Performance and Analysis of Unitized Stacked Load Units under Vibration Simulation

Bence Molnár
PhD Student
Széchenyi István University
Department of Logistics and Forwarding
Hungary

Péter Böröcz
Associate Professor
Széchenyi István University
Department of Logistics and Forwarding
Hungary

The unitized loads are the major form of the packed product transportation in logistics, and in most of the cases the packages are fixed to the pallet with straps, stretch film or these combinations to avoid the possible damages of products inside. During transportation various physical events such as vibration affect the product-packaging system. The nature of this vibration between the layers of stacked unit is not fully researched and understood. This paper focuses on the different motion of the layers in the unitized load in the function of the fixing modes using laboratory vibration simulations. Therefore, multiple unitized loads were built from the same quality corrugated paper boxes in three layers with various fixing modes to measure each layer motion separately. To carry out the simulation procedure, acceleration and vibration intensity on each layer was observed under sine and random vibration simulation. The recorded data shows, which layer motion is the most disparate from the excited motion, and which fixing variant causes this difference.

Keywords: *stacked packaging, vibration simulation, distribution packaging, stacked vibration*

1. INTRODUCTION

Vibration is one of the main hazards during the transportation [1]. This physical event can cause serious damages in the packaged-product system. The unitized load is the major form of a package-product system in distribution service [2], and they are usually built up from same packages in stack with different layout on distribution packaging device such as pallet. The most common fixing methods to stabilize the unit are the stretching and/or strapping the packages to pallet or to delivery vehicle. This paper focuses on the vibration differences between the layers of unitized load under various vibration simulation circumstances using different kinds of fixing method. The vibration simulation is one of the major forms to consider the adequacy of a packaging system. The simulations are usually based on testing standards that provide different vibration profiles such as ISO 13355 [3] (International Organization for Standardization), ASTM D4169 [4] (American Society for Testing and Materials), or ISTA series [5] (International Safe Transport Association). In these standards the vibration profiles simulate a time-compressed random signal to perform a similar vibration environment as transport vehicle platform has. Of course, there are some previous studies that focus on field measurement also and use vibration properties of a given distribution system. They measure the acceleration events with data recorder on the truck floor surface for various shipping routes, where the vibration depend on the type of the transport vehicle [6], its suspension [7], vehicle speed and the payload, and not least the quality of road [8], respectively. In the case of vibration analysis the power density (PD) levels are determined as a function of frequency based on the recorded random vibration acceleration levels as used other researches also [9,10]. The vibration environment is represented by the power density spectrum (PSD) showing a plot of the power density levels versus frequency. The energy within a specific frequency range can be obtained by integrating PSD within that frequency range (so called Overall G_{rms}). The computation of PSD is done directly using the method called Fourier transformation or computing autocorrelation function and then transforming it to use as diagnostic method [11,12].

Some of the researchers investigated the behaviour of stacked packaging unit under vibration. The frequency response and the transmissibility characteristic of top-loaded corrugated paperboard containers were observed and the results of Godshall [13] identified the resonance of containers between 8.4 and 18.2Hz. Wang [14] investigated the behaviour of stacked corrugated paper boxes along sine and random vibration simulation. Fang et al. [15] investigated the statistical characteristics of maxima of contact force in stacked corrugated containers under random vibration.

But, the authors of this paper could not find any former paper that compared the vibration behaviour of unit load built up from corrugated packages along the different types of fixing methods. The aim of this paper is to identify the vibration response of layers in these unit loads and to determine the possible resonance frequency points of these systems by varied fixing methods.

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Correspondence to: Bence Molnár
Department of Logistic and Forwarding,
Egyeten tér 1., 9026 Győr, Hungary
E-mail: molnar.bence@sze.hu
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2. METHODS

2.1 Measured unitized loads

Two similar unit loads were set up for the measurement. Each of them contained twelve pieces corrugated paperboard boxes (600x400x400 mm) that were built up in three layers and four columns on EUR pallet (800x1200mm) to simulate a general package system. The weight of the boxes was 15 kg, which value was calculated from the average shipment density showing in ASTM D4169. The filling material was PE (polyethylene) granulates in film bag, and EPS (expanded polystyrene) element secured the load at the bottom of the boxes with a width of 50mm. The samples for testing can be seen in (Figure 1). The size of the entire unitized load was 1200x800x1360 mm, with a weight of 206 kg.

Figure 1. Sample box with filling material

Figure 2. a) Stretch wrapped and b) strapped unitized loads on vibration table

The differences between the two unitized loads were only the fixing methods to the EUR pallet. The first one was fixed with stretch film, and the second one was fixed with plastic straps (Figure 2). For the stretching a hand polyethylene stretch film was used. The width of the stretch film was 500 millimetres and the thickness of the stretch film was 20 microns. Polypropylene strap tape was used for the strapping. The width of strap tape was 15mm and with a thickness of 2 mm. The straps were tensioned manually.

2.2 Vibration system

For the vibration simulation a hydraulic vibration table (LAB HV-60) was used with two VR Research 9500 vibration controllers. The table was controlled with two high sensitivity mono-axial accelerometers, and the response acceleration data were collected by four tri-axial accelerometers. These accelerometers were fixed to the boxes' outer side, near the bottom corner with double-wall adhesive tape, and an additional accelerometer was fixed to the pallet. The accelerometers were located above each other (Figure 3). The data was recorded only in the vertical direction. The reason of this is this direction is the most intensive direction on the field due to the nature of citation by road roughness. All accelerometers collected the data by sampling frequency of 1634 Hz, and FFT (Fast Fourier Transformation) type of Blackman window.

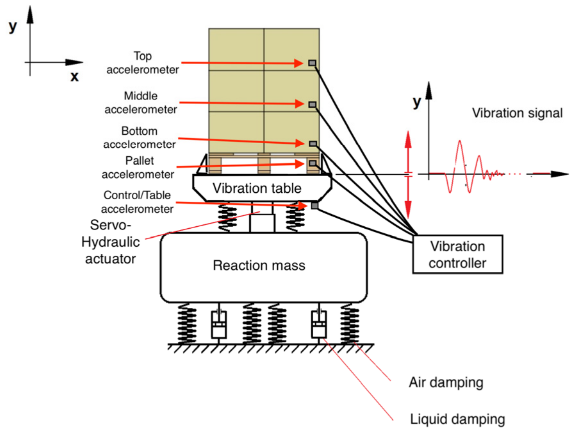

Figure 3: Position of the accelerometers

2.3 Vibration profiles

Sine sweep profile and two random (truck and air) vibration profiles were used for the observation of behaviour of units during the vibration. The whole frequency range was 2-200 Hz. The amplitude was peak to peak 25 millimeters between 2 and 4.41 Hz, and 1 G between 4.41 and 200 Hz Between 2 and 4.41Hz, the servo-hydraulic vibration table cannot operate with 1 g amplitude, therefore the amplitude was 25 millimetres in this frequency range.

The random vibration simulations were performed according to ASTM D4169 truck profile Assurance Level II and ISTA 3A air vibration profile. The following table contains the breakpoint of random vibration profiles. (Table 1) Here have to be mentioned that the units were not fixed to the vibration table, only rigid fences were used to avoid the falling out. Finally, the acceleration data obtained vibration simulations were analysed with Matlab R2017a software.

Table 1: Random profile breakpoints of truck and air vibration

ASTM D4169		ISTA 3A	
Frequency (Hz)	PD Level (g^2/Hz)	Frequency (Hz)	PD Level (g^2/Hz)
1	0.00072	2	0.00020
3	0.01800	12	0.01000
4	0.01800	100	0.01000
6	0.00072	300	0.00001
12	0.00072		
25	0.00360		
30	0.00360		
40	0.00072		
80	0.00360		
100	0.00360		
200	0.000012		
Overall Grms	0.542	Overall Grms	1.052

3. RESULTS AND DISCUSSION

3.1 Sine sweep

Figure 4 and 5 show the measured accelerations of the various layers during sine sweep vibration. The result showed the acceleration values between 4-10Hz on the middle and top layer were nearly twice as high as the excitation at stretch wrapped unit load. The bottom layer actually followed the excited acceleration of the vibration table. Above 10Hz the acceleration levels that observed on the middle and top layers rapidly decreased. In the range of 100-180Hz the acceleration levels on pallet and the bottom layer reached 3.26g and 6.12g comparing to the 1g inputs.

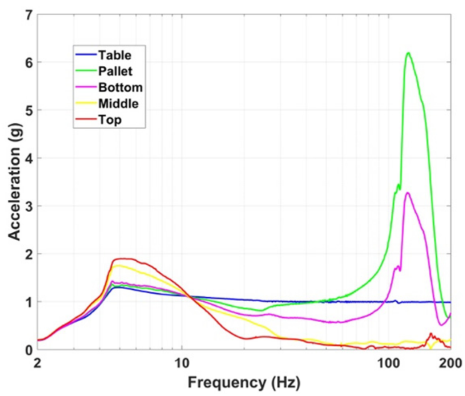

Figure 4: Acceleration levels of stretch wrapped unit load

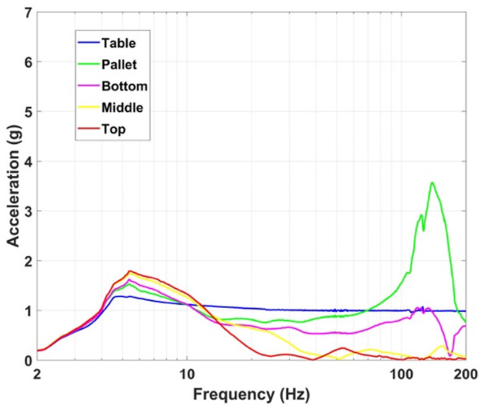

Figure 5: Acceleration levels of strapped unit load

In case of strapped version, in frequency range of 4–10Hz, similar to the previous experiment each response acceleration levels exceeded the input and felt down below the input value over 10Hz, except the pallet response. The highest captures acceleration level was on the pallet with a value of 3.53g, at 139.6 Hz.

3.2 Random vibration

The following figures (Figure 6 and 7) show the measured data during the ASTM random vibration profile. Similar to the sine vibration, the amplified PD (Power Density) levels were observed on the top and middle layers, in the range of 6-15 Hz, and then over 100 Hz on the pallet and bottom layer. Here has to be noted that bottom layer of the strapped unit was the only one, which nearly followed the excitation during the entire frequency range.

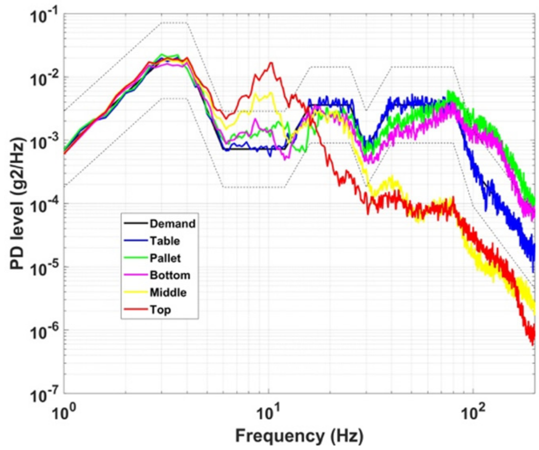

Fig. 6. PSD plot of stretched wrapped unit load

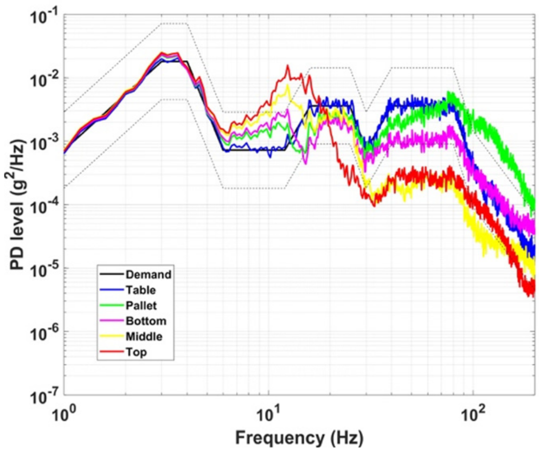

Figure 7: PSD plot of strapped unit load

Figures 8 and 9 show the differences of the two unitized load vibration responses in transmissibility plots. The peak of the transmissibility in case of the stretched unitized load's top layer was at 10.2 Hz and the transmissibility ratio was 24.91. These values were 12.4 Hz and 12.54 for the strapped one. The middle layer's transmissibility values were around 8.83Hz with a value of 6.83. The pallet and the bottom layer cannot follow the motion of the table above 80 Hz, the peak of the transmissibility was at 130.8 Hz with a ratio value of 38.44 for the wrapped unit load, and at 115.8 Hz with a ratio of 23 for strapped one.

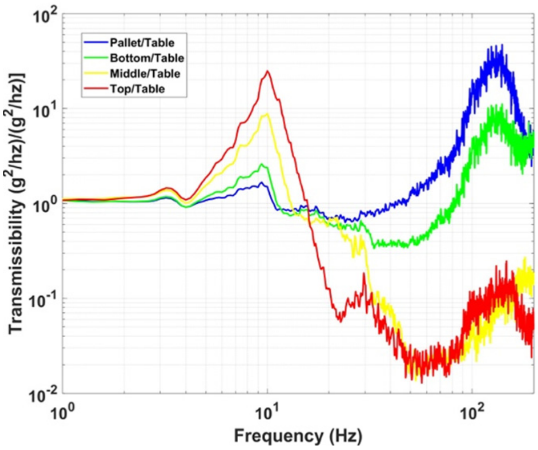

Figure 8: Transmissibility plot of stretch wrapped unit load

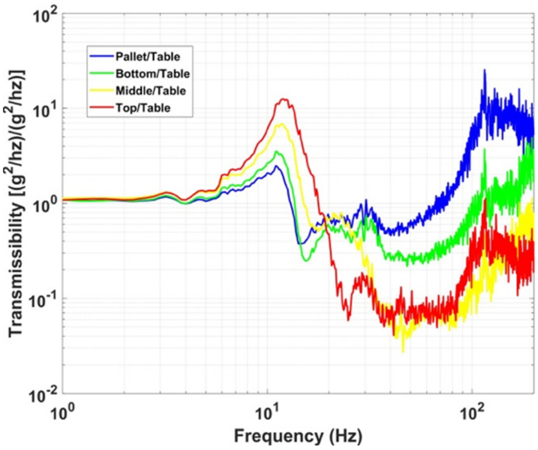

Figure 9: Transmissibility plot of strapped unit load

Finally, the unit loads were investigated under ISTA 3A Air random vibration, and similarly like at truck vibration simulation, the PSD (Figure 10 and 11) and transmissibility (Figures 12 and 13) plots are presented for this study. Likewise, at the ASTM truck random simulation, the upper layer's motion differed from the motion of bottom and the pallet layers, which follow the excitation between 5-13 Hz. Similar to the ASTM and sine vibration simulation, the middle and top layers accelerations decreased over 13 Hz. The behaviour of these layers above 130 Hz was different for the type of unit loads. In case of stretch wrapped unit, the measured PD levels of the bottom layer and the pallet significantly increased from 65 Hz.

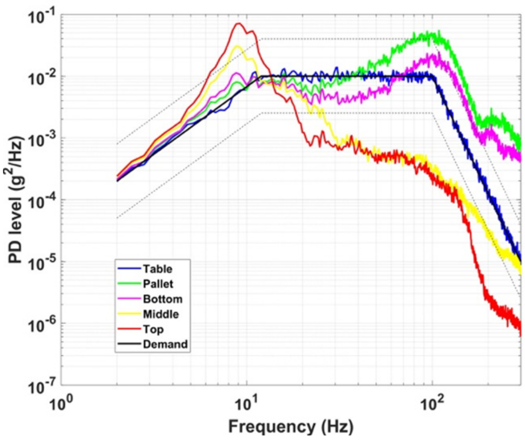

Figure 10: PSD plot of stretched wrapped unit load

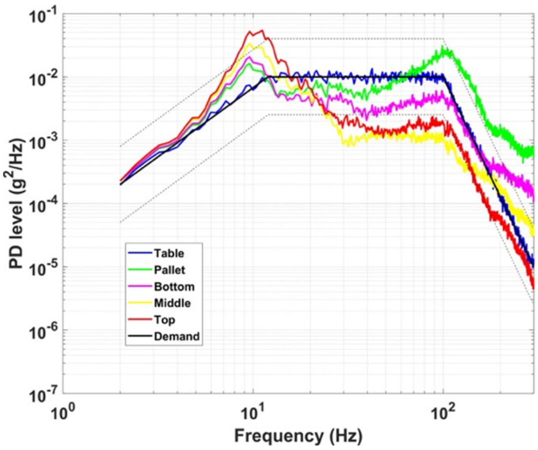

Figure 11: PSD plot of strapped unit load

The above-mentioned phenomenon can also be revealed by the following two figures (Figures 12 and 13), which illustrate the transmissibility ratio between the layers and the vibration table input. When comparing the two figures, the difference in the movement of the layers of the two variant is immediately visible. The peak of the transmissibility in case of the stretched unitized load's top layer was at 8.8Hz and the transmissibility ratio was 13.28, and these values were 10Hz and 7.26 for the strapped one. The middle layer's transmissibility values were at this frequency point 5.8 and 4.53. The pallet and the bottom layer cannot follow the motion of the table above 80 Hz, from this frequency point the transmissibility ratio continuously increased.

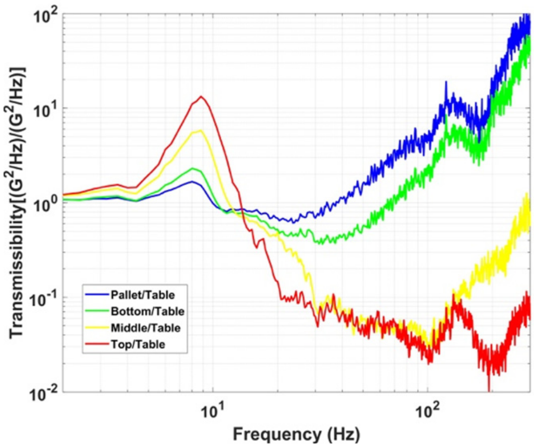

Figure 12: Transmissibility plot of stretch wrapped unit load

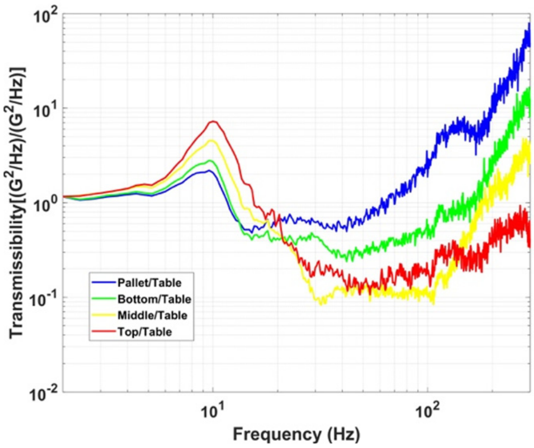

Figure 13: Transmissibility plot of stretch wrapped unit load

4. LIMITATIONS OF STUDY

The authors of this paper want to call attention to the fact that the method of PSD involves the use of the Fast Fourier Transformation (FFT) process and due to this this it produces a PSD profile with average intensity of the vibration over the frequency range of interest [16]. Furthermore, the use of presented PD levels as vibration simulation conditions do not expose the test items to extreme levels of vibration or transients like shock events, which can occur during real transportation. Last, but not least it has to be recognized by the readers of this paper that the intensity of the test standards applies time-compression [17], which artificially amplifies the vibration magnitude comparing to the real life.

5. CONCLUSION

The results show that the top and middle layers' response acceleration values in unit loads are significantly higher than the excitation in the frequency range of 6-14 Hz during sine sweep simulation. In the higher frequency range (over 80Hz) the bottom layer attenuates these layers' motion. The significantly amplified PD levels could be found during the ASTM random vibration simulation, when the top and middle layers showed the a very high amplifying in the range of 6-15Hz, and over 100Hz it could be experienced on the pallet and bottom layer only. From the results of this study the following conclusion can be drawn: the measured response acceleration values were higher at the stretch wrapped unit load than at the strapped sample. This may be due to the fact that strapping can prevent better the vertical movements than the stretch wrapping.

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ПЕРФОРМАНСЕ И АНАЛИЗА НАСЛАГАНИХ ТОВАРНИХ ЈЕДИНИЦА СПОЈЕНИХ У ЈЕДНУ ЈЕДИНИЦУ У УСЛОВИМА СИМУЛАЦИЈЕ ВИБРАЦИЈА

Б. Молнар, П. Береч

Спојене товарне јединице представљају главни проблем у логистици транспорта упаковане робе и у већини случајева пакети су фиксирани за палету помоћу каишева, еластичног филма или се користи њихова комбинација да би се избегло могуће оштећење робе унутар паковања. У току транспорта јављају се различите физичке појаве као што су вибрације које утичу на систем паковања. Природа вибрација између слојева спојених товарних јединица није до краја истражена. Овај рад се бави различитим кретањима слојева у спојеним товарним јединицама да би се онемогућило кретање ових слојева применом симулације вибрација. У циљу истраживања товарне јединице су израђене од кутија од таласастог картона и спојене у три слоја различитим средствима за фиксирање да би се мерио начин померања сваког слоја појединачно. Поступак симулације, интензитет убрзања и вибрација посматран је код сваког слоја уз симулацију синусних и случајних вибрација. Резултати показују који се слој највише разликује у погледу побуђеног кретања и која варијанта фиксирања највише утиче на ову разлику.