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Achieving Effective Pallet Stack Unitization in Intermodal Shipping

By Per G. Reinhall, Ph.D., and Ron Carstens
University of Washington and Key Tech Corp.

FOCUS: The cost of trucking and intermodal shipping product damage to palletized loads in the United States is significant. Understanding the interplay between the major parameters that need to be considered during the design of palletized loads is paramount to achieving optimum pallet load packaging. In experimentation aimed at addressing this need, the strength of pallet stacks unitized by stretch wrap, liquid cohesive and a combination thereof were monitored through use of a portable self-contained data acquisition system. The measurements indicate that lateral vibration can be a major cause of pallet stack failure. It was concluded that the strength of the load could be significantly increased by the combined use of wrap and a liquid cohesive system, and that column stacking can, in some cases, help increase the lateral strength of the load further.

Introduction

The amount of intermodal shipping has nearly doubled in the past decade. Unfortunately, this type of shipping can increase the probability of product damage due to its combined use of trucks and rail. As intermodal shipments have increased, so has the percentage of unsaleable product from 0.5 percent of total goods in 1989 to an estimated 1 percent in 1998, or $4 billion of goods per year, according to statistics from the Grocery Manufacturers Association (GMA). The GMA attributes about 85 pecent of unsaleables to shipping/handling-related causes.

In the environment of deregulated shipping, product damage and lost merchandise have become an increasingly important issue since the associated cost is now charged back to the manufacturer. It is not enough that individual boxes and merchandise arrive intact—pallet stacks must have sufficient stability to tolerate handling with forklifts and other equipment without severe shifting or breaking-up.

The shipping strength of palletized loads secured by various amounts of stretch wrap and/or Lock 'N Pop® (LNP), a liquid cohesive pallet unitizing system, was investigated[1]. The research was conducted in two stages: The first investigated the strength and natural frequencies of palletized products, secured with various combinations of stretch wrap and LNP, through the use of hydraulic vertical and horizontal shaker tables. The second examined vibration to which pallet loads are subjected during intermodal shipping.

Methodology

Intermodal shipping vibration—Vibration during six intermodal shipments was recorded via a small self-contained vibration recorder[2]. Accelerations in the lateral, longitudinal and vertical directions were recorded by programming the recorder to trigger on accelerations exceeding $\frac{1}{10}$th of a g. Each trigger resulted in the recording of an approximately 16-second event. The recorder was set to store the 500 events with the largest acceleration.

During shipping, the recorder was attached to the side of the pallet of the stack situated at the side and above the rear axle of the trailer. All trailers were loaded to full weight capacity and with only one product. The pallet stacks were secured with either one layer of wrap only, LNP and top stretch wrap or LNP and one full layer of wrap.

Pallet strength—The shipping strength of palletized products was investigated with the help of two hydraulic vertical and horizontal shaker tables. Two types of boxes were

[1] Study was conducted under the direction of Dr. Per Reinhall, University of Washington, in cooperation with three shipping companies using intermodal trasportation.

[2] Instrumented Sensor Technology, Okemos, MI.

used: a 200# RSC, 14″x8″x8″, 27-lb. box (Type 1) containing one-liter beverage containers; and a 200# b-flute, side RSC, 11″x10.5″x12″, 42.5-lb. box (Type 2) containing 12 1.5-liter mineral water bottles. Both types were used to make pallet stacks five-high.

The effectiveness of several combinations of stretch wrap and LNP applied to pallet stacks were investigated using the following test procedure: A pallet stack was loaded onto the shaker table and fastened. The stack geometry was then measured (*Lancaster and White, 1994*) by recording the location of each layer in the stack through the use of plumb lines. The testing procedure started by determining the natural frequencies of the pallet stack, both in the vertical and lateral directions, by subjecting the stack to a low intensity sine sweep between 0.5 Hz to 30 Hz. The stack was vibrated with amplitudes below its damage threshold. No damage, i.e., no shifting or sliding of boxes, took place during this sine sweep.

The strength of each pallet stack was determined through a series of increasingly severe five-minute vibration tests. The stacks were inspected and measured after each test to determine if stack failure had occurred. If the stack was determined to be intact after five minutes of vibration, the test was repeated with a slightly higher vibration intensity. The procedure was ultimately stopped when the vibration level had reached a high enough level to cause failure of the stack.

The highest vibration level to which the stack could be exposed without failing was recorded as the measure of strength of the pallet stack. The vibration during each five-minute test had constant energy between 0.25 Hz and 30 Hz (Gaussian "white" noise). The excitation level was increased by 0.03 g rms between each five-minute run.

The constant frequency spectra level between 0.25 and 30 Hz constitutes a worst case scenario (*Gillespie, 1985; Reinhall, et. al., 1995; Singh, et. al., 1992*).

Results

Pallet natural frequencies—The natural frequencies for the pallet types and for a range of pallet securement methods were obtained by a low-intensity sine sweep between 0 and 30 Hz. Figure 1 shows typical frequency response curves of a pallet stack made from Type 2 boxes.

The addition of stretch wrap to the stack had only a small effect on the natural frequency of the stacks, indicating that it is not possible to significantly shift the resonance peaks of a pallet stack to avoid overlap with peaks in the frequency spectra of the shipping (container) vibration by adding stretch wrap. Parameters that can influence the natural frequencies of the stack include stack geometry, box stiffness and stack weight. A comparison between the two types of stacks used show that the lighter stack made from Type 1 boxes had a first natural frequency approximately 2 Hz higher than the heavier stack made from Type 2 boxes.

Intermodal shipping vibration—The peak accelerations during intermodal shipping were significant along all three directions—lateral, vertical and longitudinal. However, maximum acceleration events can be very short in duration and/or only contain frequencies to which the stack is insensitive and are, hence, not necessarily the main cause of failure.

Failure is caused by motions of the stack with accelerations high enough to cause high box-to-box interface stress and slippage. The

Figure 1

Frequency Response Curve of Pallet Stacks
Made from Type 2 Boxes
(Stack is secured by LNP combined with top wrap only.)

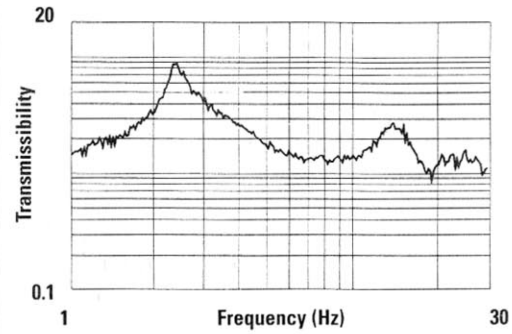
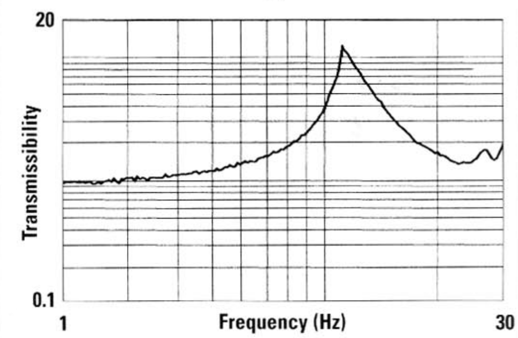


Figure 2

Vertical Frequency Response of Stack
Made from Type 2 Boxes



The ability to design the load such that its natural frequencies are well separated from the peaks of power spectrum of the shipping vibration is limited. Stretch wrap, stacking pattern and the presence of LNP do not tend to change the natural frequencies of the load significantly.

The problem is further compounded by the fact that the frequency corresponding to the shipping vibration peaks will vary with the mode of transportation, the gross weight of the rail road car or trailer and the speed of travel. Therefore, taking these varying factors into account, it is difficult to fine tune the location of the natural frequency of the pallet stack in order to avoid the shipping vibration peaks.

Figure 5

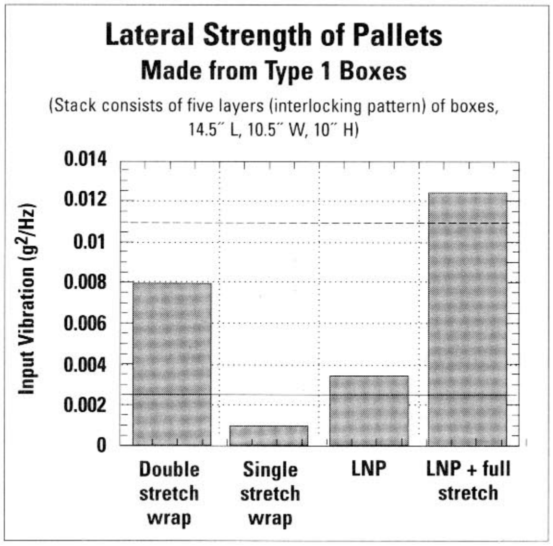
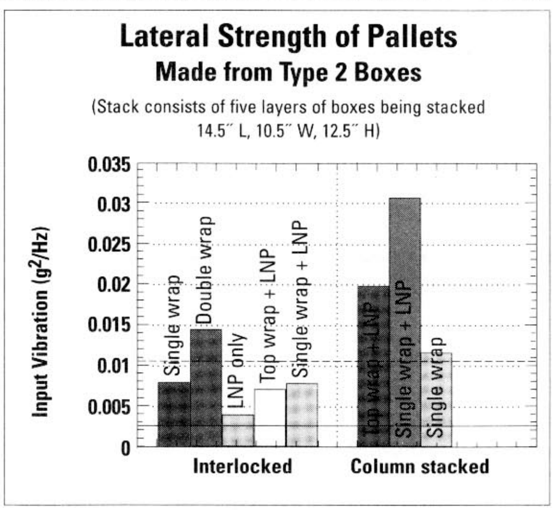


Figure 6



It is more practical to design the load such that it can actually survive a potential overlap of any peak in the power spectrum of the shipping vibration with a nearby pallet's resonance peaks.

The horizontal solid lines in Figures 5-7 represent the level of white noise that would yield a power spectra density of the top layer of the pallet equivalent to that caused by the maximum vibration level measured during the intermodal shipping routes (excluding handling during the initial and final phase of the shipping process). Pallet loads should be designed to withstand at least this level of vibration.

The dashed horizontal lines represent lateral handling loads measured during the initial and final phase of the shipping process. These vibratory loads are typically higher than the normal shipping loads but are often much shorter in duration, and their destructiveness can therefore not be directly related to the pallet strength test used.

Pallet strength—The lateral strengths of the pallet stacks made from Type 1 boxes for various combinations of stretch wrap and LNP are shown in Figure 5. The strength of the pallets is given as the maximum level of the input spectra (uniform between 0.25 Hz-30 Hz) of the lateral vibration which the pallet can tolerate without experiencing failure. As shown, the weakest of the tested configurations was the pallet with one layer of stretch wrap, while the strongest stack was produced by the combined use of LNP and one layer of stretch. The stack that was unitized by LNP only failed by the stack "walking" off the pallet as an intact unit. No relative motion between the boxes could be detected. This is in contrast to the other loads, where the relative motion between boxes led to stack failure.

Figure 6 shows the lateral strength of pallets made from Type 2 boxes. The column stacking pattern produced a significantly stronger load than the interlocked pattern. Column stacking of the Type 2 boxes resulted in pallets strong enough to tolerate lateral accelerations that exceeded the maximum accelerations recorded during both shipping and handling of the load. The largest increase in strength came when LNP was used in combination with one layer of stretch wrap.

The pallets made from the Type 2 boxes were also tested for vertical strength by the use of a vertical shaker table (Figure 7). The strength of the interlocked pattern was found to be significantly stronger in the vertical direction compared to the lateral direction and well above the maximum recorded acceleration. It can therefore be concluded by comparing Figures 6 and 7 that an interlocked pallet stack made from Type 2 boxes would most likely fail during shipping in the lateral direction and not in the vertical direction.

The column stacked pallets unitized with a combination of LNP and full wrap, however, were found to have enough strength to tolerate acceleration well above the recorded maximum intermodal levels in both the lateral and vertical directions.

Conclusion

Lateral vibration can be a major cause of failure of pallet stacks. The effect of vertical vibration was found to be benign due to high naturamplitude can only become large if the input vibration contains significant energy in frequencies to which the pallet stack is sensitive. An indirect measure of the total energy of the input (trailer) vibration to the pallet stack is the root mean square of the wood pallet acceleration. In reviewing the recorded data during the shipment, it was found that the rms value of the longitudinal vibration was lower than the other directions and that the rms of the lateral vibration was often comparable to that of the vertical vibration.

It must be emphasized that it is not possible to judge the destructiveness of the shipping vibration by looking at its overall rms value and the maximum acceleration levels. The relationship between the frequency response of the pallet stack and the frequency content or the power spectra of the shipping vibration must be considered. The shipping vibration becomes especially destructive when a peak in its power spectra overlaps with a resonance peak in the frequency response of the pallet stack. This can cause the response of the pallet stack to the shipping vibration to reach unacceptable high levels even when the rms value is moderate.

The maximum power spectra of the vertical acceleration from all triggered events during the intermodal shipping route was obtained by calculating the spectra for all events and plotting the maximum of all events on a point-for-point basis along the frequency axis. Hence, it represents the maximum energy, for each frequency point, to which the load was subjected along the shipping route. The peak of the vertical shipping vibration spectra was well separated from the peak in the frequency response plot of vertical motion of the pallet stack as shown in Figure 2.

This explains why the vertical shipping vibration in this case was less destructive than anticipated. Most of its energy occurred at a frequency range in which the pallet stack was insensitive (10 Hz- 13 Hz). That is, the high vertical natural frequency of the pallet stack compared to the main peak in the power spectrum of the vertical shipping vibration prevented a destructive resonant situation.

Figure 3 shows the vertical average power spectra of the rail and truck portions of all events from a typical intermodal route. Only a minimum difference between the power spectra of the vertical truck motion and the corresponding rail motion can be seen.

The energy of the maximum lateral shipping motion was distributed over a wider frequency range than the vertical motion. There is a significant overlap of the frequency resonance peak of the lateral motion of the pallet (Figure 1) with the lowest frequency peak in the power spectra of the lateral shipping motion (1.5 Hz-3.75 Hz). The lateral shipping vibration in this case could, therefore, cause significant motion of the load due to a resonance phenomena, potentially leading to a lateral destruction of the stack.

The power spectra of the lateral accelerations corresponding to the average of all events from a typical train and rail route is shown in Figure 4. The energy of the motion during the rail portion was mostly distributed between 2 Hz - 6 Hz, while the largest peak in the truck/trailer spectra was between 15 and 23 Hz. Excitation of the lowest lateral mode of the stack was, therefore, most likely to take place during the rail portion of the shipment.

Figure 3

Average Vertical Power Spectrum of Measured Intermodal Shipping Vibration for a Typical Route

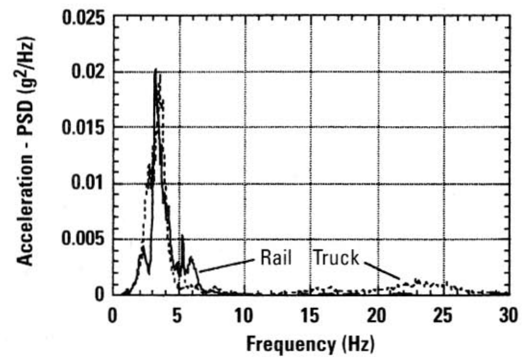


Figure 4

Average Lateral Power Spectrums of Measured Rail and Truck Portions of Intermodal Shipping Vibration for a Typical Route

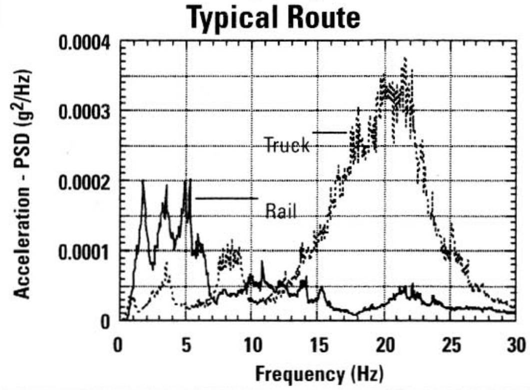
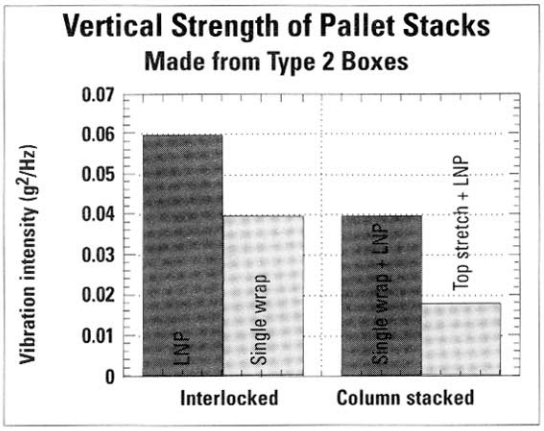


Figure 7



al frequencies of the stacks in the vertical direction and high vertical pallet strength. Test results indicate that the vertical and longitudinal motions are not likely to be a major cause of failure for the investigated stacks.

Unitization using LNP in combination with stretch wrap and an appropriate stacking pattern resulted in stacks that could withstand the maximum recorded shipping and handling accelerations. The investigation established that column stacking can increase the lateral strength of a pallet. ❑

For more information about this topic, contact the authors at (425) 347-3600.

About the Authors*: Dr. Per G. Reinhall is Professor of Mechanical Engineering at the University of Washington. His research includes studies in nonlinear and linear vibrations, acoustics, sensors and finite elements. He is the author of more than 60 technical publications and holds five patents.*

Ron Carstens is President of Key Tech Corp., a Mukilteo, WA-based manufacturer of packaging/shipping protection products including Lock 'N Pop® for unitizing pallet loads. He has a M.S. in Chemical Engineering.

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