-2 This is shown in Figure 3.3. It is a stringer type pallet. The pallet dimensions are 36"x36"x 4 7/8" and it weighs 33 lbs. The pallet is square and is used for shipping Diet Coke. The fastening system on this pallet is nails which connect the bottom/top deck boards to the stringer. This is a two way pallet.

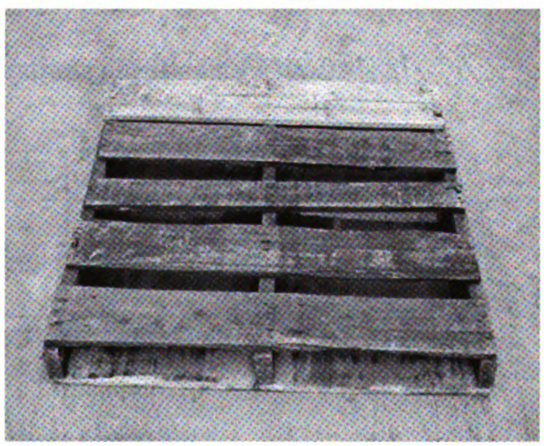


Figure 3.3: G.M.A Pallet-2 used to ship Diet Coke.

3.2. Accelerometer Piezoelectric accelerometers were used to measure the input (vibration table) and response (pallet load) accelerations during vibration. The specifications are shown in Table 3.1. The input accelerometer was under the table and the response accelerometer was on the top package of the pallet load. It was mounted using Super Glue.

Accelerometer	Input Accelerometer	Response Accelerometer
ID	2052616	4210
Channel	1 (under the table)	2 (On top of Unit Load)
Sensitivity	50.06 mv/G	49.71 mv/G
Full Scale	199.76 G's	201.17 G's

Table 3.1: Accelerometer Details.

3.3. Electro Hydraulic Vibration Table

A single degree of freedom (up/down) vibration table was used to vibrate the pallet loads. The specifications are shown in Table 3.2.

Company	Model number	Table size
Lansmont Corporation Monterey CA	10000-10	60" x 60" Platform

Table 3.2: Electro Hydraulic Table Details.

3.4. Test Methods and Data Collection

Vibration tests were conducted using sinusoidal and random vibration. The test methods used were ASTM D999-08 for sinusoidal vibration and ASTM D4728-06 for random vibration. Accelerometers attached to the table and pallet load measured transmitted vibration levels.

3.4.1. ASTM D999-08 [1] is the American Society for Testing and Materials Standard Test method for Vibration Testing of Shipping Containers. This test is used for the performance of products in packages. Method C was used for this study. This standard uses a sinusoidal vibration system to find the resonance frequency of the package or unit load. Guide fences are used to restrict horizontal movement during vibration. The vibration table is made to vibrate up and down with a gradually increasing frequency. The frequency range covered is 3-100 Hz at a sweep rate of 1 octave per minute with a constant acceleration of 0.50 g's.

3.4.2. ASTM D4728-06 [2] is the Standard Test Method for Random Vibration Testing of Shipping Containers. This method uses Power Spectral Density (PSD) plots to direct the hydraulic vibration table. Assurance level-II (average conditions) was used for testing pallet loads. The setup is similar to the sinusoidal method.

3.5. Test setup

The input accelerometer was mounted underneath the vibration table and two response accelerometers were attached to the top of the unit load. All three accelerometers were oriented with their axes in the vertical direction. One response accelerometer was located directly above the front deck board's right edge (location A) and other above the left edge (location B). Two locations were selected to get symmetrical results at two points. See Figure 3.4. The vibration signals were sent from the accelerometer through a cable to the sensor of the Laser USB Vibration Control

Interface (Shaker Control System). The computer system has Test Partner (Lansmont, Version 2) software which records the data from the accelerometers and gives the transmissibility in the form of a graph.

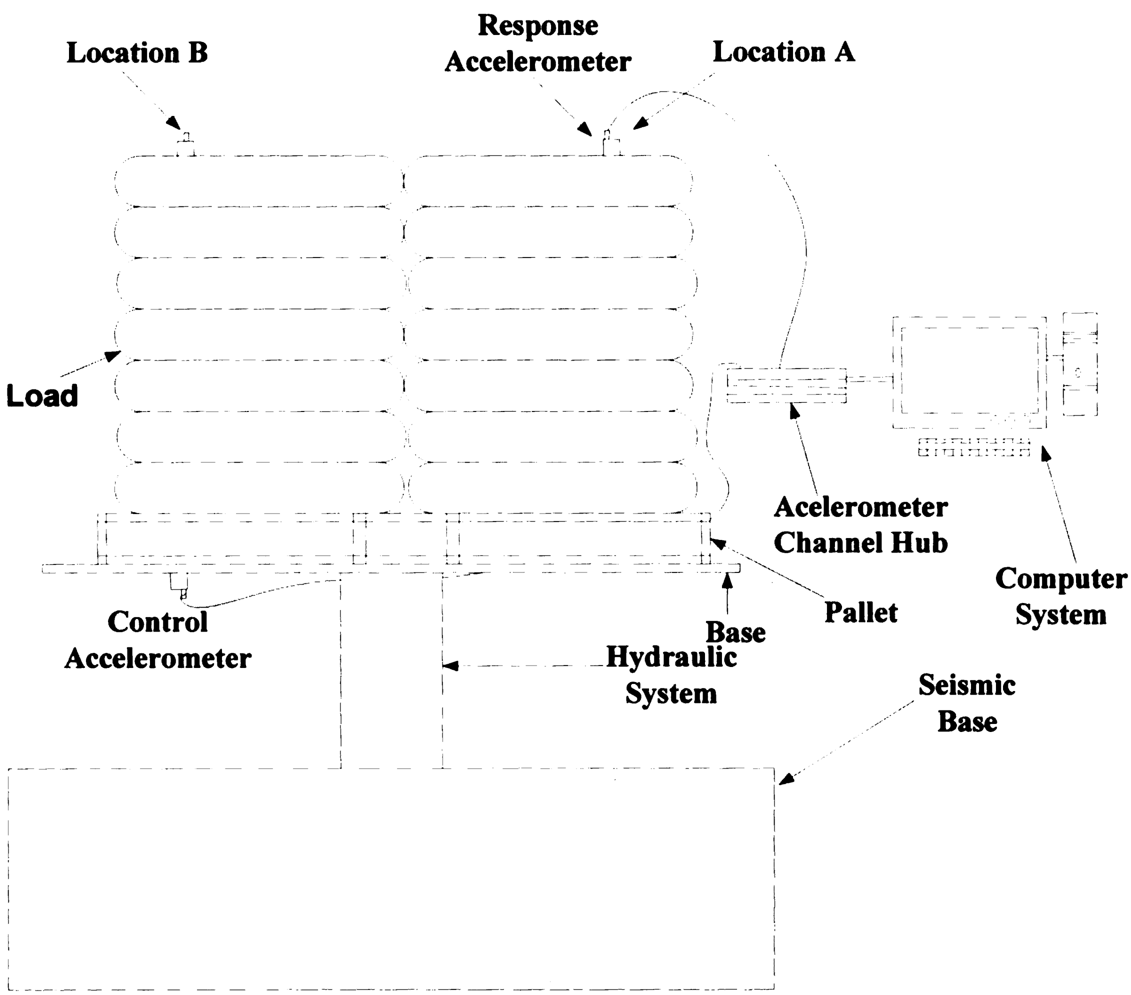


Figure 3.4: Set up

Four different unit loads were tested. Table 3.3 describes the pallet loads. Appendix A shows additional pictures of these same pallet loads. The accelerometers were always at same locations for collecting data. Figures 3.5-3.8 show them.

Product	Unit Load Weight (Dowel Pallet)	Unit Load Weight (G.M.A. Pallet)
Apple Juice	2353 lbs	2352 lbs
Baked Beans	2107 lbs	2106 lbs
Maple Syrup Cases	279 lbs	278 lbs
Diet Coke	1849 lbs	1953 lbs (G.M.A.-2 Pallet)

Table 3.3: Unit Loads

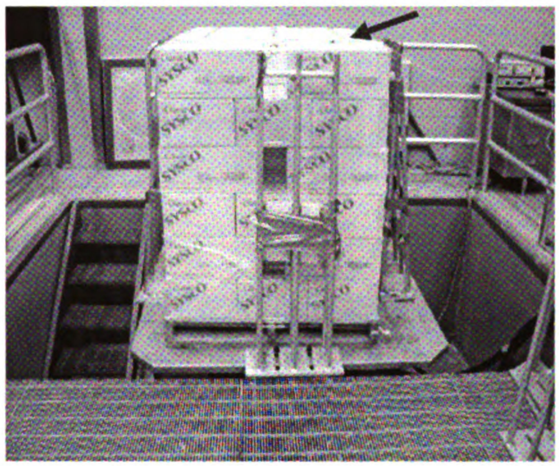


Figure 3.5: Apple Juice

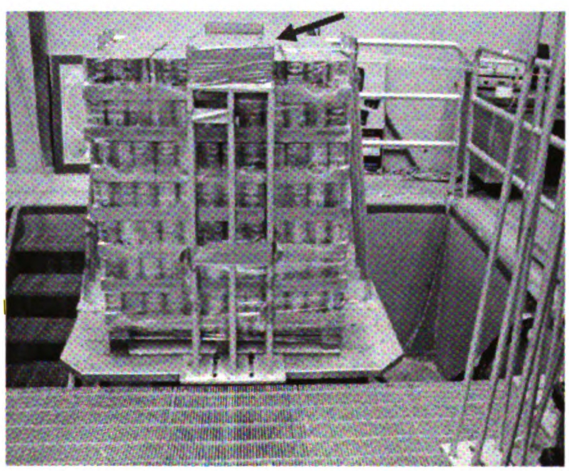


Figure 3.6: Baked Beans

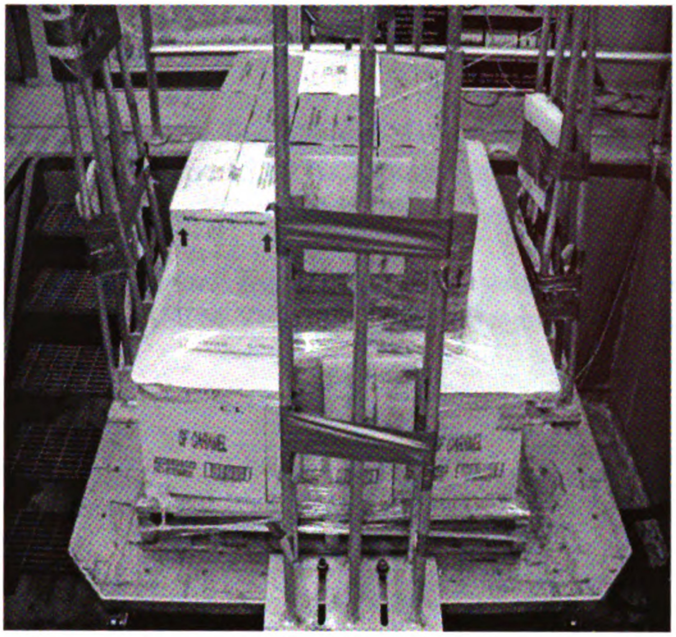


Figure 3.7: Maple Syrup Cases

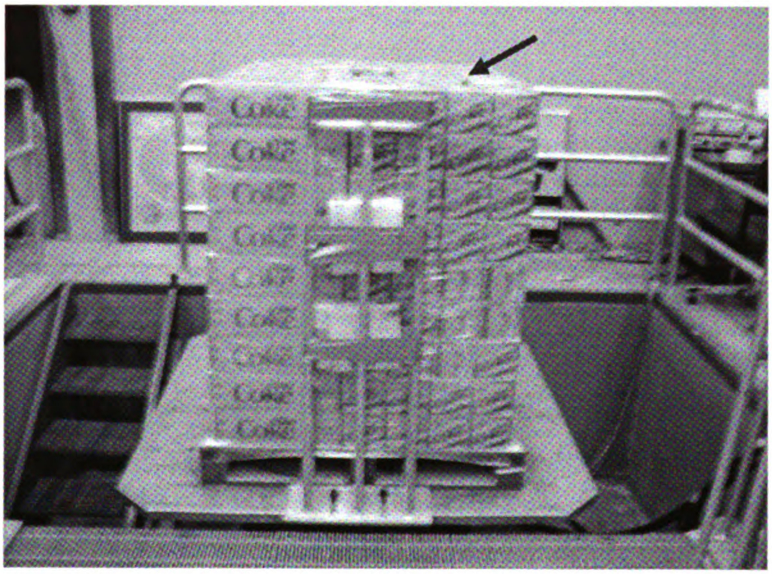


Figure 3.8: Diet Coke

References:

1.) ASTM D999 - 08 *Standard Test Methods for Vibration Testing of Shipping Containers*, ASTM Volume 15.10 Packaging; Flexible Barrier Packaging.

2.) ASTM D4728 - 06 *Standard Test Method for Random Vibration Testing of Shipping Containers*, ASTM Volume 15.10 Packaging; Flexible Barrier Packaging

CHAPTER 4: RESULTS

4.1 Sine Vibration Results

The Dowel Pallet, the G.M.A-1 and G.M.A.-2 pallets were compared using sinusoidal vibration. Method ASTM D999-08 was followed using a 3-100 Hz frequency sweep at 0.5 G peak. Tables 4.1 and 4.2 show resonant frequency and transmissibility values obtained from the sinusoidal vibration plots in Appendix B. The results show that transmissibility is lower and the resonant frequency is higher for Dowel pallet unit loads compared to the both G.M.A-1 and G.M.A-2 pallets. This is due to the greater stiffness of the Dowel pallets. The dowel fastening system appears to make it a more rigid platform compared to the G.M.A pallets.

Unit Load	Apple Juice	Apple Juice	Apple Juice	Apple Juice	Baked Beans	Baked Beans	Baked Beans	Baked Beans
Pallet Type	GMA-1	Dowel	GMA-1	Dowel	GMA-1	Dowel	GMA-1	Dowel
Location	A	A	B	B	A	A	B	B
Resonance frequency in Hz.	7.3	7.7	7.2	7.5	8.7	8.9	11.1	11.3
Transmissibility	4.4	3.2	4.1	3.7	3.4	3.0	3.3	2.9

Table 4.1: Transmissibility and resonant frequency values for Apple Juice and Baked Beans

Unit Load	Maple Syrup Cases	Maple Syrup Cases	Maple Syrup Cases	Maple Syrup Cases	Diet Coke	Diet Coke	Diet Coke	Diet Coke
Pallet Type	GMA-1	Dowel	GMA-1	Dowel	GMA-2	Dowel	GMA-2	Dowel
Location	A	A	B	B	A	A	B	B
Resonance frequency in Hz.	9.8	14.7	9.1	13.1	12.8	16.8	12.6	14.6
Transmissibility	4.3	1.90	4.5	2.3	3.2	2.3	3.2	2.3

Table 4.2: Transmissibility and resonant frequency values for Maple Syrup Cases and Diet Coke

4.2 Random Vibration Results

Appendix C shows the input and response Power Spectral Density plots for all tests. The response plots are compared in the 1-10 Hz range because this range causes most of the floor motion. Most damage is attributed to this range. The PSD plots are also compared in the 1-100 Hz range. The results are shown in Tables 4.3, 4.4, 4.5 and 4.6.

The data shows that there is a significant reduction in transmitted vibration between the GMA wood pallets and the Dowel pallet. The Dowel pallet significantly reduced the amount of energy transmitted to the load, so the amount of primary and secondary packaging may be able to be reduced when using Dowel pallets.

Unit Load	Apple Juice	Apple Juice	Apple Juice	Apple Juice	Baked Beans	Baked Beans	Baked Beans	Baked Beans
Pallet Type	GMA-1	Dowel	GMA-1	Dowel	GMA-1	Dowel	GMA-1	Dowel
Location	A	A	B	B	A	A	B	B
GRMS Value	0.78	0.69	0.77	0.64	0.51	0.49	0.52	0.47

Table 4.3: Grms values in the 1-10 Hz. range for Apple Juice and Baked Beans

Unit Load	Cases	Cases	Cases	Cases	Diet Coke	Diet Coke	Diet Coke	Diet Coke
Pallet Type	GMA-1	Dowel	GMA-1	Dowel	GMA-2	Dowel	GMA-2	Dowel
Location	A	A	B	B	A	A	B	B
GRMS Value	0.62	0.38	0.62	0.41	0.42	0.39	0.42	0.37

Table 4.4: Grms values in the 1-10 Hz. range for Maple Syrup Cases and Diet Coke

Unit Load	Apple Juice	Apple Juice	Apple Juice	Apple Juice	Baked Beans	Baked Beans	Baked Beans	Baked Beans
Pallet Type	GMA-1	Dowel	GMA-1	Dowel	GMA-1	Dowel	GMA-1	Dowel
Location	A	A	B	B	A	A	B	B
GRMS Value	2.87	1.46	1.48	1.40	1.63	1.60	1.63	1.53

Table 4.5: Grms values in the range 1-100 Hz. for Apples and Baked Beans

Unit Load	Cases	Cases	Cases	Cases	Diet Coke	Diet Coke	Diet Coke	Diet Coke
Pallet Type	GMA-1	Dowel	GMA-1	Dowel	GMA-2	Dowel	GMA-2	Dowel
Location	A	A	B	B	A	A	B	B
GRMS Value	1.55	1.39	1.56	1.39	2.08	1.70	1.85	1.64

Table 4.6: Grms values in the range 1-100 Hz. for Maple Syrup Cases and Diet Coke

The GRMS values in the tables are measures of the overall severity of the vibration levels experienced. The higher the rms G, the more intense the vibration. A comparison was done using differences in GRMS values for the Dowel Pallet and

G.M.A-1 and G.M.A.-2 pallets at location A and location B. The percent differences in means and standard deviations are shown in Tables 4.7 and 4.8.

Unit Load	Apple Juice	Baked Beans	Cases	Diet Coke
Location A	11.7	3.5	38.7	5.9
Location B	17.6	9.3	33.7	11.9
Mean	14.6	6.4	36.2	8.9
S.D	4.1	4.1	3.5	4.2

Table 4.7: Percentage Reduction in Grms values in the 1-10 Hz range

Unit Load	Apple Juice	Baked Beans	Cases	Diet Coke
Location A	49.2	1.7	9.8	18.1
Location B	5.5	6.1	10.7	11.1
Mean	27.3	3.9	10.3	14.6
S.D	30.9	3.1	0.6	4.9

Table 4.8: Percentage Reduction inGrms values in the 1-100 Hz range

CHAPTER 5: CONCLUSIONS

This study compared the vibration levels experienced by four different palletized products on GMA pallets and "Dowel" pallets. The results show that in all four cases, the Dowel pallet reduces the amount of vibration to the product. This is due to the stiffness of the pallet deck. As a result, the amount of primary and secondary packaging needed to protect products during shipping and handling may be able to reduce.

Locations A and B gave different results during vibration testing. This may be due to the product shifting. In case of sinusoidal vibration, the results differ more than in the case of random vibration results.

From the engineering theory of elastic beams [1], the deflection of the deckboards midway between the stringers depends on the weight W on the deck board, the width b and thickness t of the deck board, and the unsupported length (span) L between the stringers. For the situation shown in Figure 5.1, the midspan deflection is

$$d = \frac{CW}{b} \left(\frac{L}{t}\right)^3 \qquad (5.1)$$

where C is a constant that depends on the modulus of elasticity (stiffness) of the wood and the type of end support. For a "fixed end" where the deck board is rigidly attached to the stringers, C is lower than for "pinned ends", where the deck board is loosely attached.

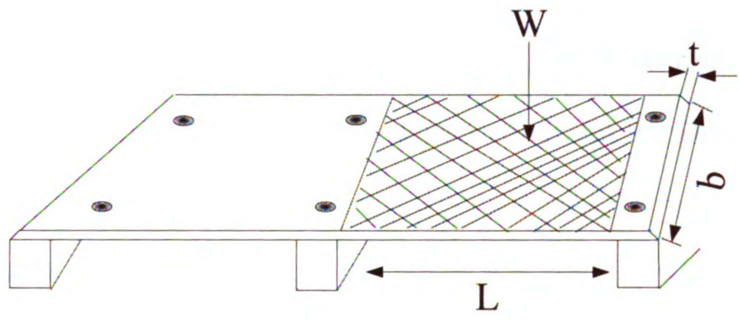


Figure 5.1: Deck board with weight W on Unsupported Span L

The three pallets tested had different deck board dimensions. The deck board thickness t, total width b of all deck boards together, and span L for the Dowel pallet and the G.M.A.-1 pallet are shown in Table 5.1.

	Dowel Pallet	G.M.A.-1
Thickness (t)	0.625"	0.4375"
Span (L)	16.125"	18.1875"
Total Width (b)	39.45"	26.57"

Table 5.1: Deck board dimensions for Dowel and G.M.A. pallets

From Table 3.3, the total weight of the apple juice pallets was 2350 lbs for the Dowel and G.M.A-1 pallets. So W in Equation 5.1 was the same for both. Using the dimensions in Table 5.1, the deflections are

$d = CW/39.45(16.125/0.625)^3 = 435\ CW$ for the Dowel pallet

$d = CW/26.57(18.188/0.4375)^3 = 2700\ CW$ for the G.M.A.-1 pallet

The midspan deflection of a deck board on the G.M.A.-1 pallet is therefore 2700/435=6.2 times that for the Dowel pallet. This is due primarily to the thinner deck boards used on the G.M.A. pallet, the longer span, and the shorter width. So the Dowel pallet is much stiffer.

The Dowel pallets used a wooden dowel system for fastening the deck boards to the blocks. This is helpful when using RFID technology during shipment of these products because there is no interference from metal nails or screws. Recyclability is also better because the wooden fastener system will not damage the saw during cutting. In G.M.A. pallets, loosening of the nails or screws could damage the product and packaging during distribution. It could also cause the stiffness to decrease even further, making the transmissibility higher.

It is not clear how effective the dowel fastening system is compared to nails. In theory it should be better, meaning a stiffer pallet and lower transmissibility. The results of this study by themselves cannot be used to answer this question because the three pallets tested had different h, b and t dimensions. To make a fair comparison and there for be able to identical pallets should be constructed and tested: one with nails and the other with dowels.

The testing should also be done on metal pallets because they provide the stiffest base compared to all other pallet manufacturing materials. This should give the low transmissibility. Pallet deckboard stiffness does not guarantee a reduction in the transmissibility, because movement of the package/products in unit load offset the results too.

Using stiffer pallets may cut costs for primary and secondary packaging, but at the same time we are buying more expensive pallets. Another consideration is that if use a stiffer pallet, and do not find any more damage during testing than with the existing G.M.A pallets, then we are wasting money More studies should be done with reduced primary and secondary packaging on these pallets to compare damage.

References:

1.) Beer Ferdinand Pierre and E. Russell Johnston, Jr., *MECHANICS OF MATERIALS*, (New York,: McGraw-Hill Book Company, 1981), 416.

Appendix A

Product and Pallet Configurations

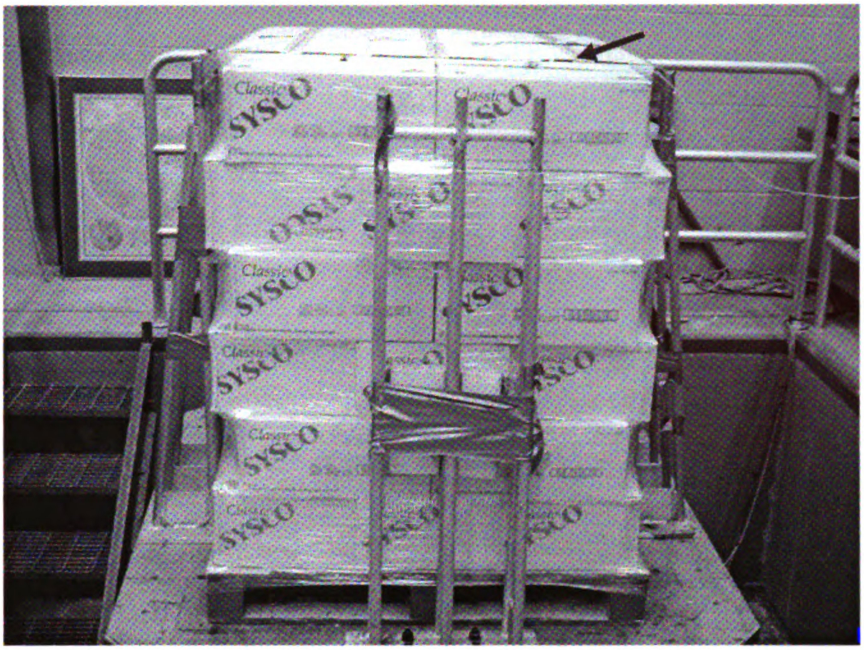


Figure A.1: Dowel Pallet, Apple Juice, Accelerometer Location A

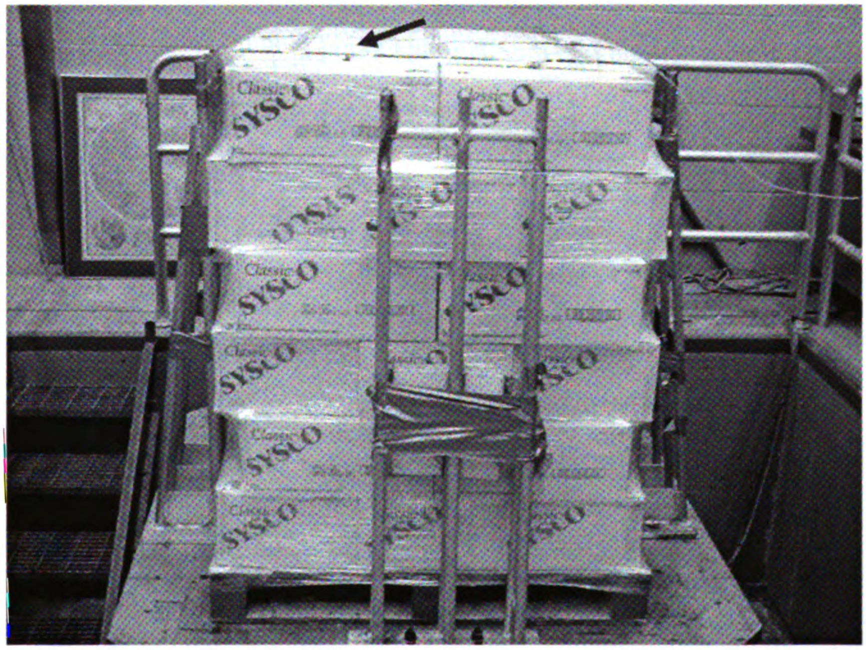


Figure A.2: Dowel Pallet, Apple Juice, Accelerometer Location B

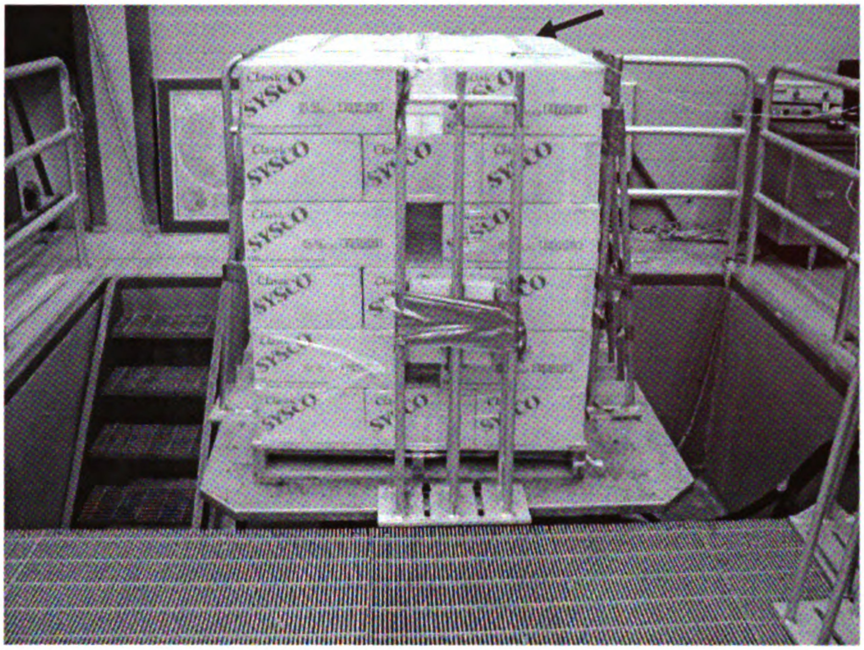


Figure A.3: G.M.A -1 Pallet, Apple Juice, Accelerometer Location A

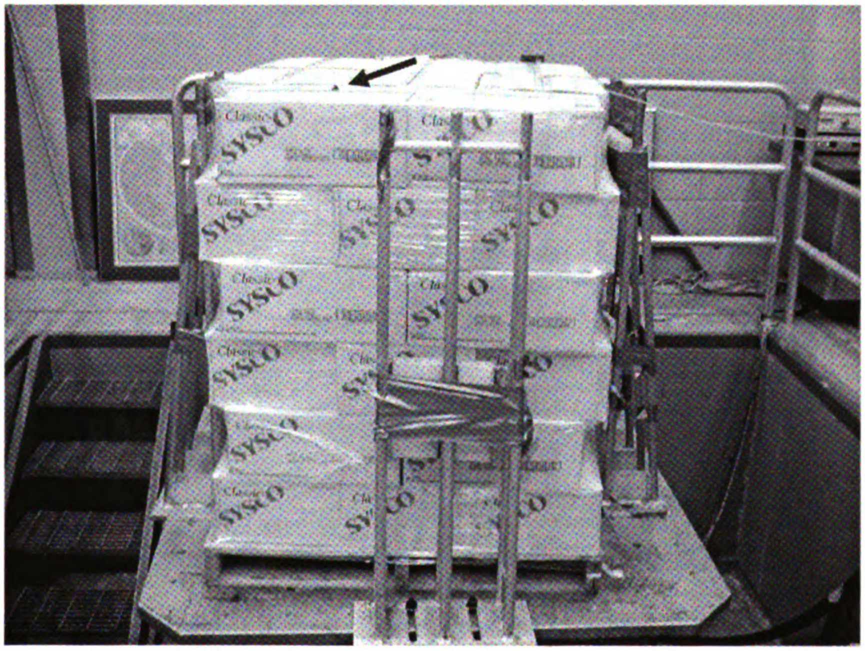


Figure A.4: G.M.A.-1 Pallet, Apple Juice, Accelerometer Location B

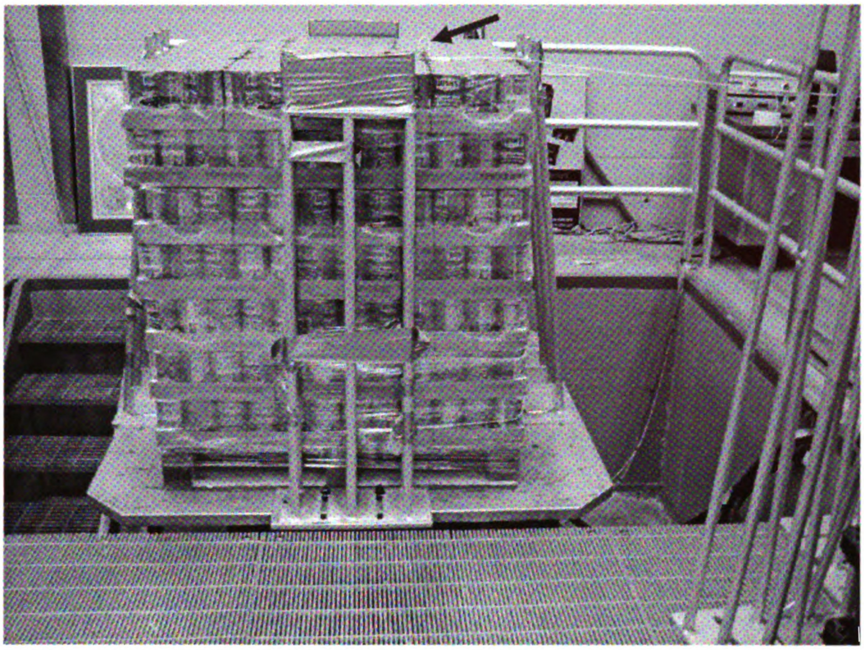


Figure A.5: Dowel Pallet, Baked Beans, Accelerometer Location A

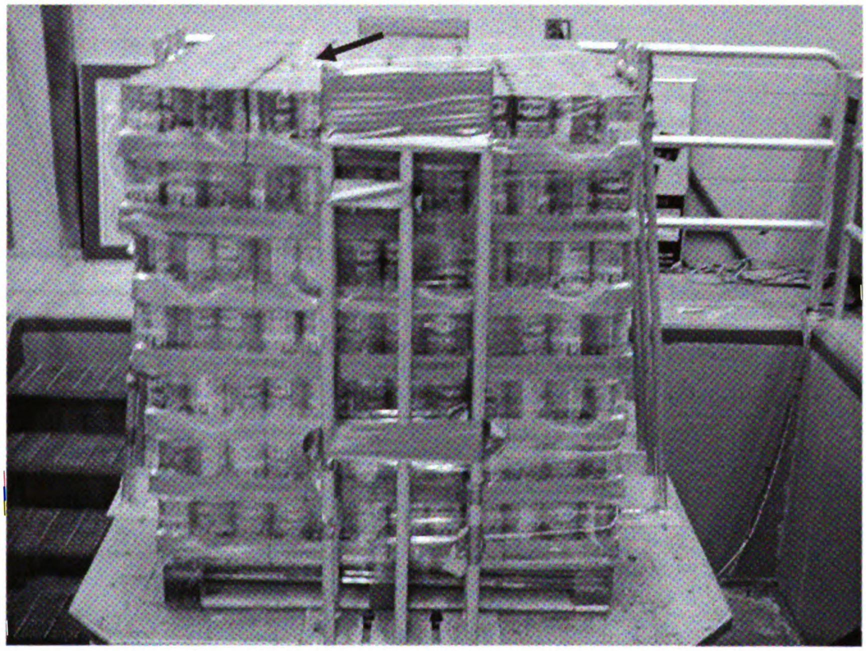


Figure A.6: Dowel Pallet, Baked Beans, Accelerometer Location B

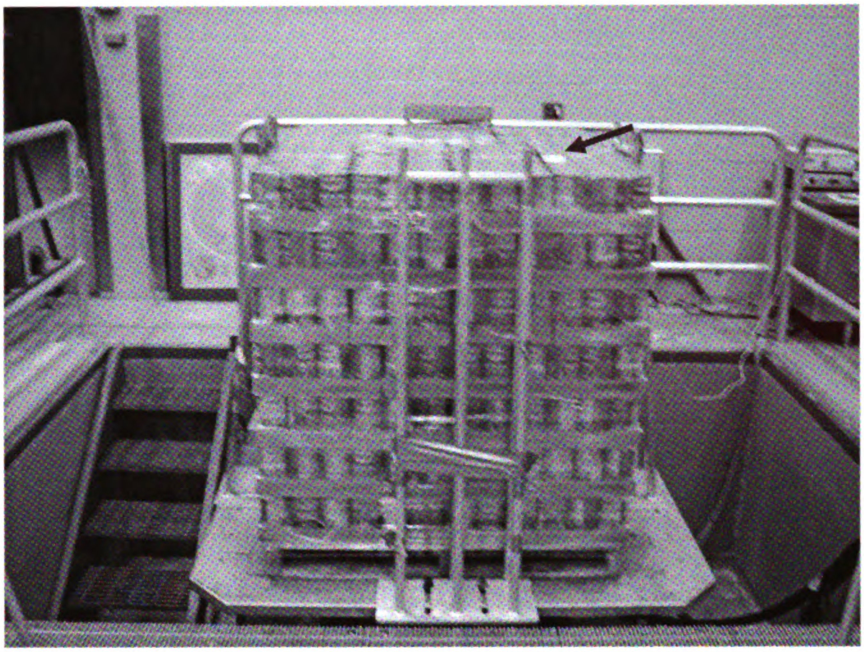


Figure A.7: G.M.A.-1 Pallet, Baked Beans, Accelerometer Location A

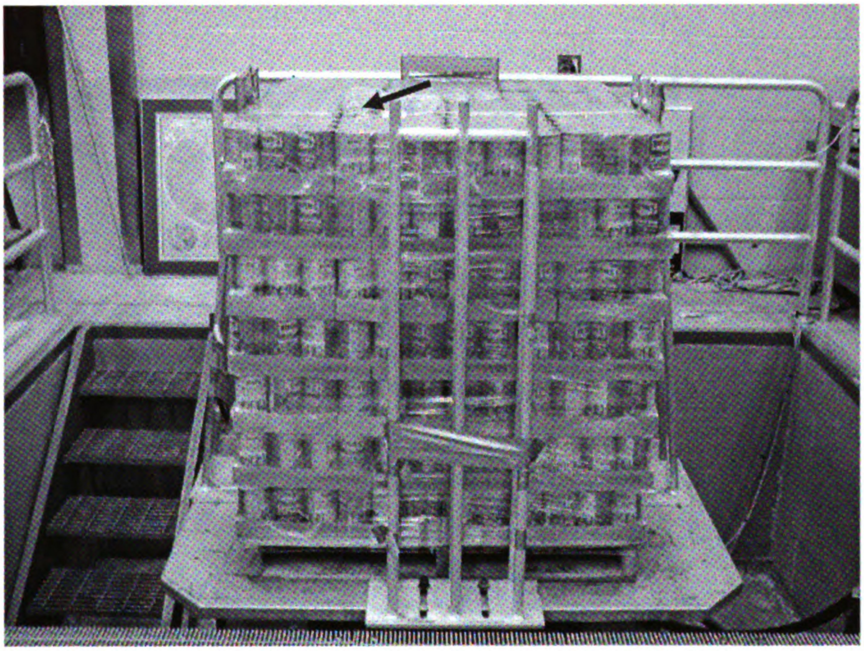


Figure A.8: G.M.A.-1 Pallet, Baked Beans, Accelerometer Location B

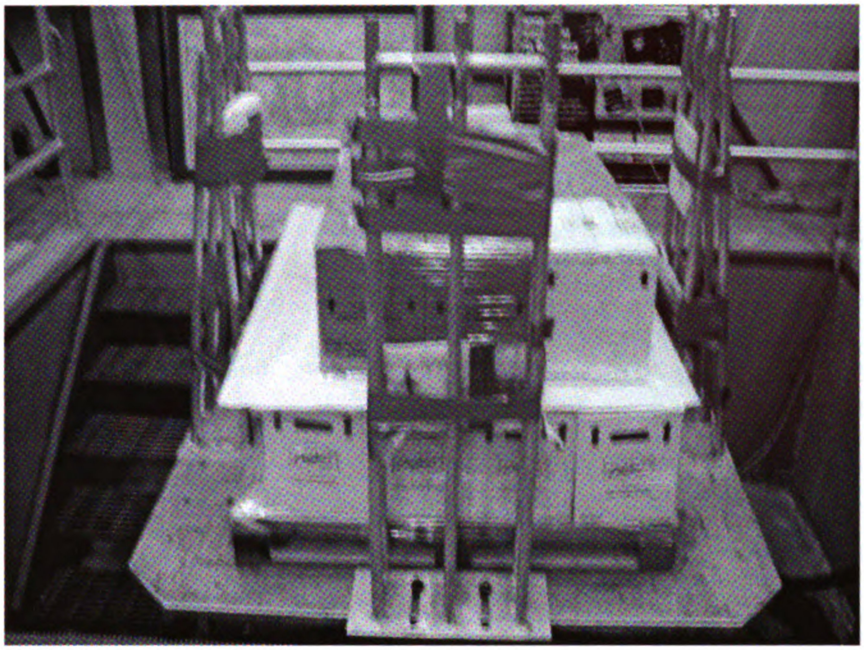


Figure A.9: Dowel Pallet, Maple Syrup Cases, Accelerometer Location A

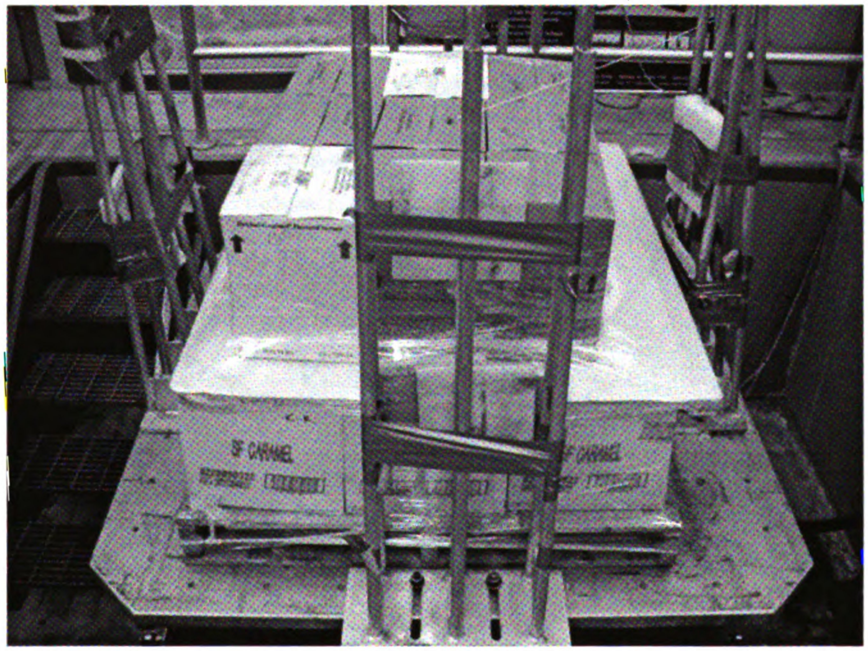


Figure A.10: G.M.A.-1 Pallet, Maple Syrup Cases, Accelerometer Location A

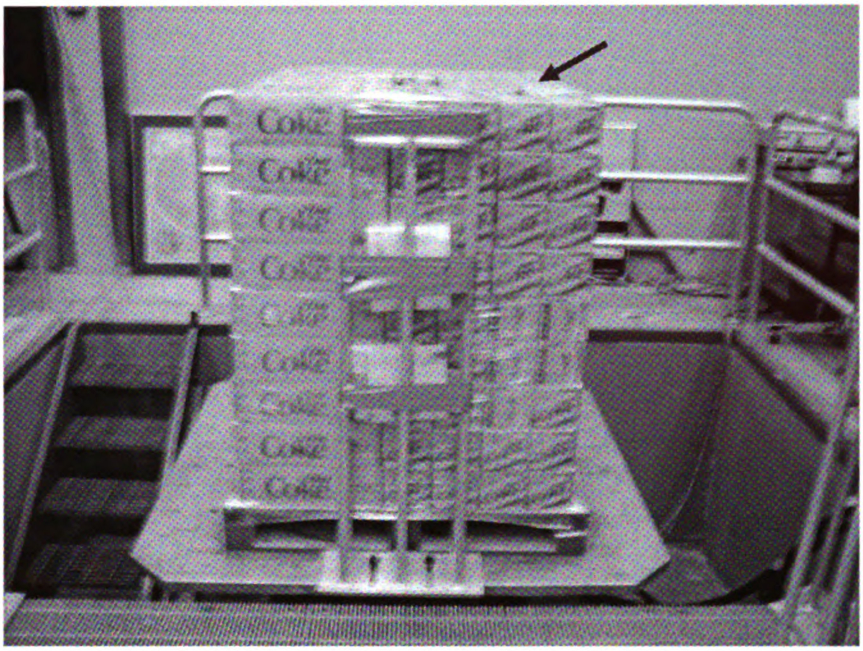


Figure A.11: Dowel Pallet, Diet Coke, Accelerometer Location A

Figure A.12: Dowel Pallet, Diet Coke, Accelerometer Location B

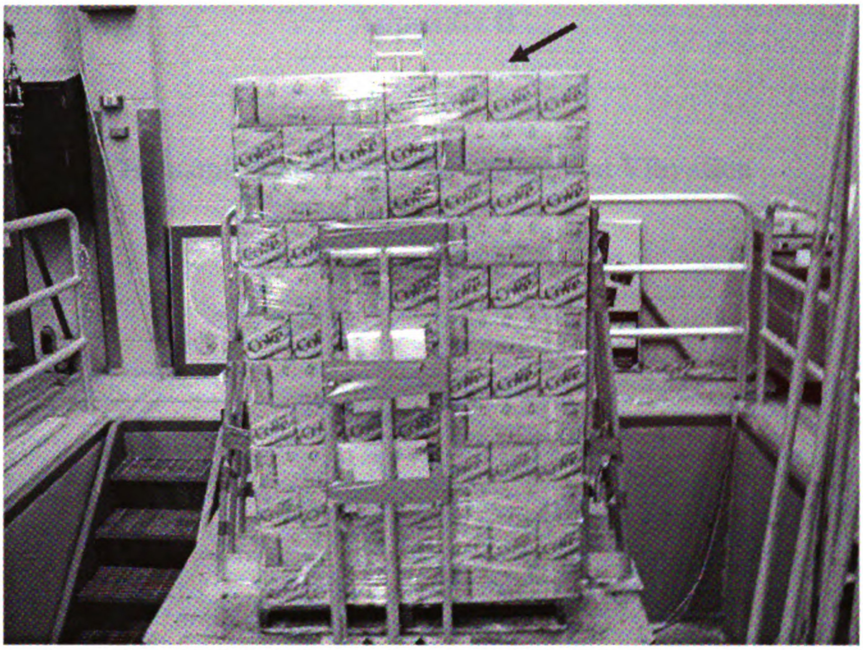


Figure A.13: G.M.A.-2 Pallet, Diet Coke, Accelerometer Location A

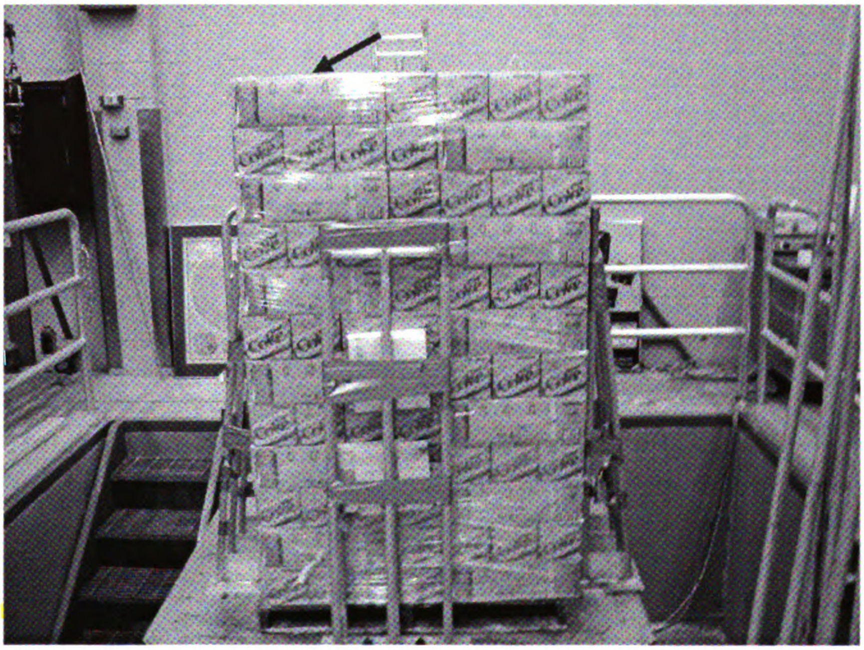


Figure A.14: G.M.A.-2 Pallet, Diet Coke, Accelerometer Location A

Appendix B

Transmissibility Plots for Sinusoidal Vibration

In the following plots, "Ch 1" (Channel 1) is the input accelerometer and "Ch 2" is the response accelerometer. The "Ch 1" plot is the constant table acceleration of 0.5 g's. The two plots labeled "Ch 2" are the forward sweep (3-100 Hz.) and the reverse sweep (100-3Hz.) overlaid on each other. The transmissibility plot is the ratio of the Ch 2 to Ch 1 accelerations.

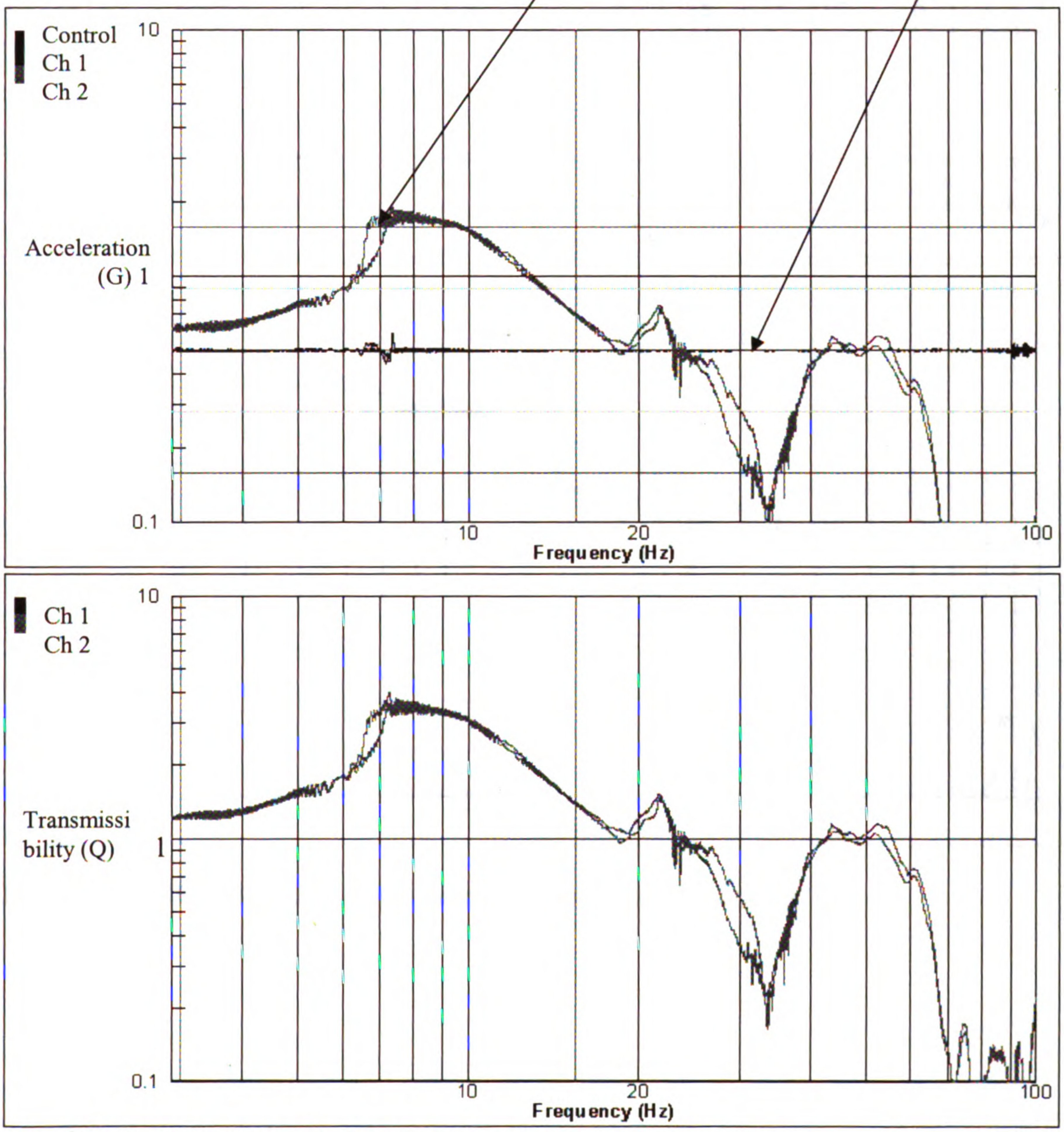


Figure B.1: GMA-1 pallet, Apple Juice, Acceleration Location A

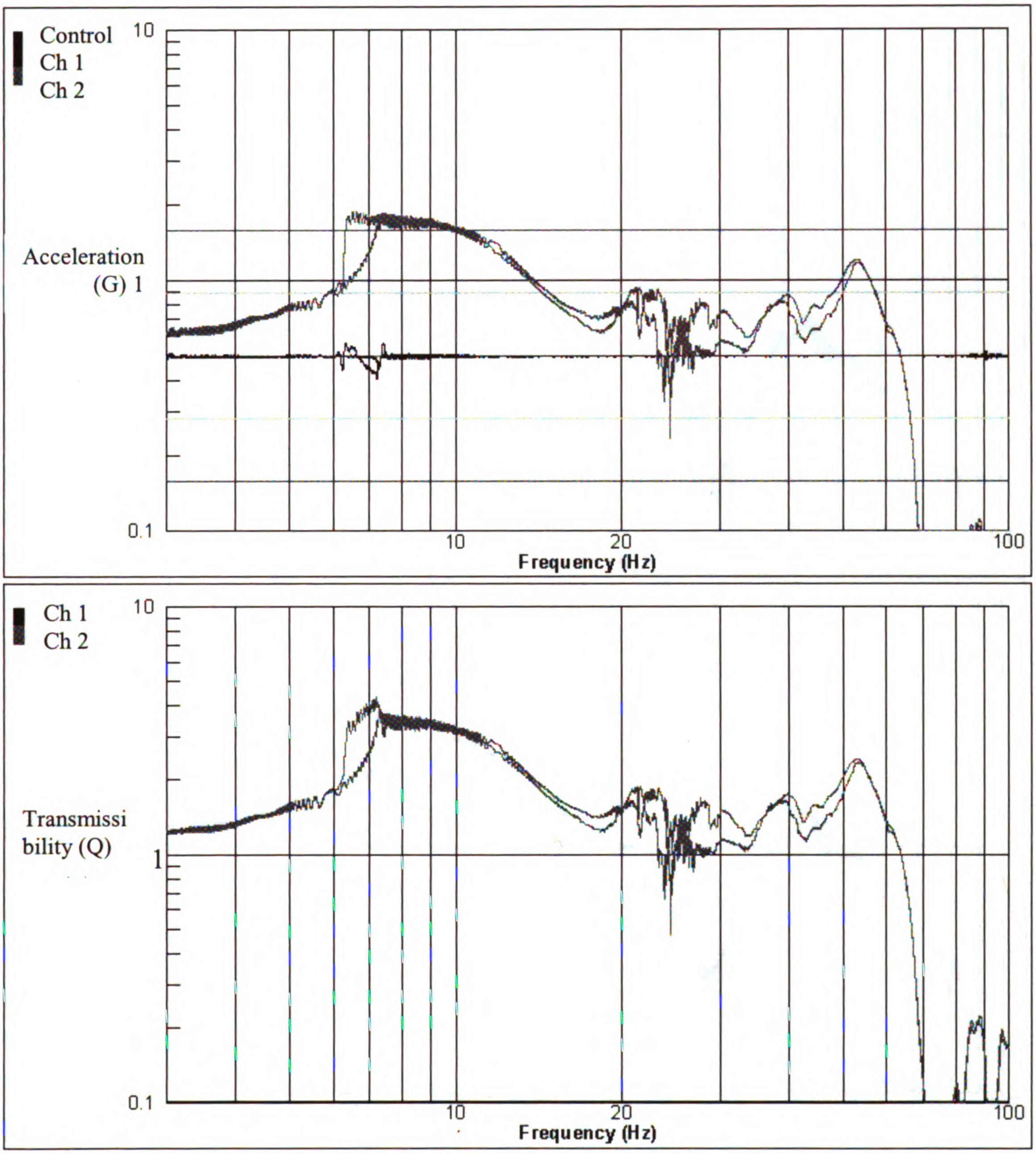


Figure B.2: GMA-1 pallet, Apple Juice, Accelerometer Location B

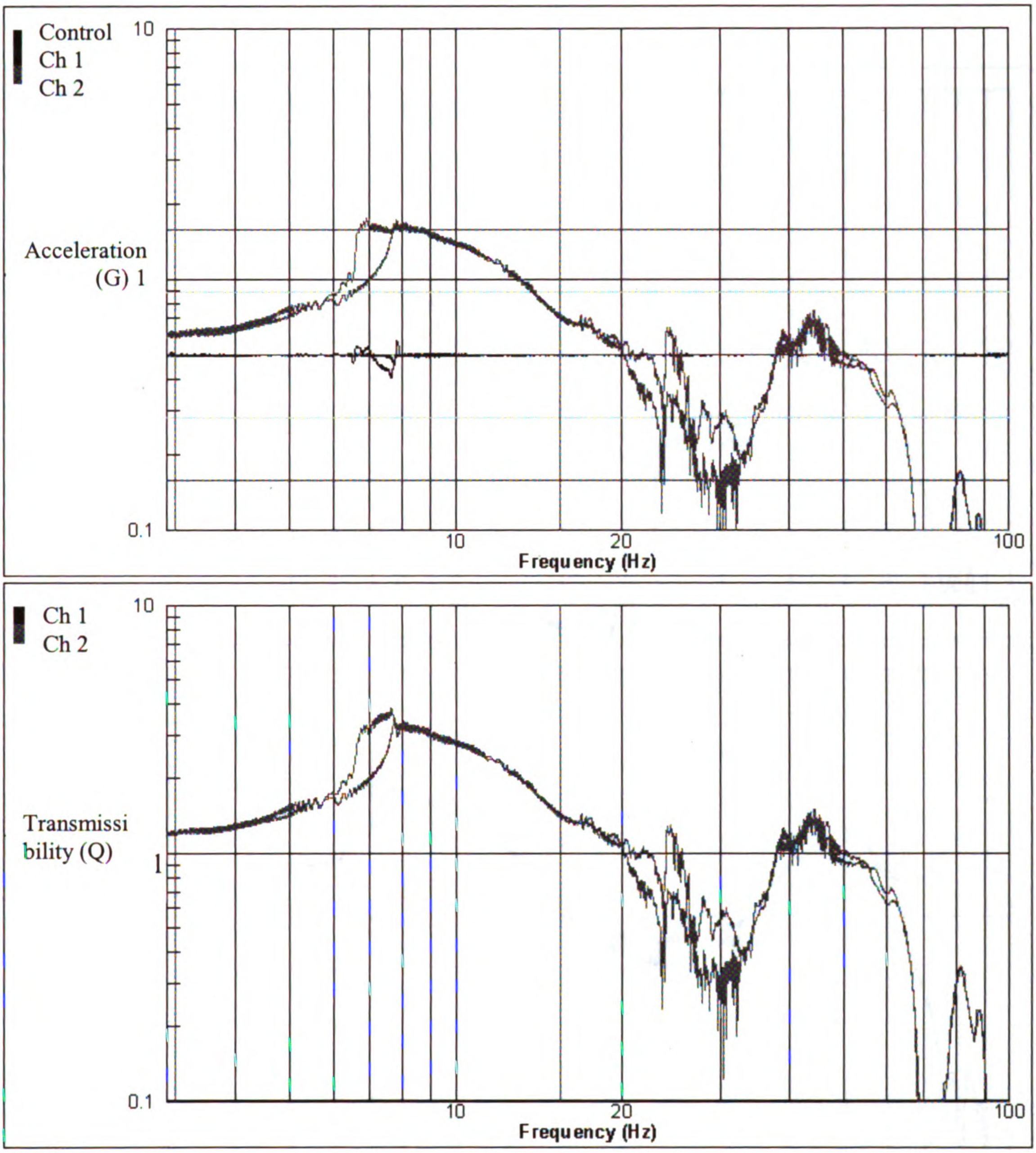


Figure B.3: Dowel pallet, Apple Juice, Accelerometer Location A

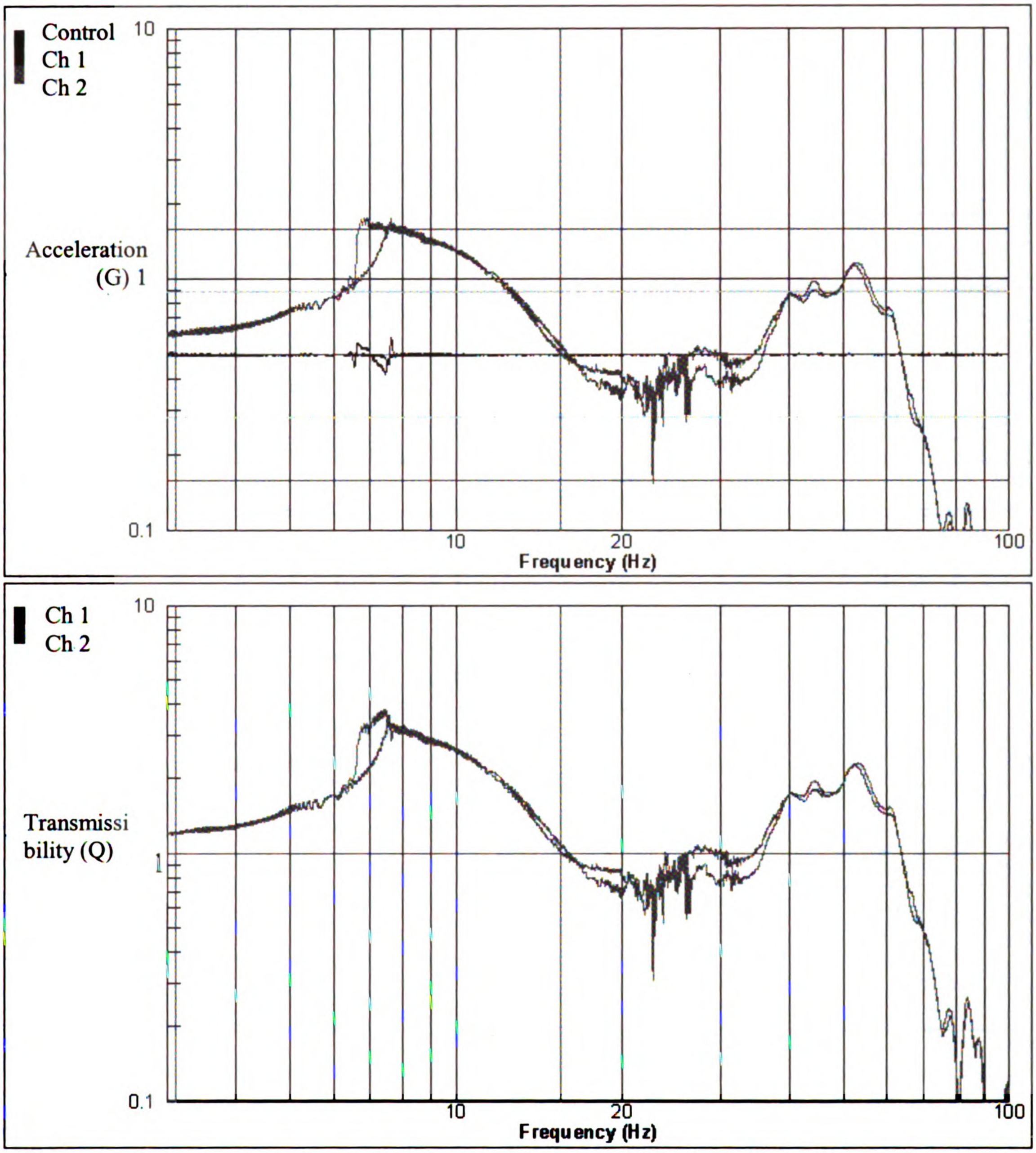
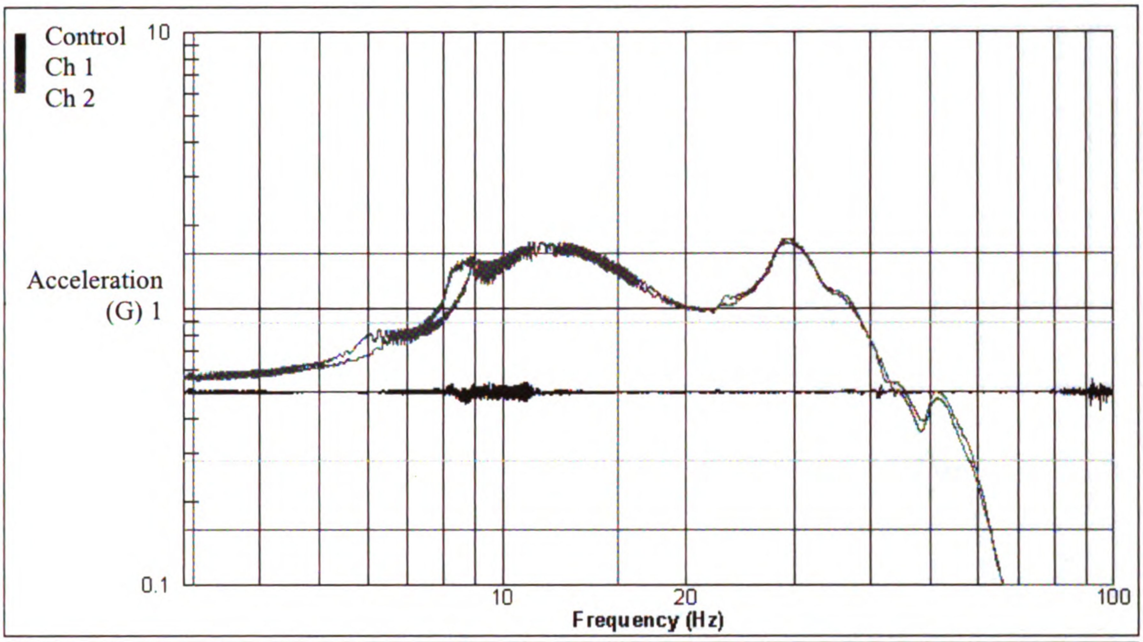


Figure B.4: Dowel pallet, Apple Juice, Accelerometer Location B



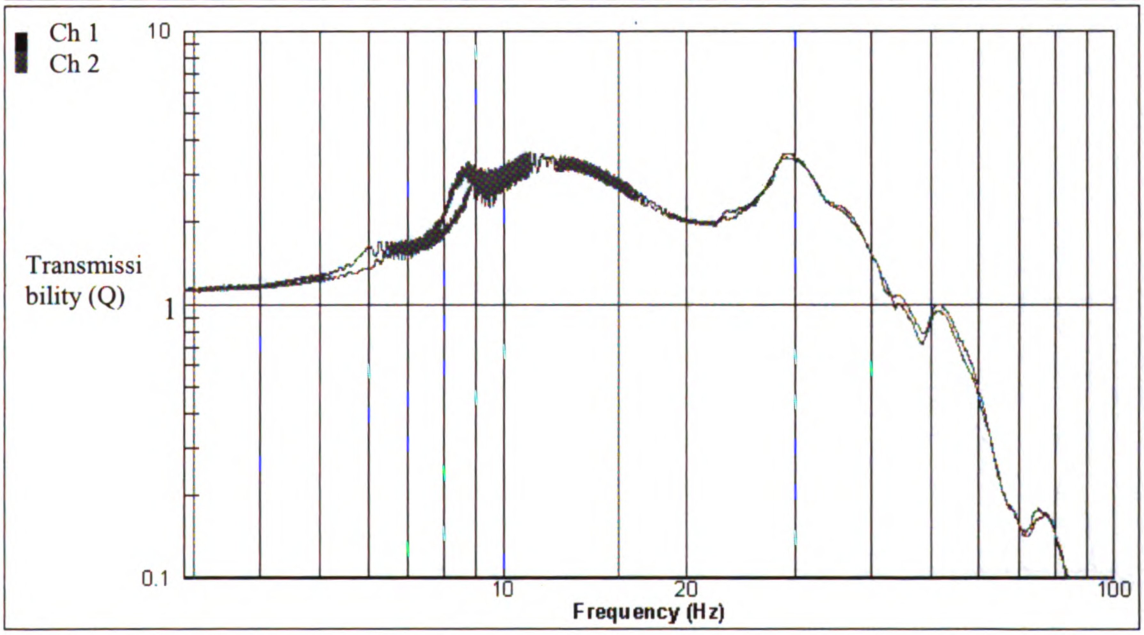


Figure B.5: GMA-1 pallet, Baked Beans, Accelerometer Location A

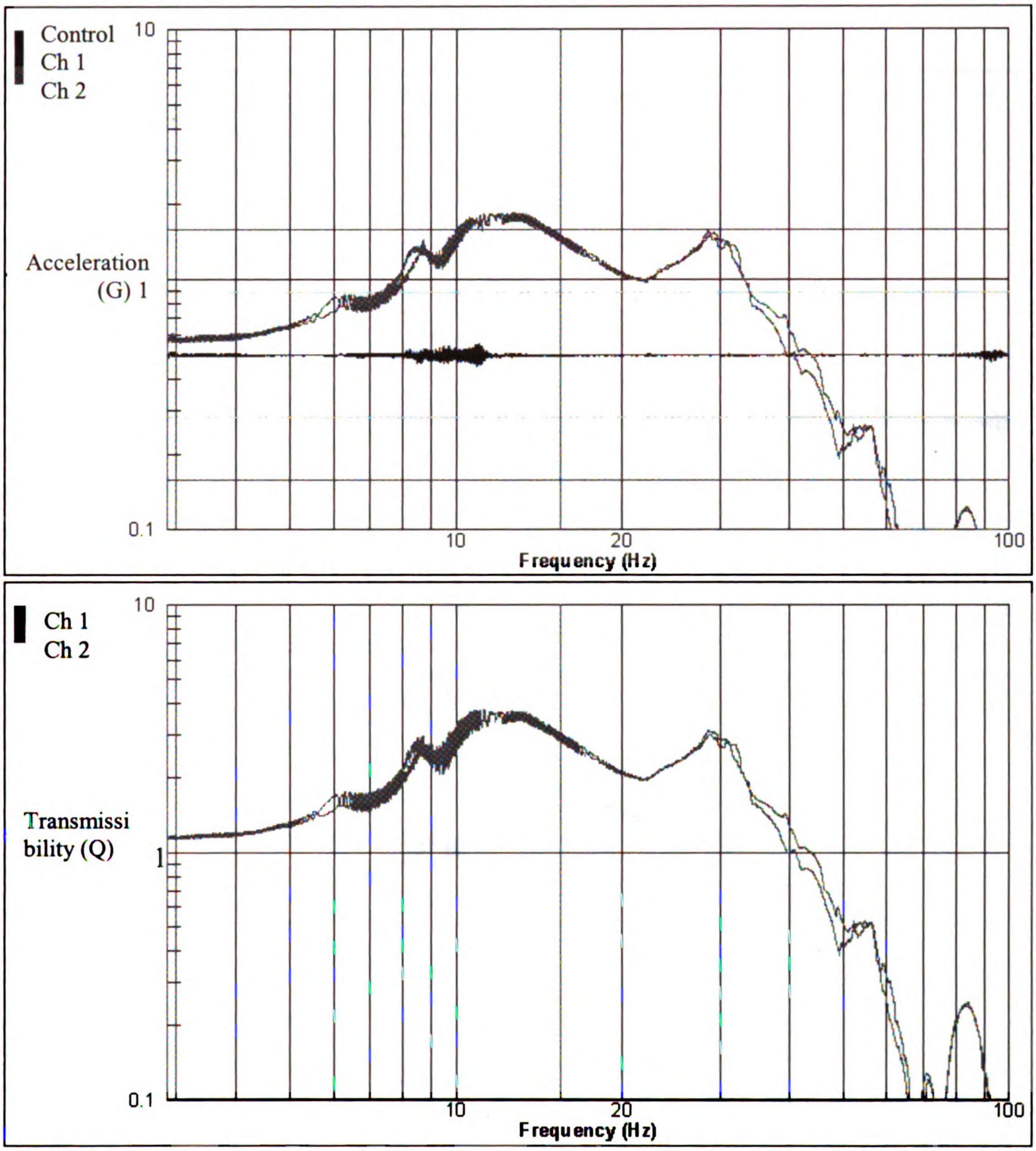


Figure B.6: GMA-1 pallet, Baked Beans, Accelerometer Location B

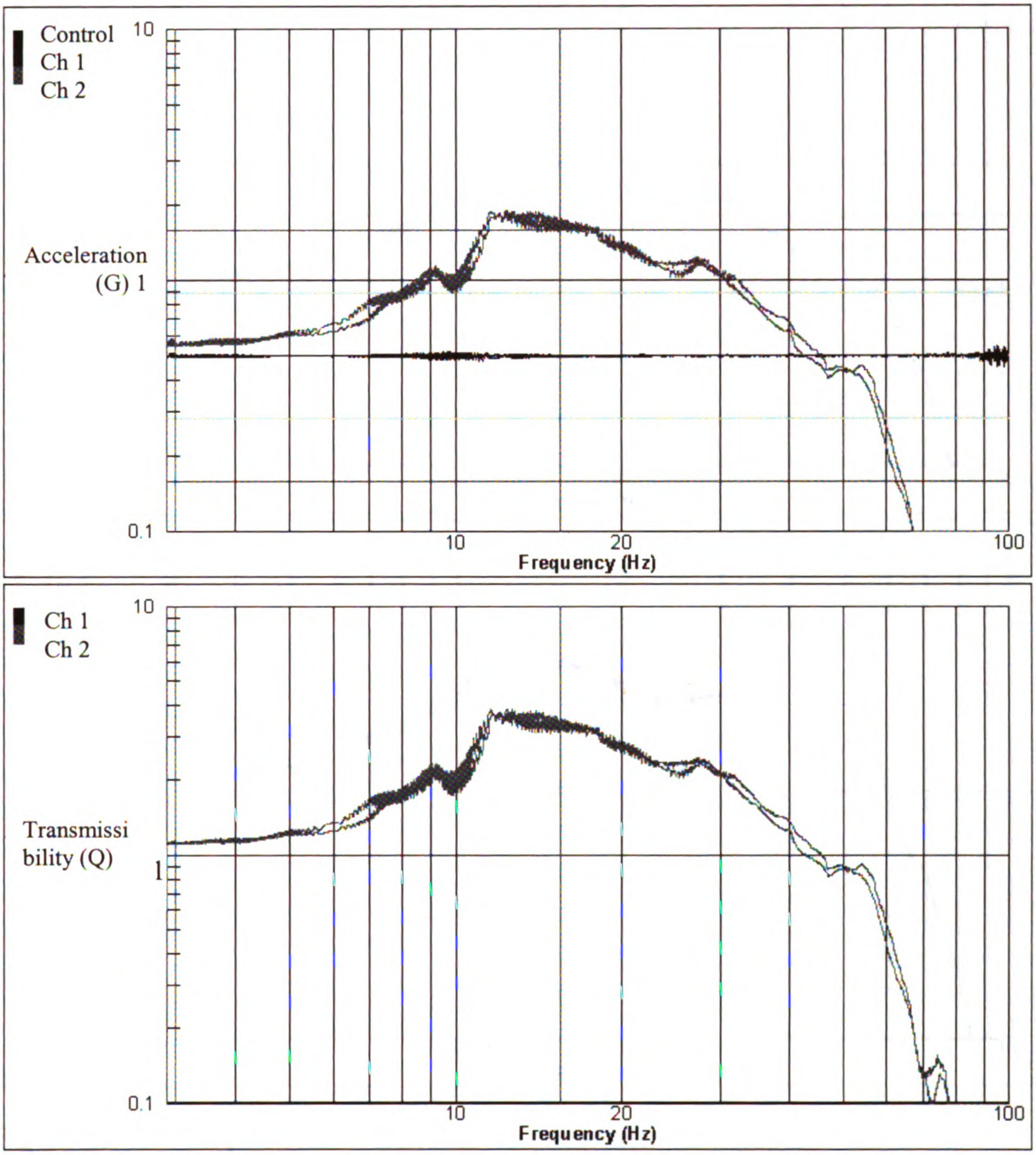


Figure B.7: Dowel pallet, Baked Beans, Accelerometer Location A

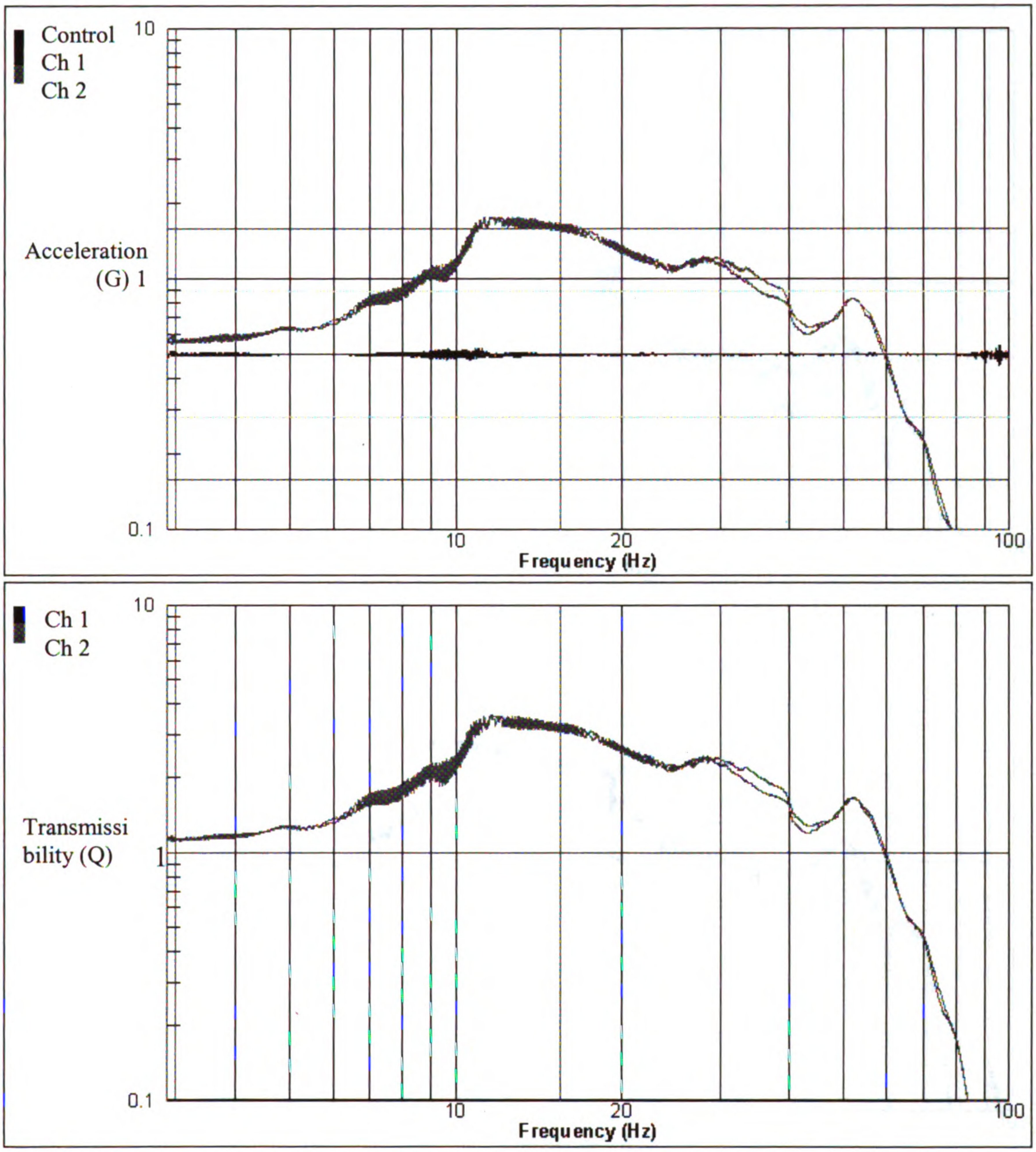


Figure B.8: Dowel pallet, Baked Beans, Accelerometer Location B

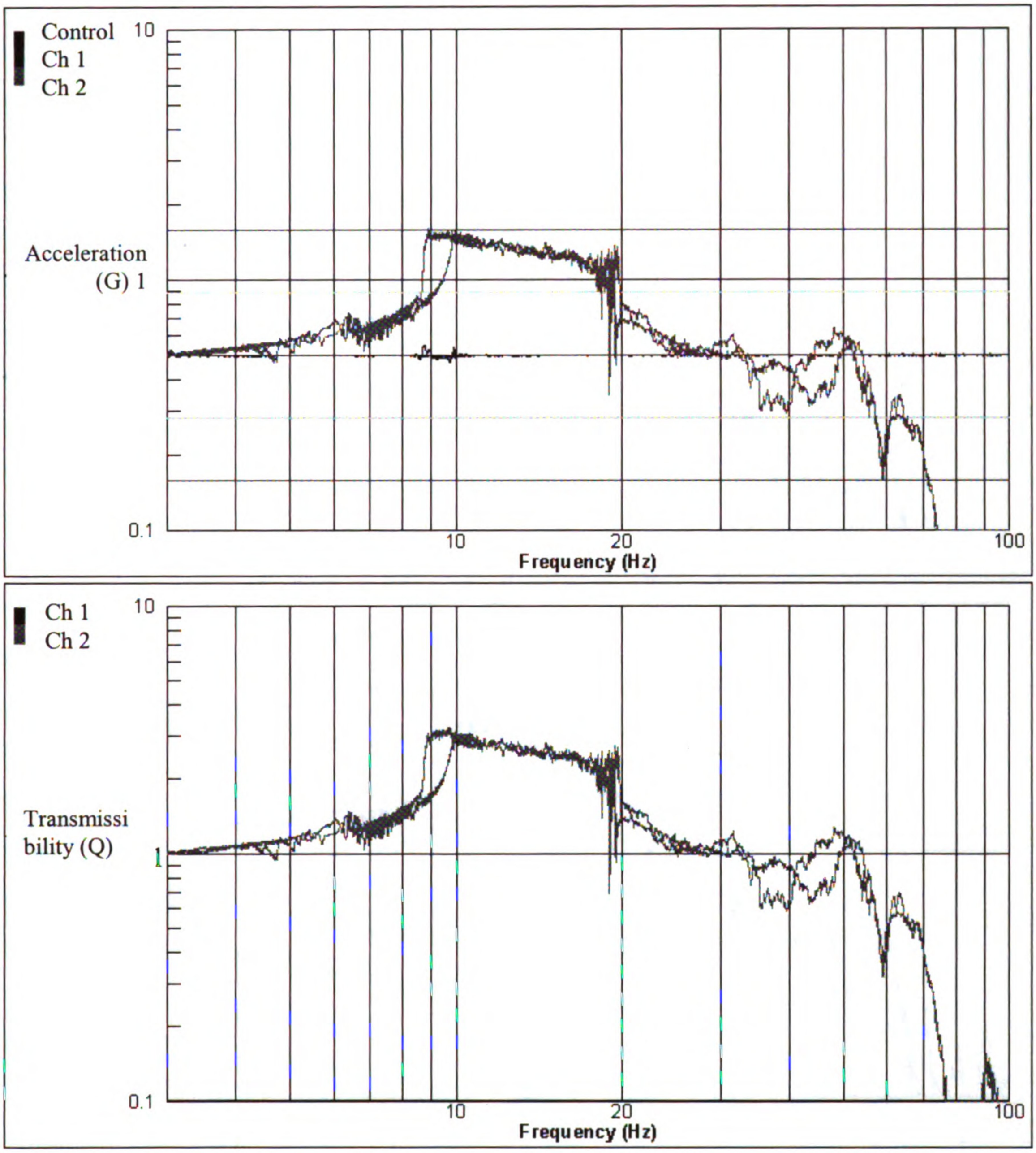


Figure B.9: G.M.A.-1 pallet, Maple Syrup Cases Accelerometer Location A

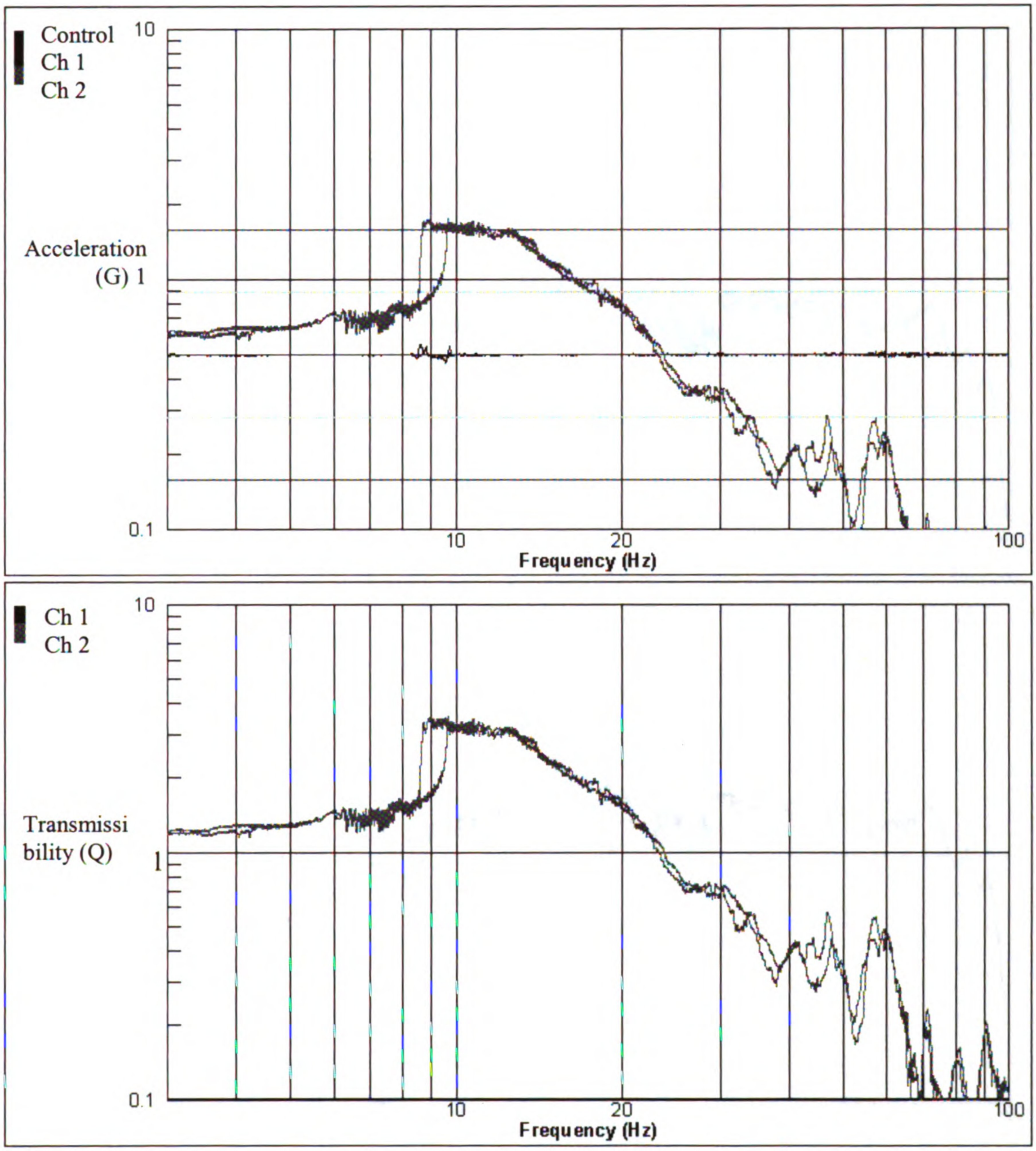


Figure B.10: G.M.A.-1 pallet, Maple Syrup Cases, Accelerometer Location B

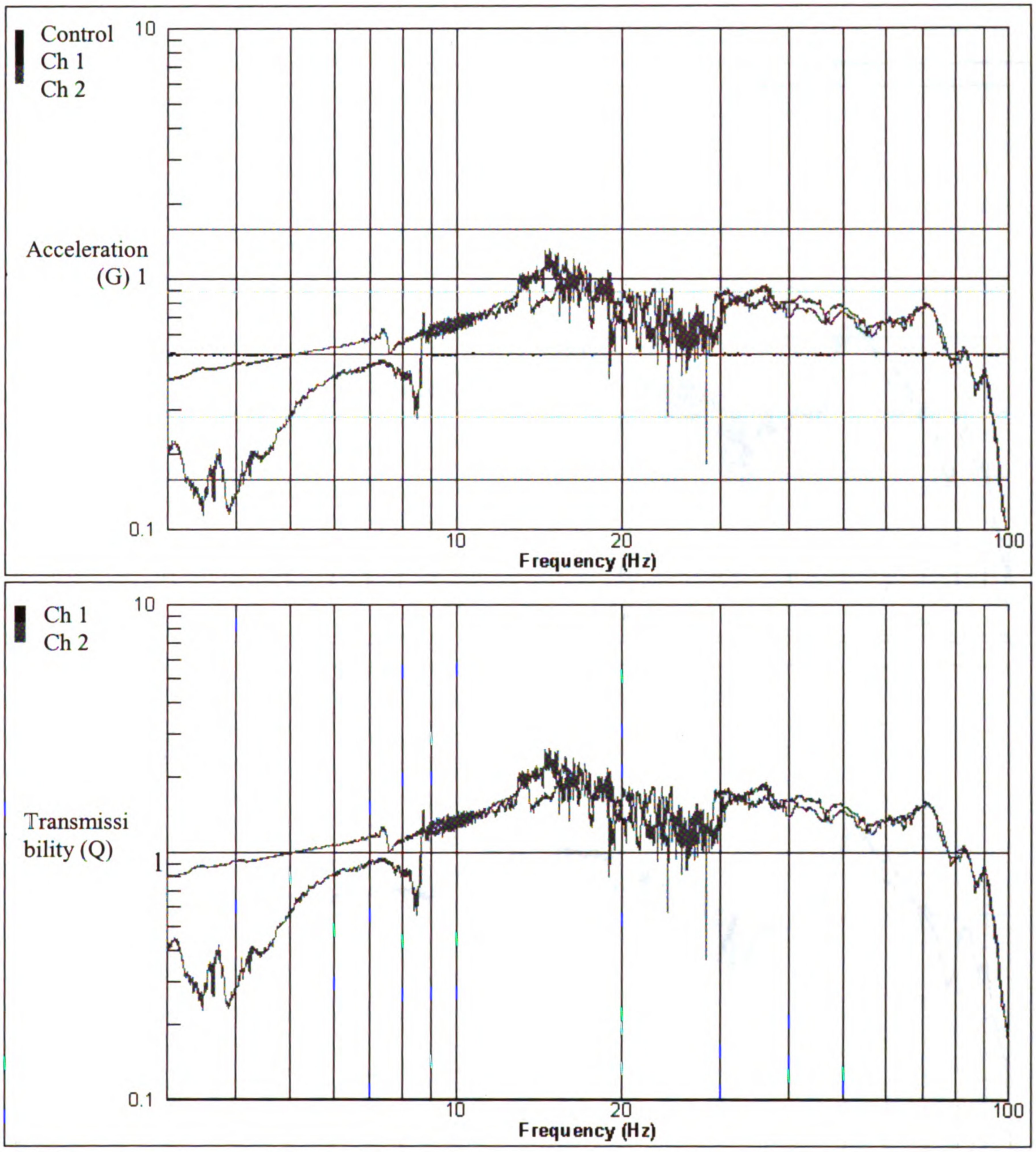


Figure B.11: Dowel pallet, Maple Syrup Cases, Accelerometer Location A

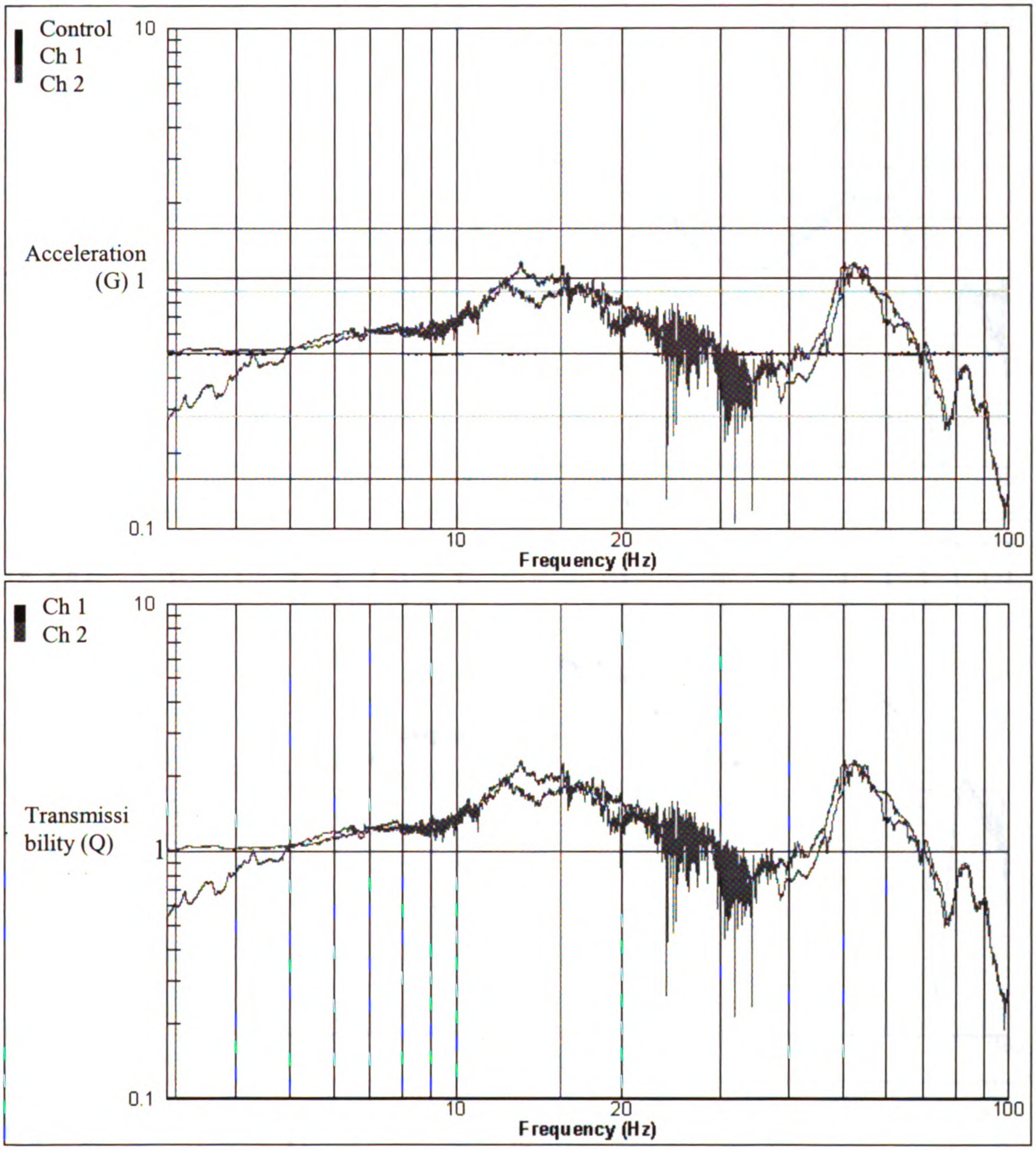


Figure B.12 Dowel pallet, Maple Syrup Cases, Accelerometer Location B

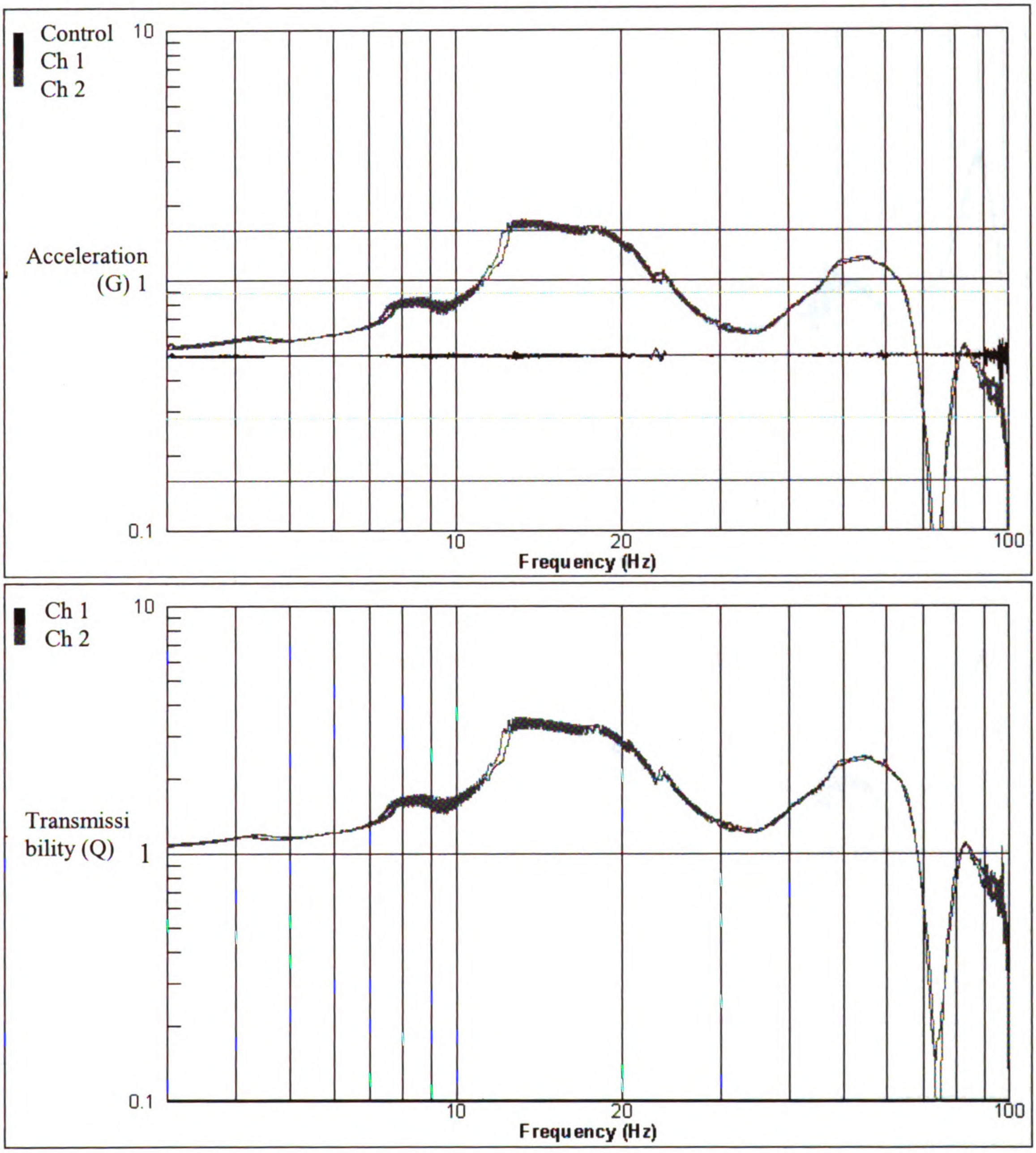


Figure B.13: G.M.A.-2 pallet, Diet Coke, Accelerometer Location A

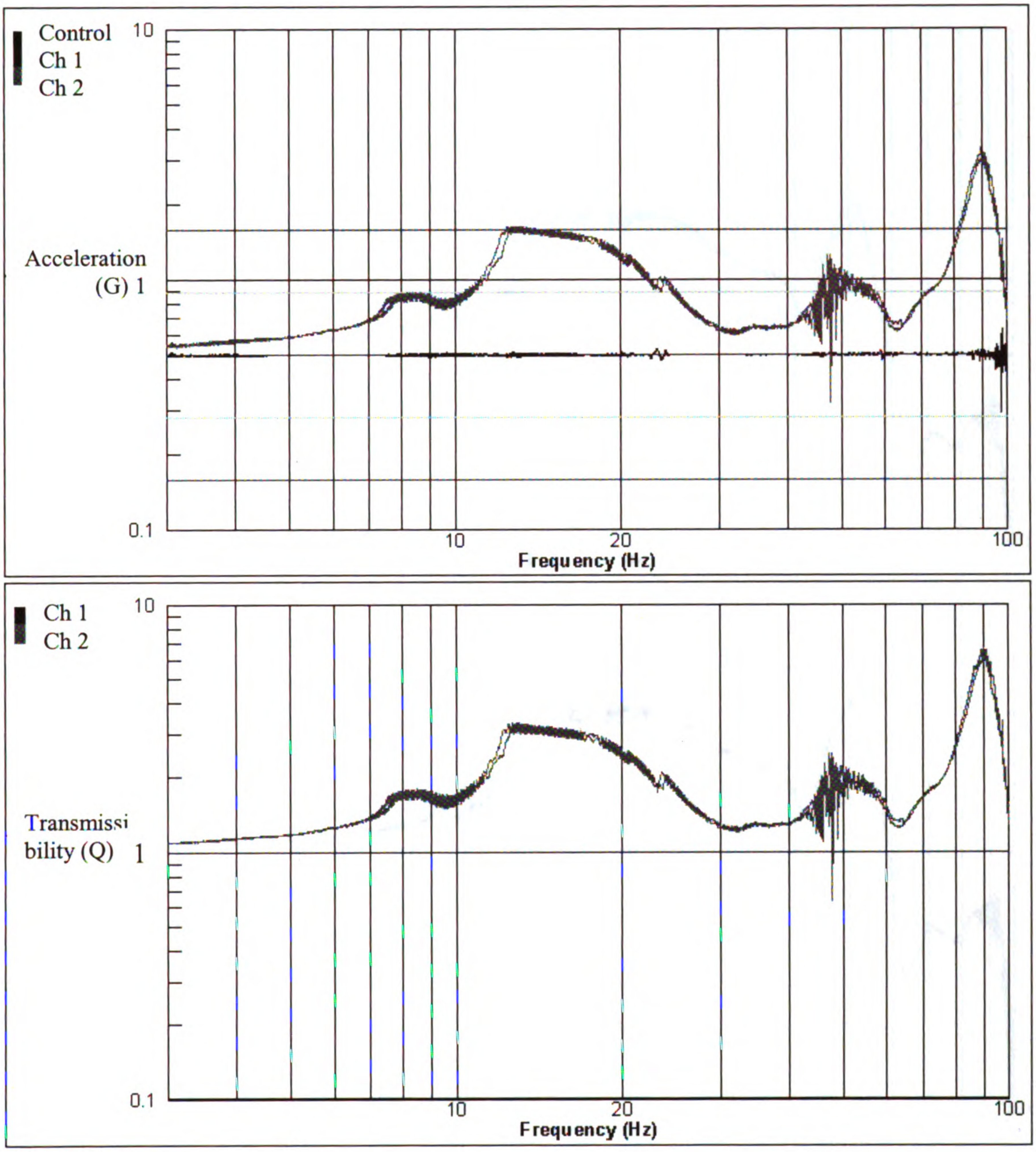


Figure B.14: G.M.A.-2 pallet, Diet Coke, Accelerometer Location B

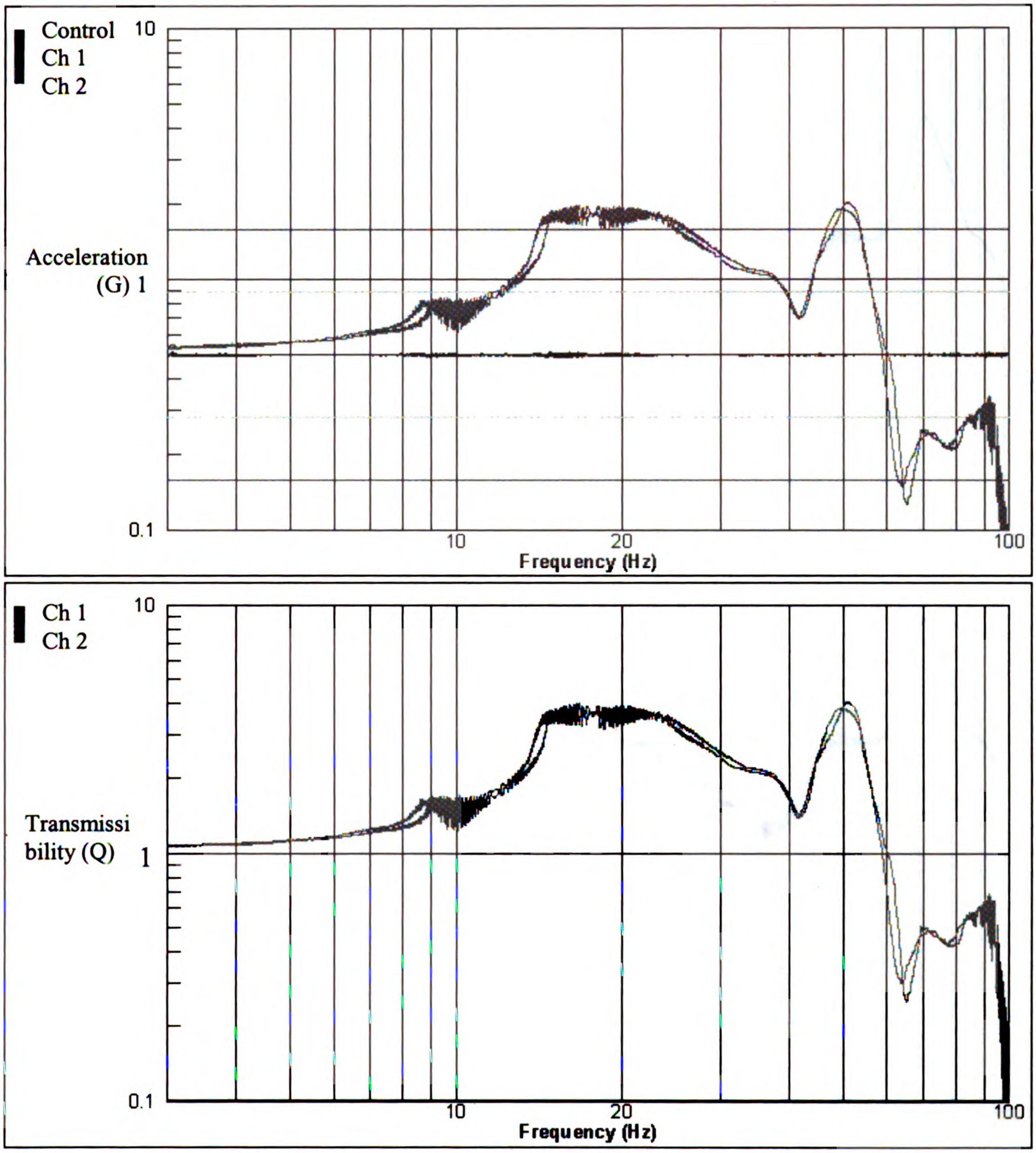


Figure B.15: Dowel pallet, Diet Coke, Accelerometer Location A

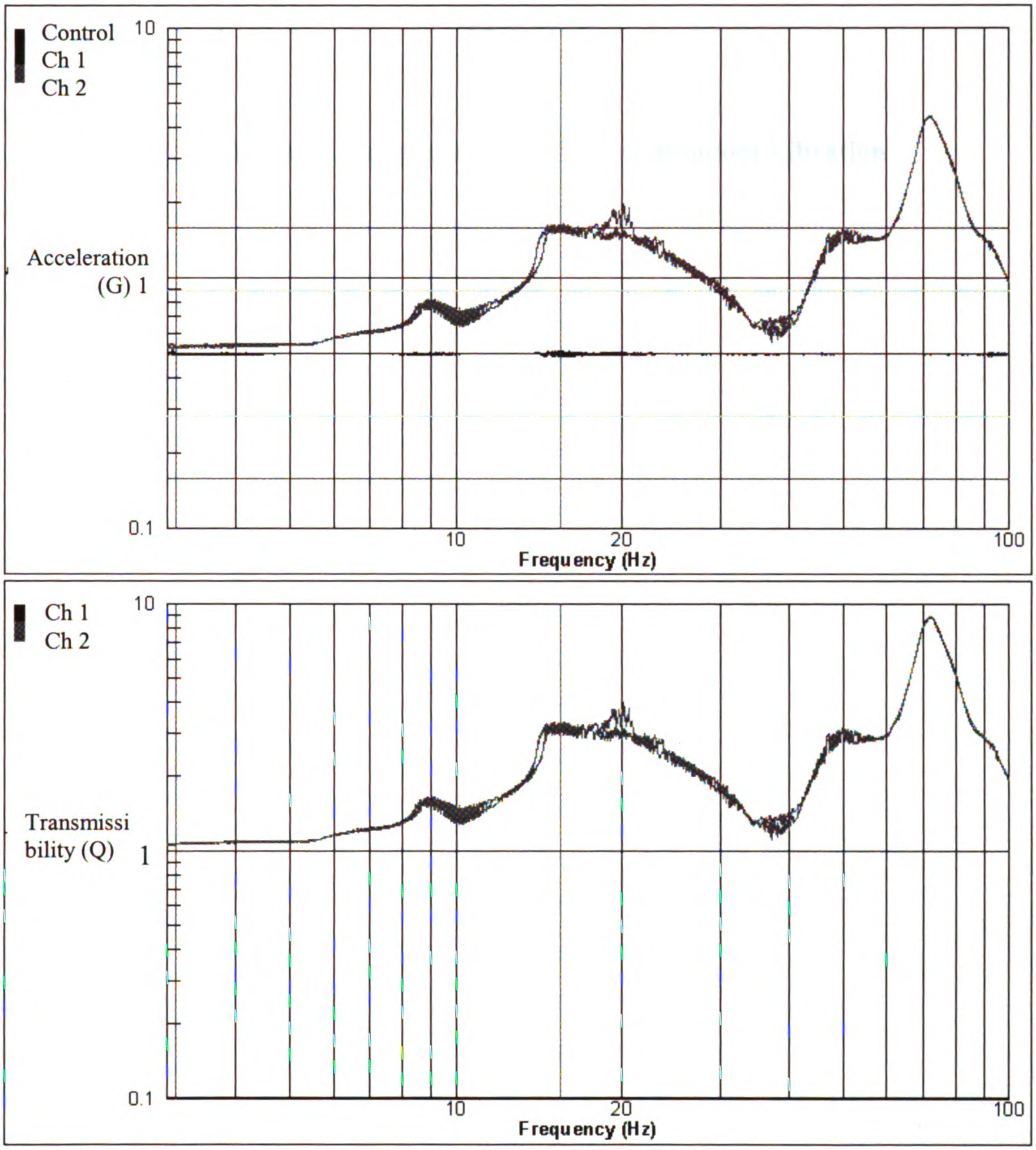


Figure B.16: Dowel pallet, Diet Coke, Accelerometer Location B

Appendix C

PSD Plots and Transmissibility Plots for Random Vibration

In theses plots, Channel 1 is the input (table) accelerometer and channel-2 is the response (pallet load) accelerometer

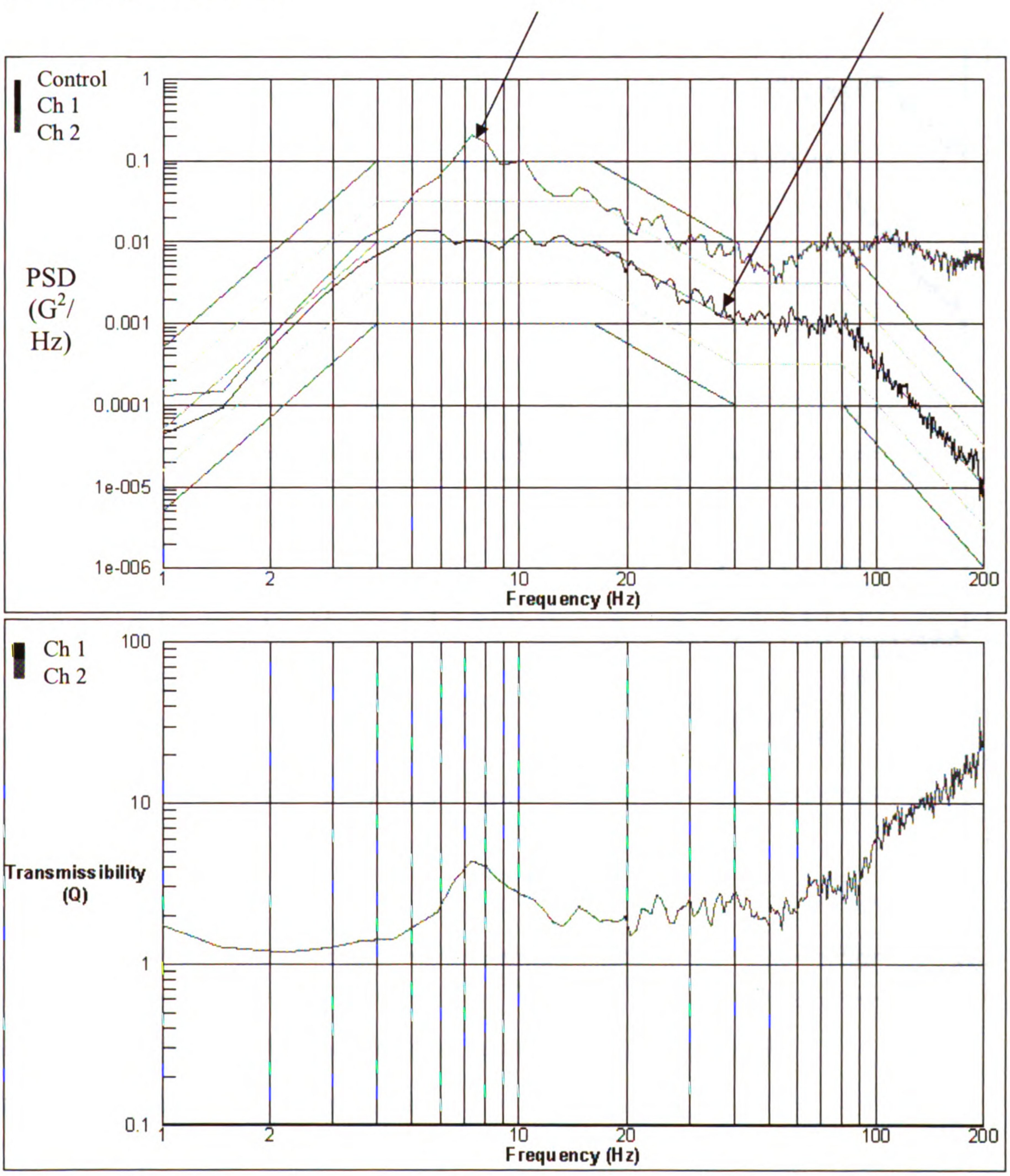


Figure C.1: GMA-1 pallet, Apple Juice, Accelerometer Location A

The transmissibility plot shows a transmissibility of 4.37 at 7.324 Hz.

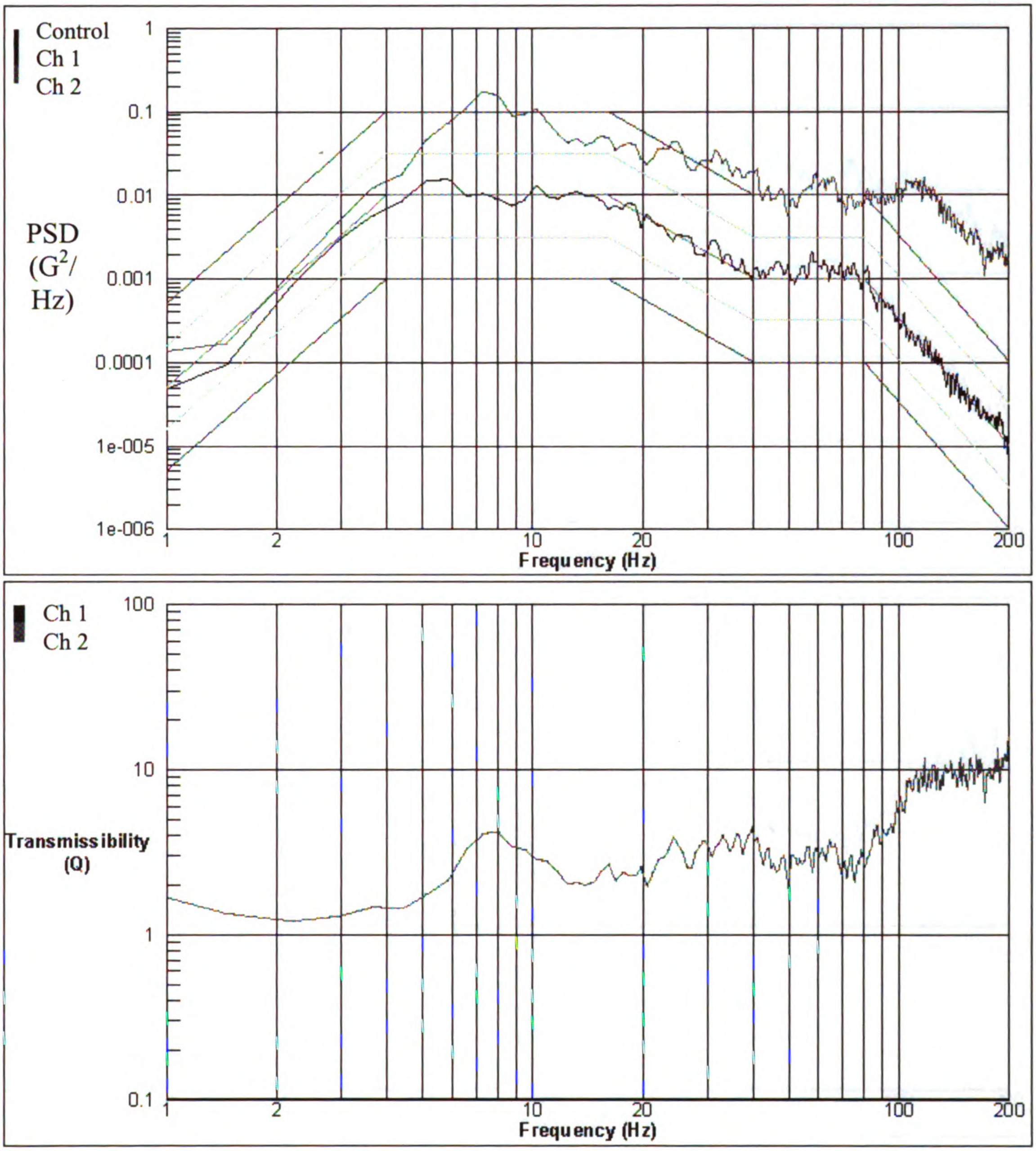


Figure C.2: GMA-1 pallet, Apple Juice, Accelerometer Location B

The transmissibility at 7.324 Hz is 4.09.

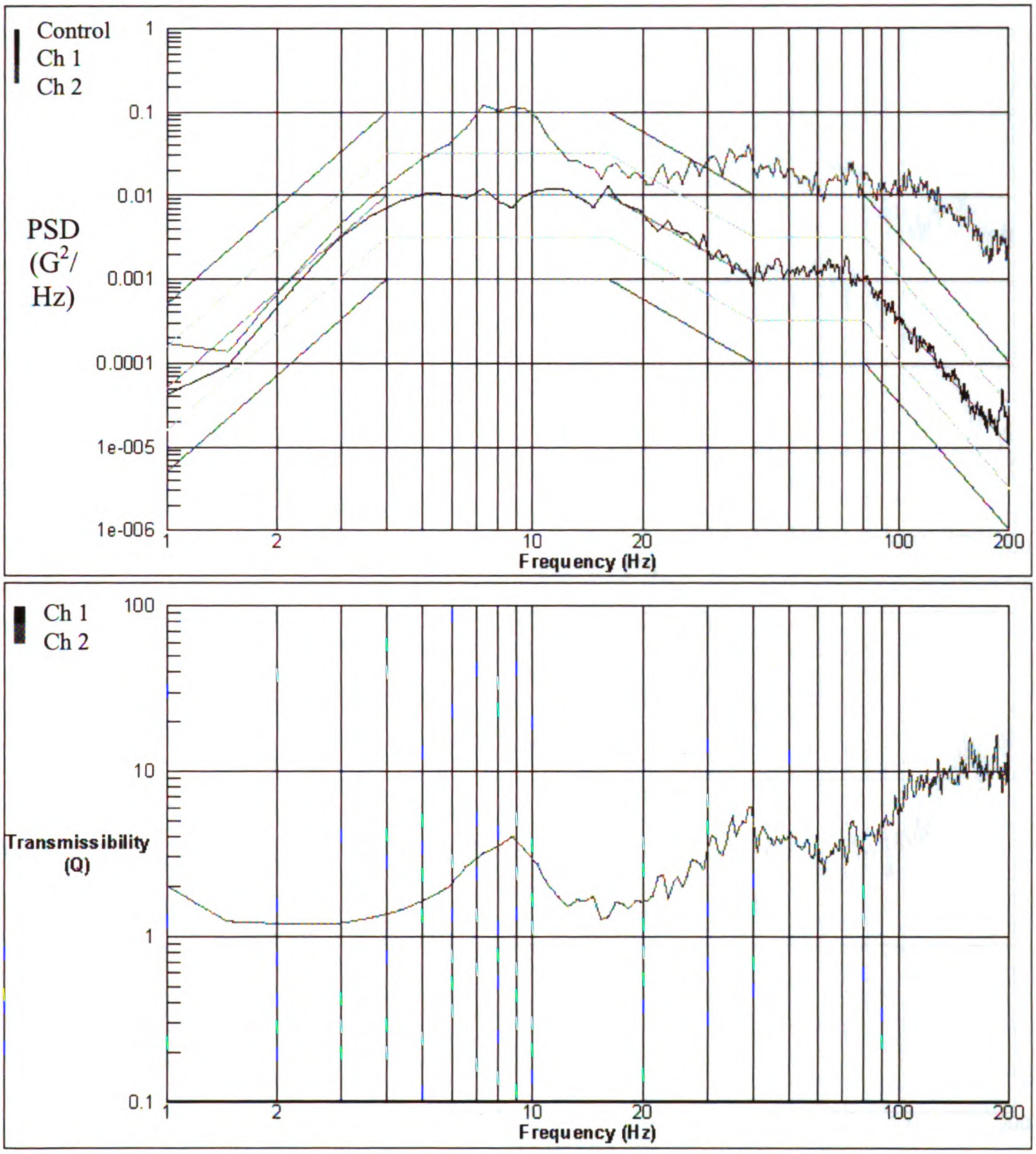


Figure C.3: Dowel pallet, Apple Juice, Accelerometer Location A

The transmissibility at 7.324 Hz is 3.18 and at 8.78 Hz is 4.03.

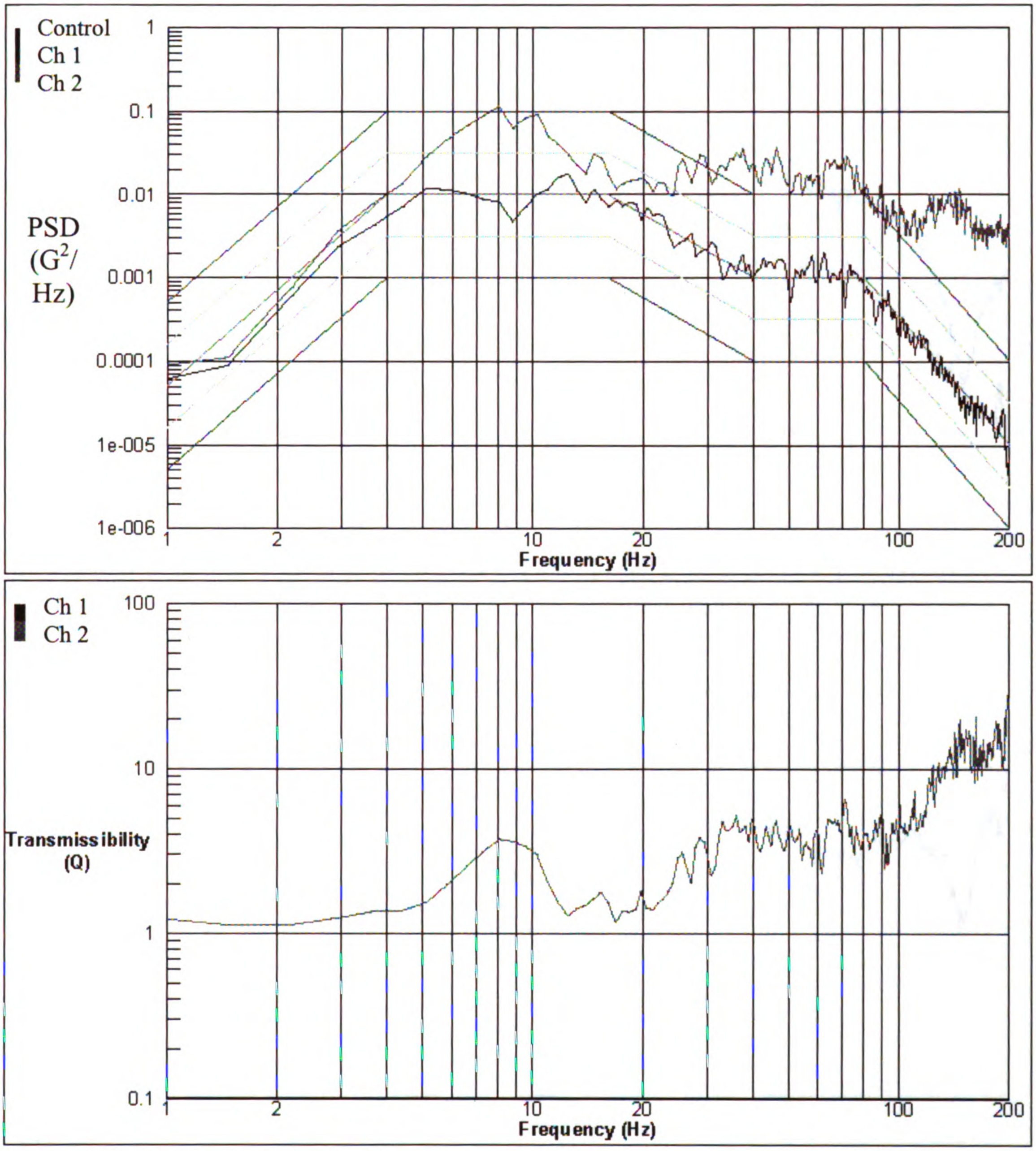


Figure C.4: Dowel pallet, Apple Juice, Accelerometer Location B

At 8.057 Hz. the transmissibility is 3.74, which is lower than G.M.A-1 pallet.

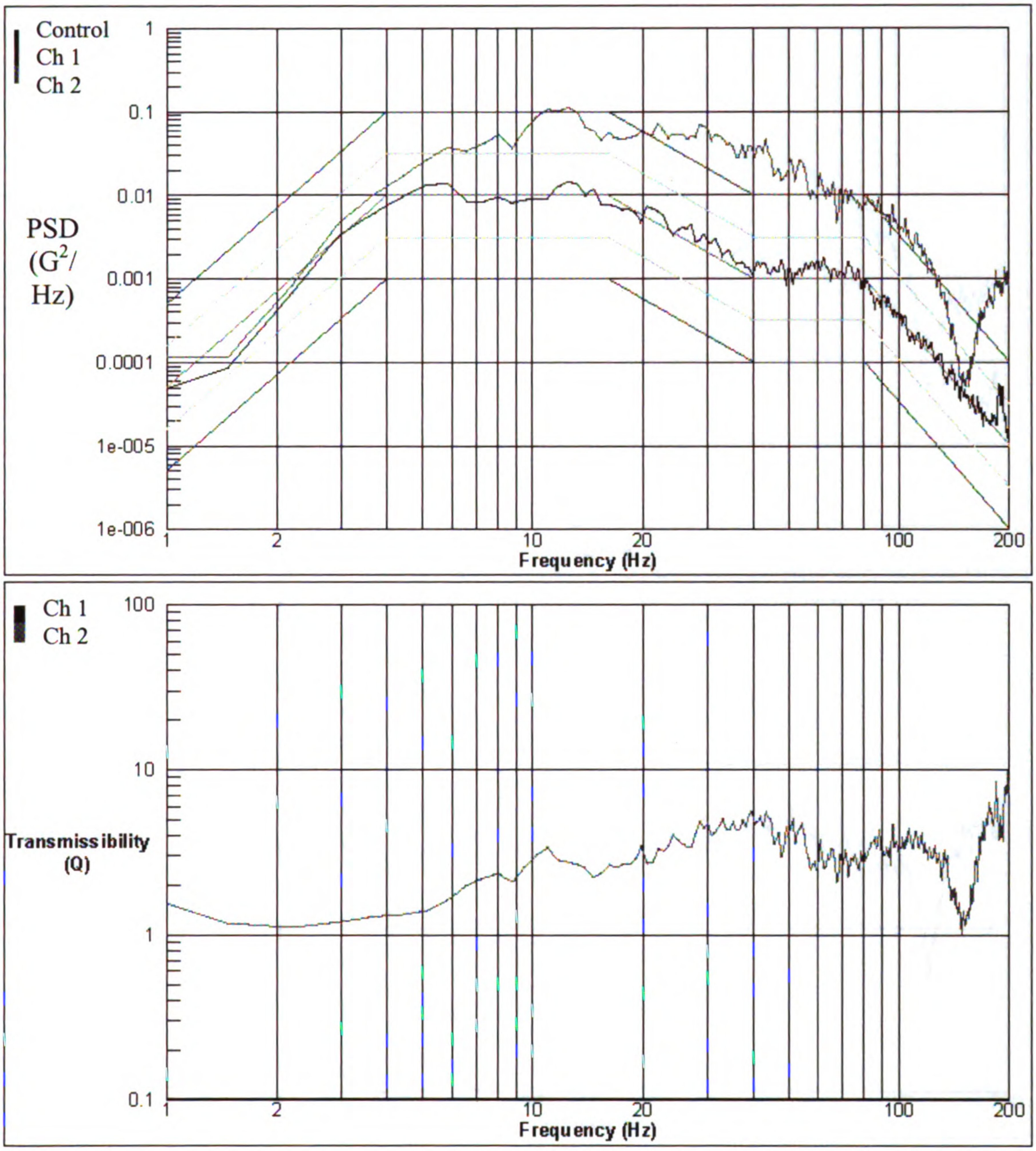


Figure C.5: G.M.A-1 pallet, Baked Beans, Accelerometer Location A

The transmissibility at 12.45 Hz. is 3.5.

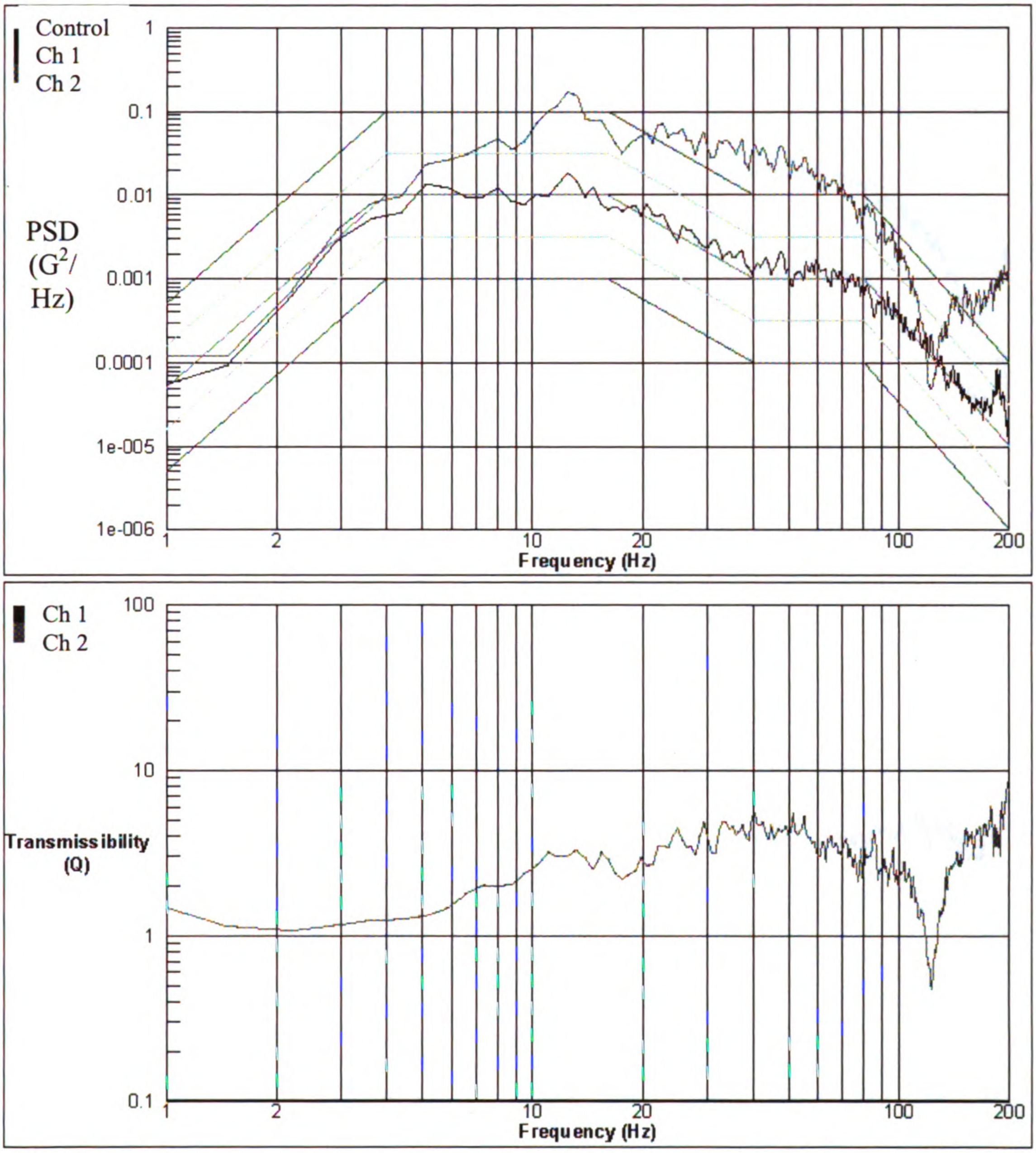
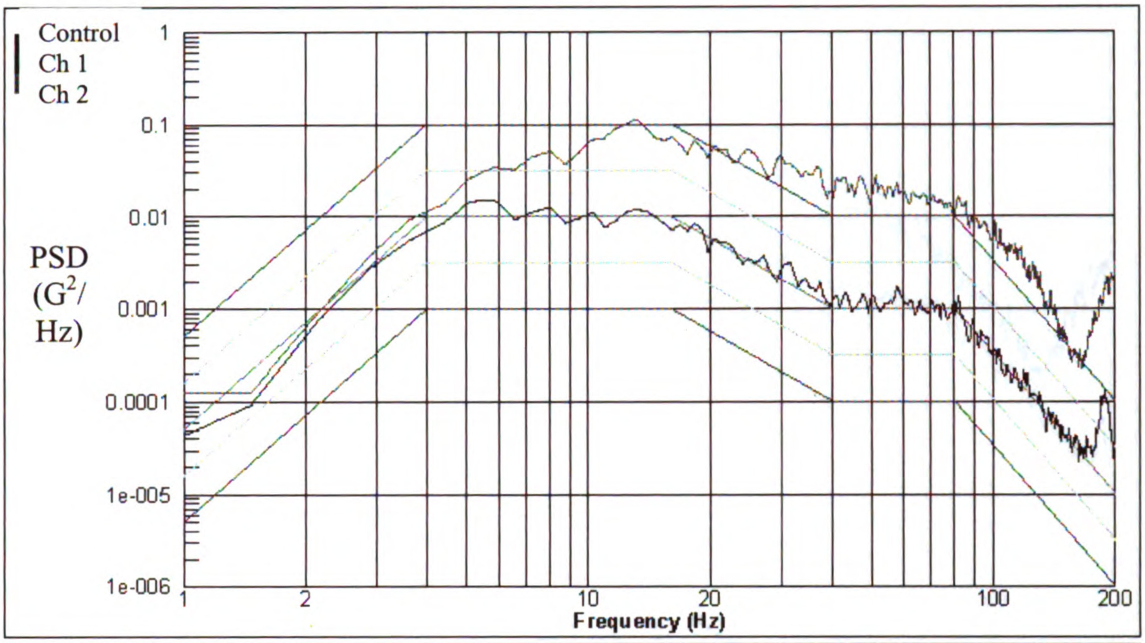


Figure C.6: G.M.A-1 pallet, Baked Beans, Accelerometer Location B

The transmissibility is 3.30 at 13.184 Hz.



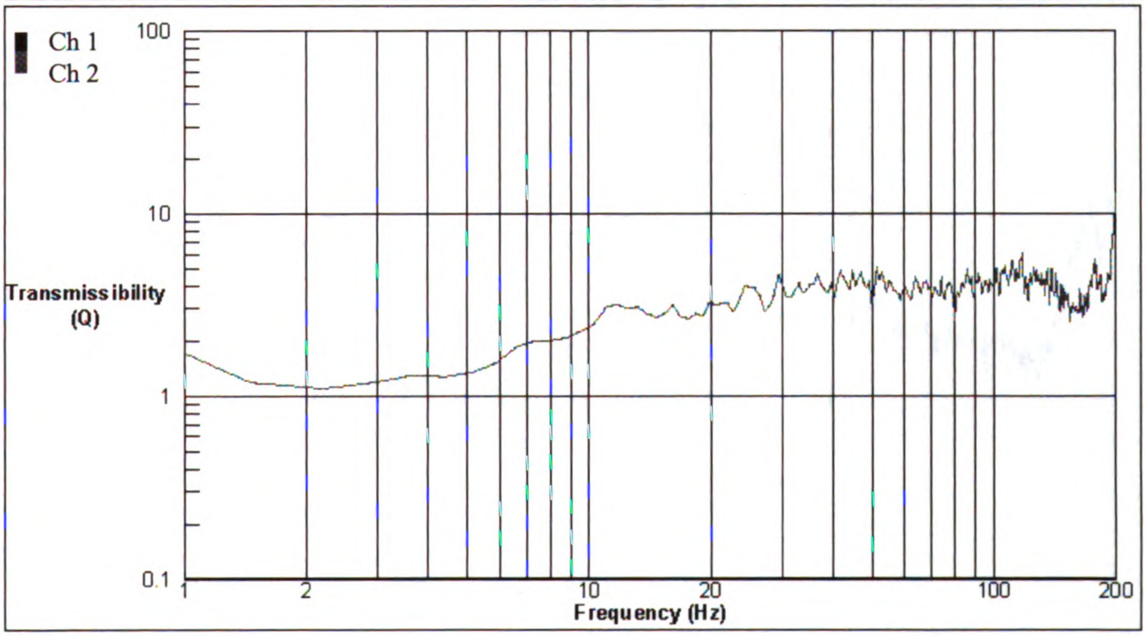


Figure C.7: Dowel pallet, Baked Beans, Accelerometer Location A

The transmissibility is 3.0 at 12.451 Hz.

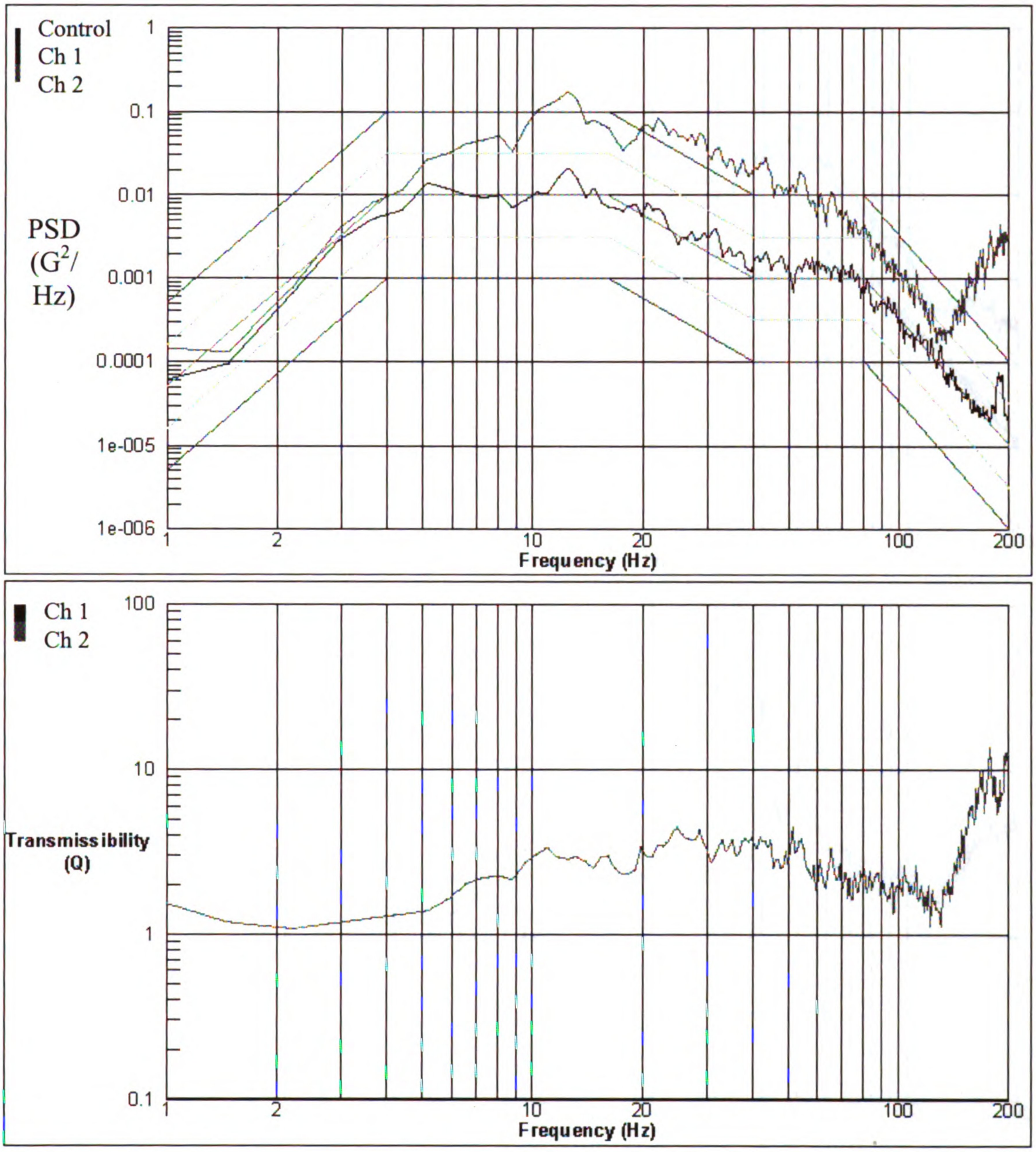
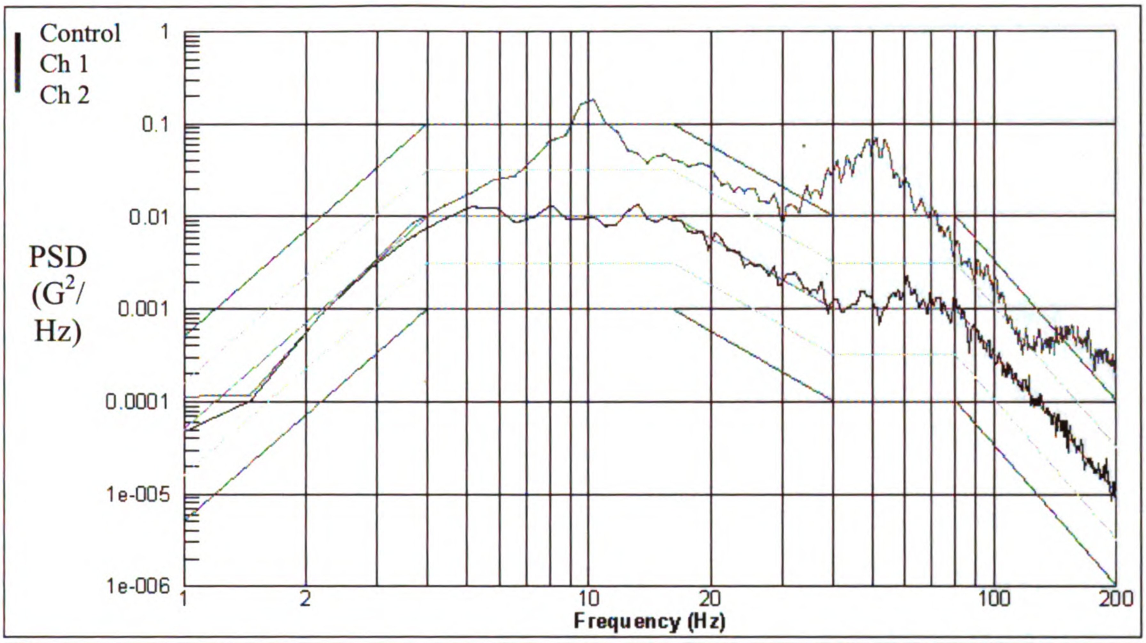


Figure C.8: Dowel pallet, Baked Beans, Accelerometer Location B

The transmissibility is 2.86 at 12.455 Hz.



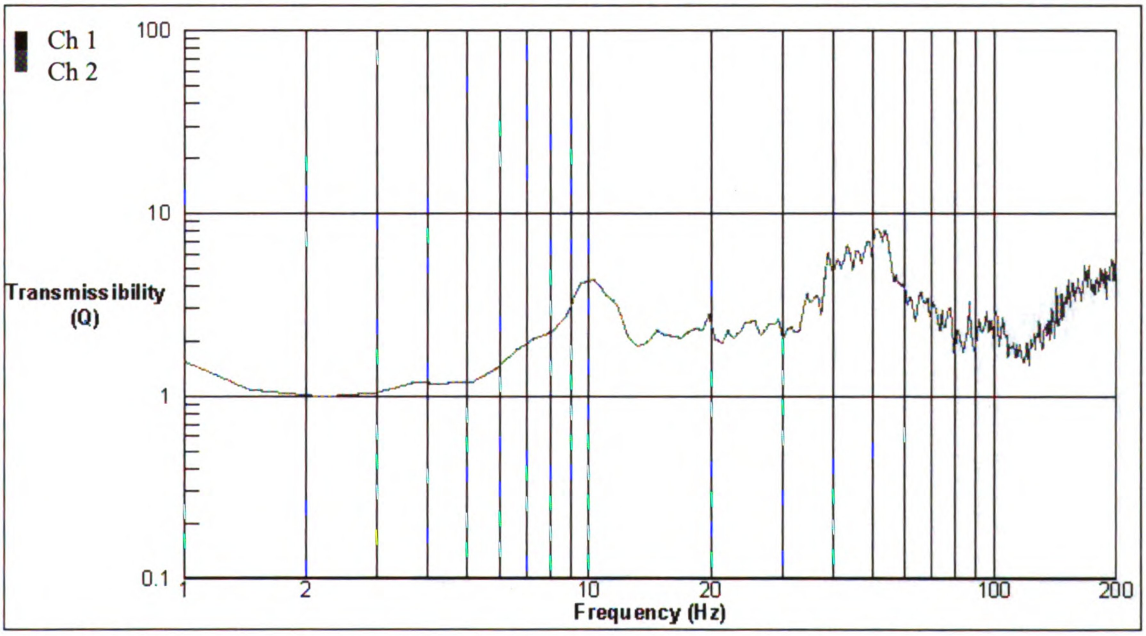


Figure C.9: GMA-1 pallet, Maple Syrup Cases, Accelerometer Location A

The transmissibility is 4.32 at 10.254 Hz.

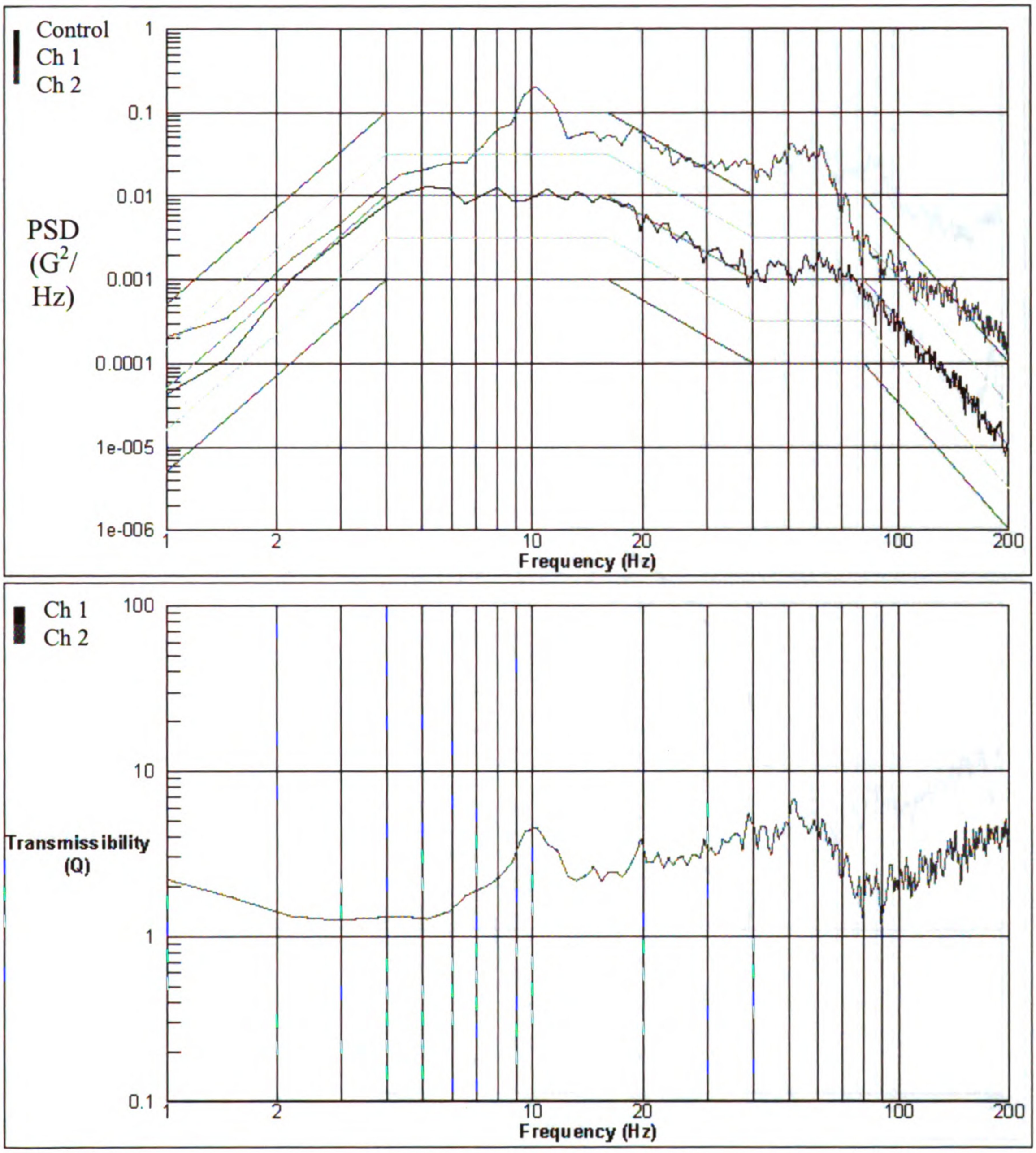


Figure C.10: GMA-1 pallet, Maple Syrup Cases, Accelerometer Location B

At 10.254 Hz the transmissibility is 4.53.

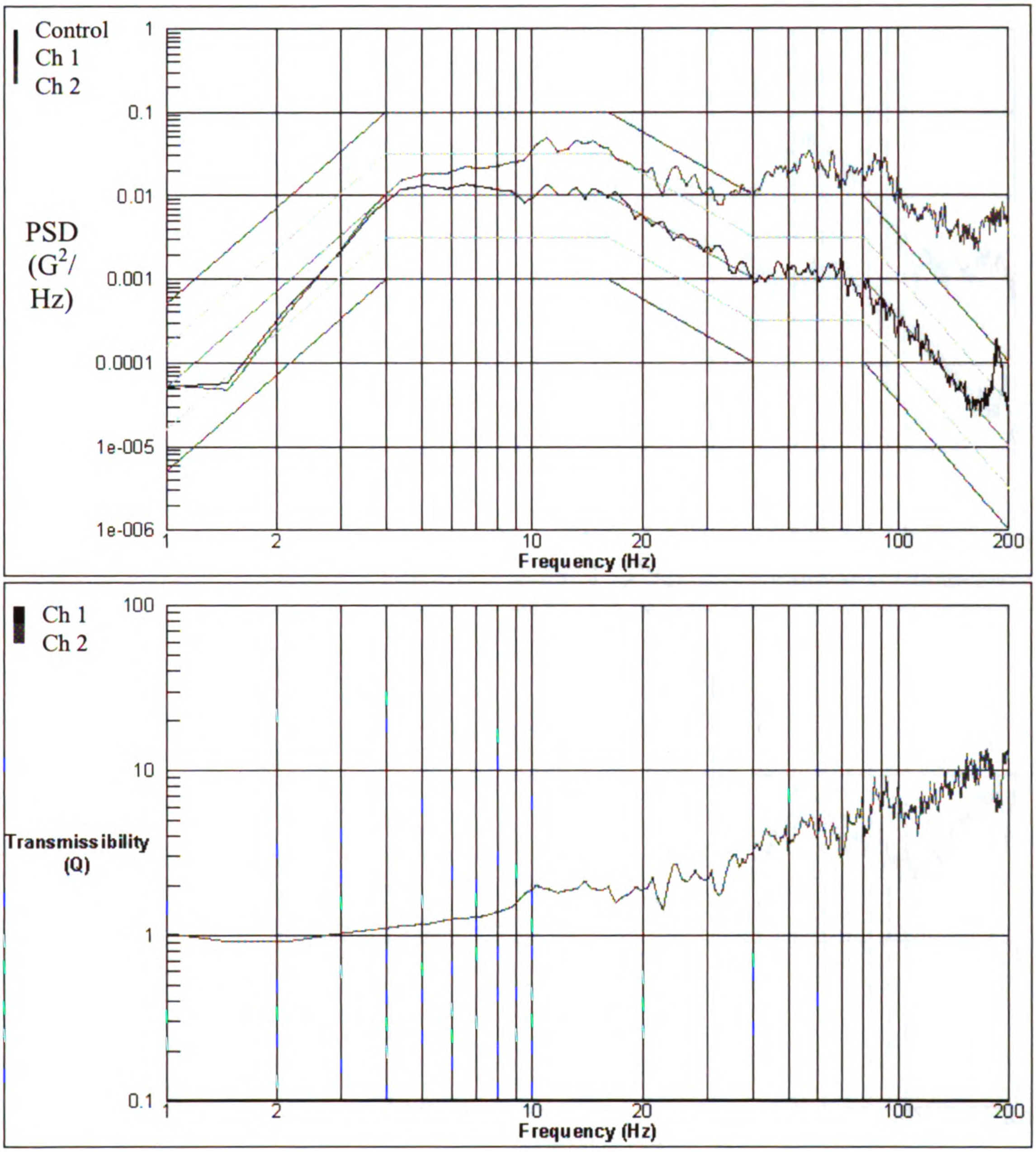


Figure C.11: Dowel pallet, Maple Syrup Cases, Accelerometer Location A

The transmissibility is 1.90 at 10.986 Hz.

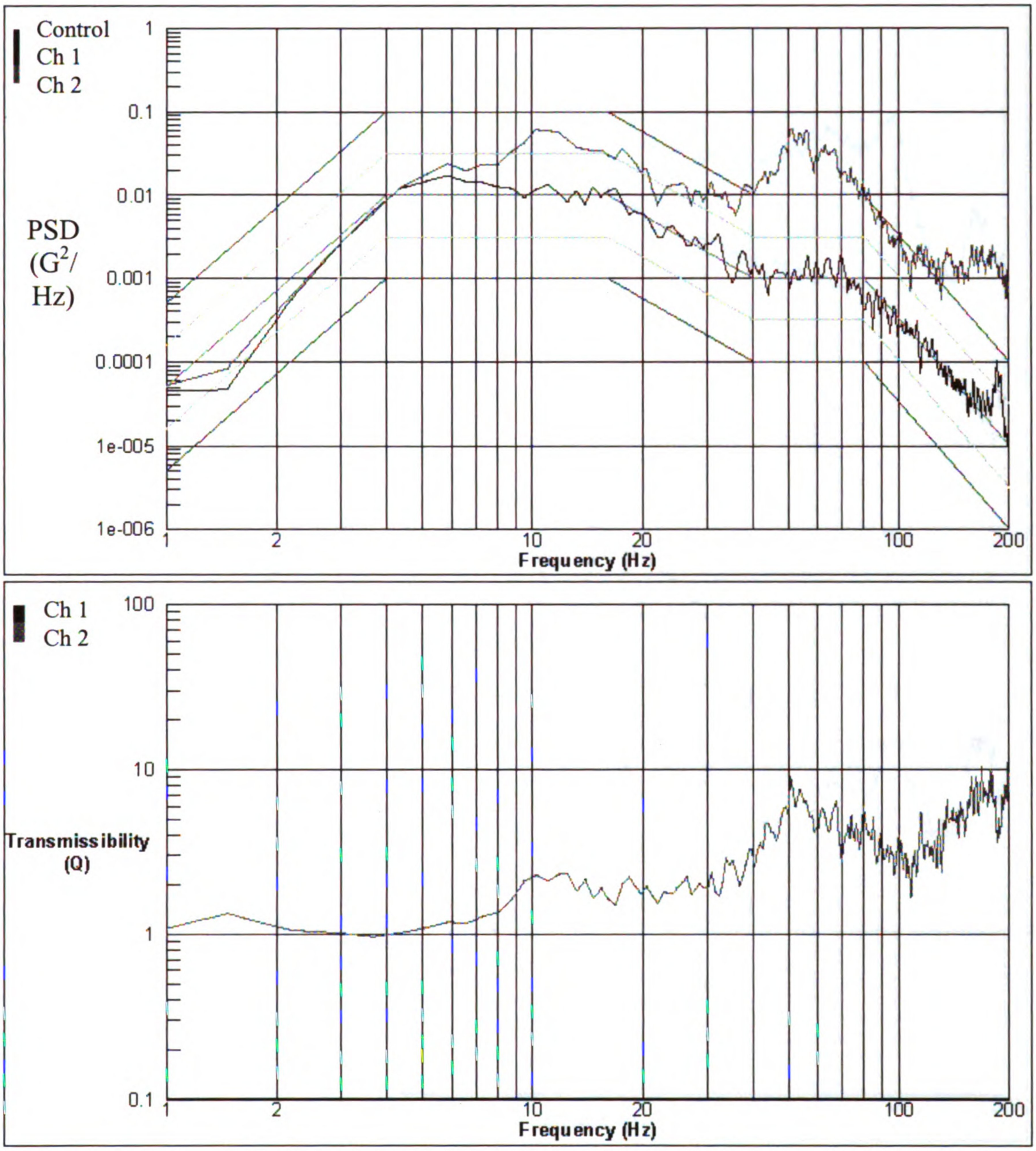


Figure C.12: Dowel pallet, Maple Syrup Cases, Accelerometer Location B

At 10.254 Hz, the transmissibility is 2.29.

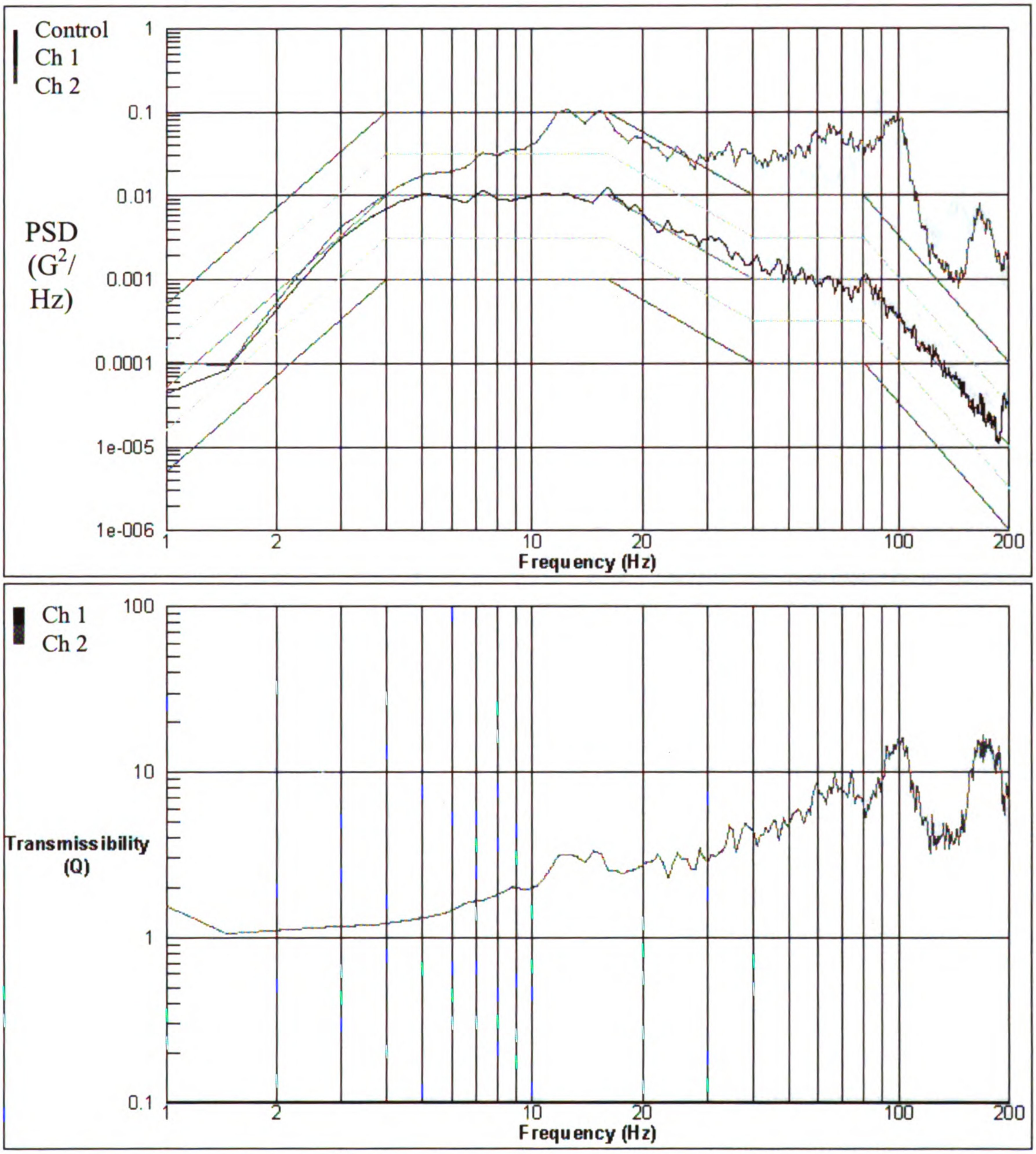


Figure C.13: G.M.A-2 pallet, Diet Coke, Accelerometer Location A

The transmissibility is 3.18 at 12.451 Hz.

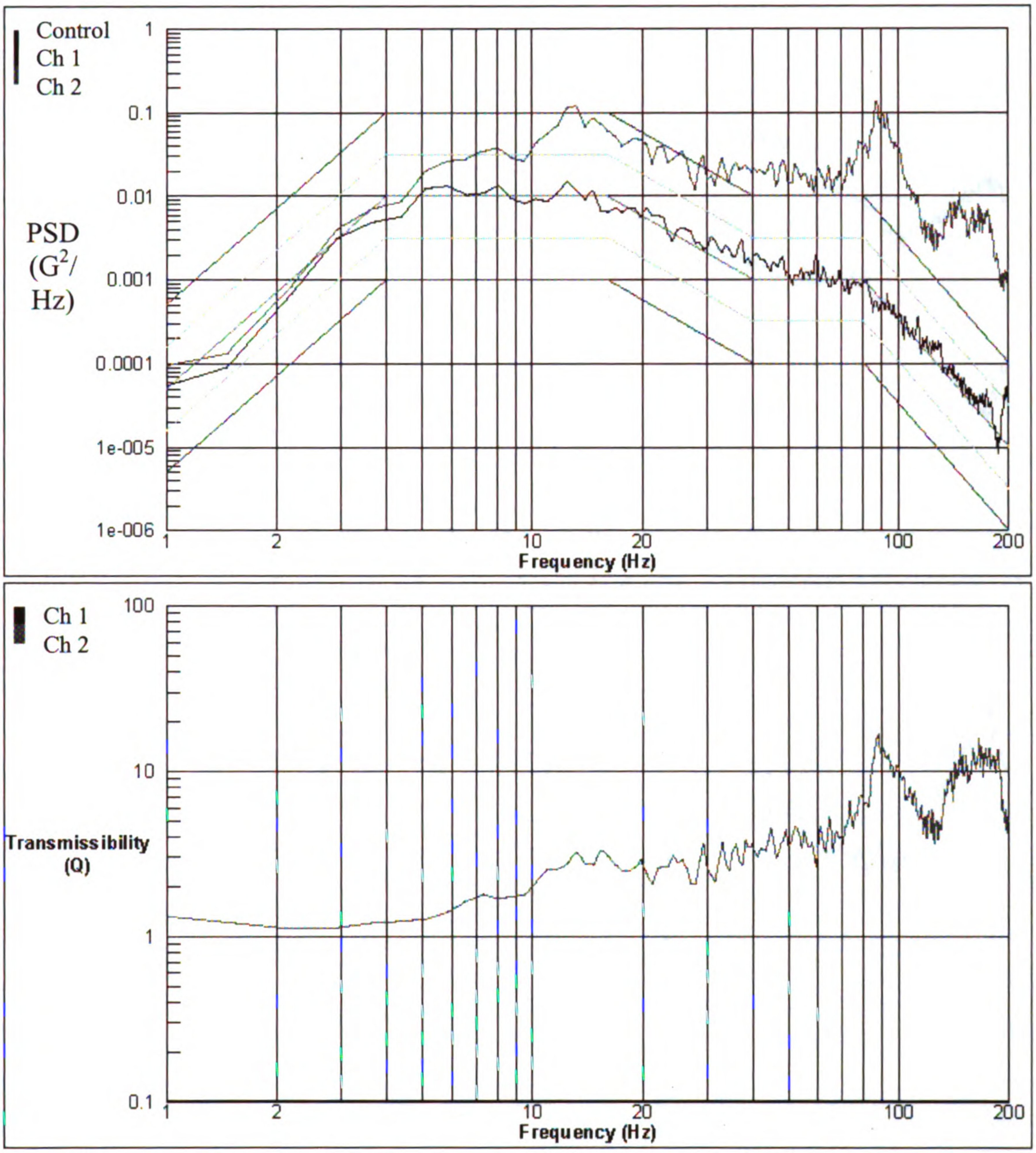


Figure C.14: G.M.A-2 pallet, Diet Coke, Accelerometer Location B

The transmissibility is 3.22 at 13.184 Hz.

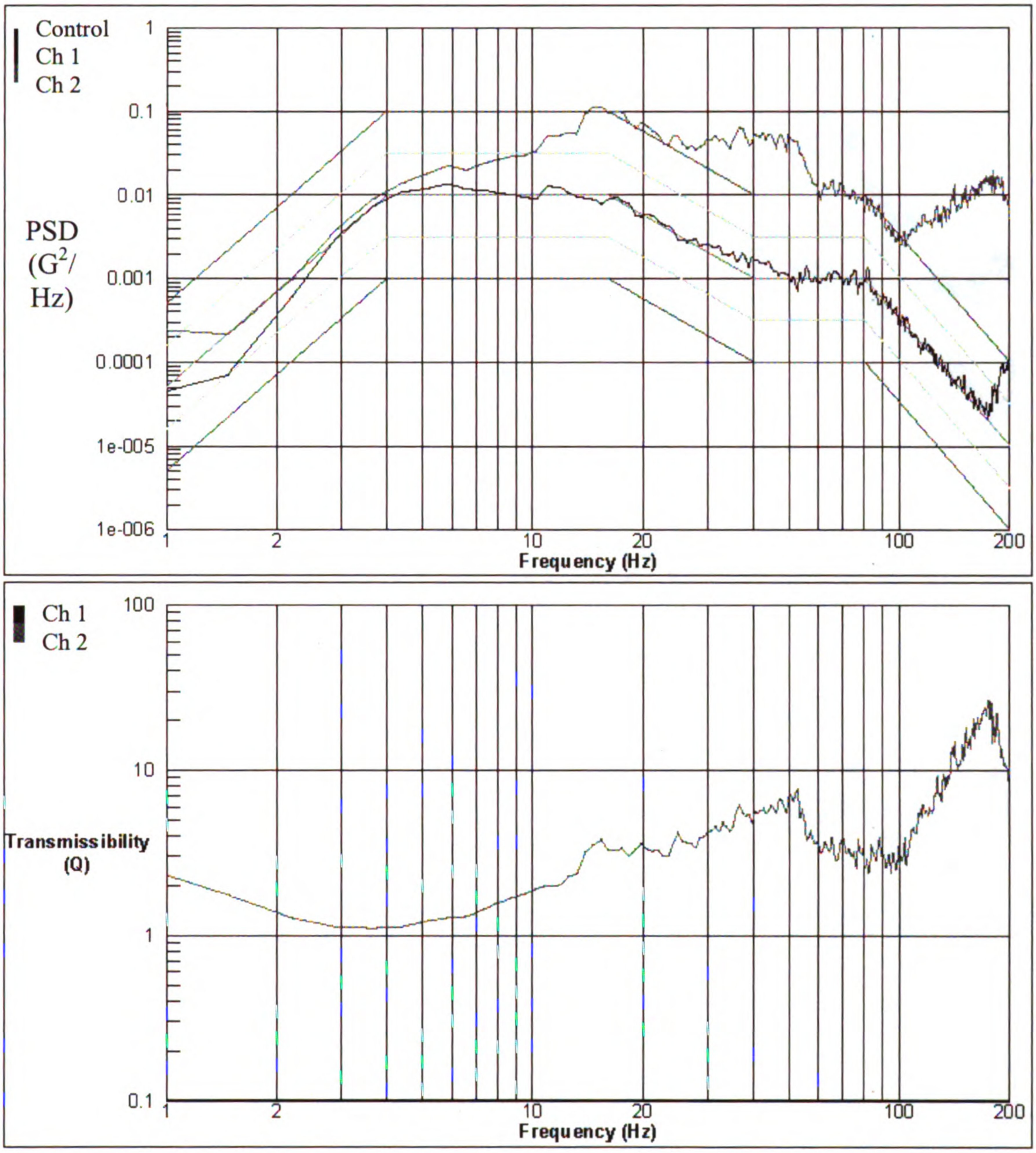


Figure C.15: Dowel pallet, Diet Coke, Accelerometer Location A

The transmissibility is 2.27 at 12.451 Hz.

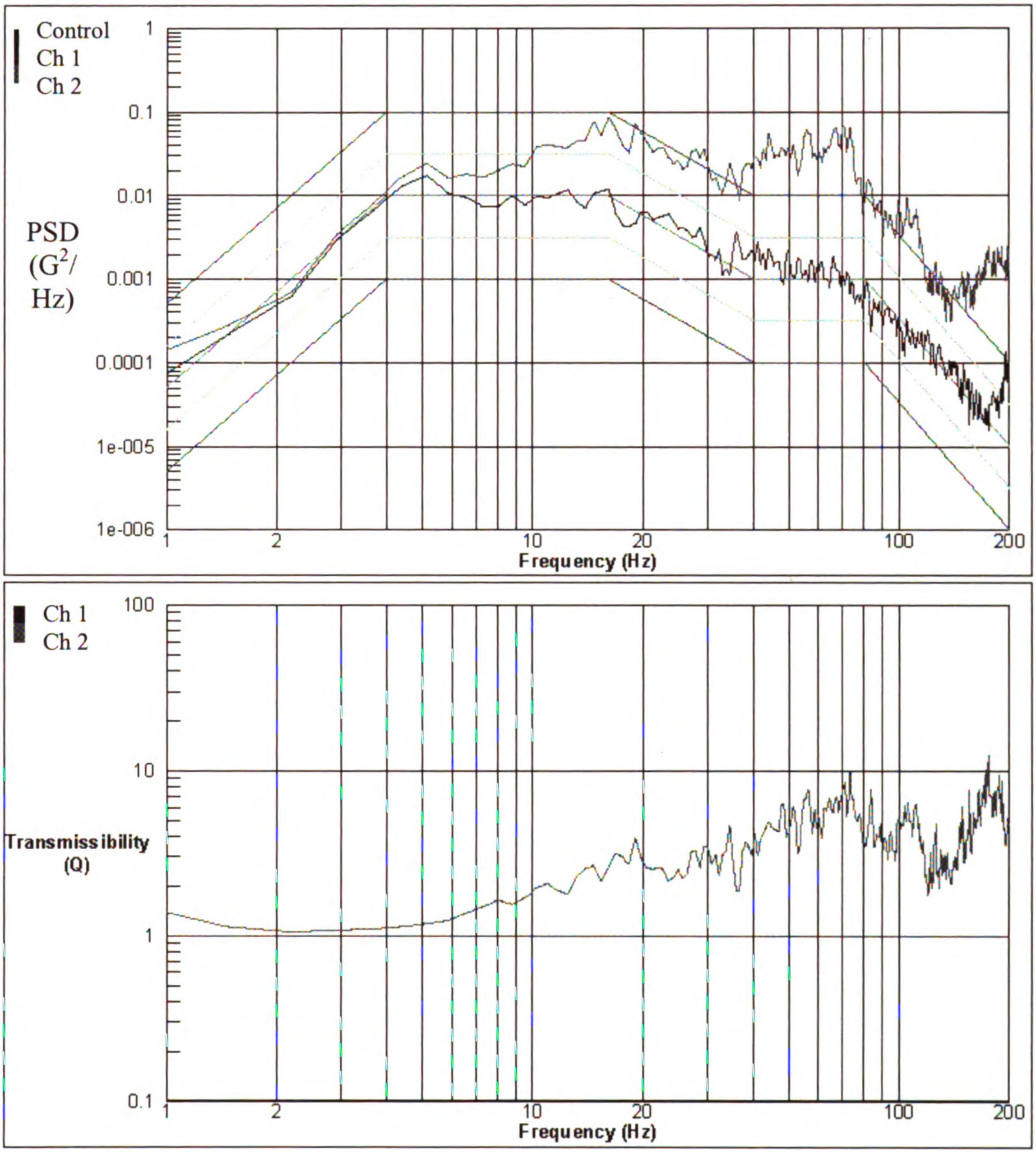


Figure C.16: Dowel pallet, Diet Coke, Accelerometer Location B

At 13.184 Hz. the transmissibility is 2.31.