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Measurement and Analysis of Truck Transport Environment in Brazil

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ABSTRACT

Increasing trade in today's global economy requires packaging to be designed to contain, protect and deliver products without damage during transportation and handling. Vibration forces that occur during transportation are one of the most significant causes of damage during shipping. The objective of this study was to quantify and analyse the vibration that occurs during truck transport in Brazil. The study was done using two types of trucks: small local trucks for local metropolitan distribution areas and larger tractor-trailers for cross-country transportation. Ten metropolitan areas in different regions of Brazil were selected for 1-day trips representing normal delivery. These trips encountered varying road surfaces (asphalt, concrete, stone and dirt). The long distance trips were done on highways that were more than 1200 km long. The vertical vibration levels were higher than the lateral and longitudinal levels as expected. A composite power density spectrum of all trips is provided in this paper to simulate truck transport in Brazil using random vibration test methods.

KEY WORDS: vibration; truck transport; power density spectrum, Brazil

INTRODUCTION

Truck transport is commonly used worldwide for the distribution of goods for trade. Although relatively expensive when compared with bulk shipments by rail and sea, truck transport is usually the most economical way to provide distribution of goods in places where inexpensive (e.g. railways) or natural (e.g. ports, rivers) transport alternatives are not available. The global economy is increasingly demanding that products be distributed on a worldwide basis. International free-trade agreements have leveraged the quality standards and expectations of consumer products to the point that it is not possible to predict anymore where a product will be ultimately sold. For the global economy to flourish, packaging designers need to broaden their knowledge of potential hazards (e.g. vibration) found during transportation to help design and test packages to be shipped on an international scale.

Brazil is the ninth largest economy in the world, based on gross domestic product (GDP) and purchasing power parity (PPP) according to estimates from the International Monetary Fund (IMF). It is also the largest economy in Latin America and the southern hemisphere. The recently reported 15 greatest economies by the IMF are listed in Table 1 (values in US$ million).[1]

Table 1. GDP in PPP of the 15 leading economies in the world

Rank	Country	GDP (PPP) ($ million)
1	USA	12 277 583
2	China	9 412 361
3	Japan	3 910 728
4	India	3 633 441
5	Germany	2 521 699
6	UK	1 832 792
7	France	1 830 110
8	Italy	1 668 151
9	**Brazil**	**1 576 728**
10	Russia	1 575 561
11	Canada	1 104 701
12	Spain	1 089 103
13	Mexico	1 072 563
14	South Korea	994 399
15	Indonesia	977 419

Source: International Monetary Fund, 2006

Since 2001, the international net trade of Brazil has increased significantly as shown in Figure 1. Brazil's foreign trade is evenly divided among a number of main partners: the European Union (27%), the USA through North America Free Trade Agreement (26%), South America (especially within Mercosul-Southern Common Market, 25%) and Asia (12%). Other regions make up the remaining 10%.[2] Brazil's economy is backed by a wide array of natural resources and a diversified infrastructure on the way to modernization. Open regionalism combined with strengthening the multilateral trading system manifests Brazil's fundamental interest in preserving balanced trade and financial ties with the various regions and countries of the world. The result is an increasing net income of the international trade as shown in Figure 1. Geographically, most of the goods produced for export are made in the eastern region of Brazil, where the majority of the people reside. Figure 2 shows the contribution of each Brazilian state to the total national export according to the 2004 data from the Applied Economics Research Institute of Brazil.[2]

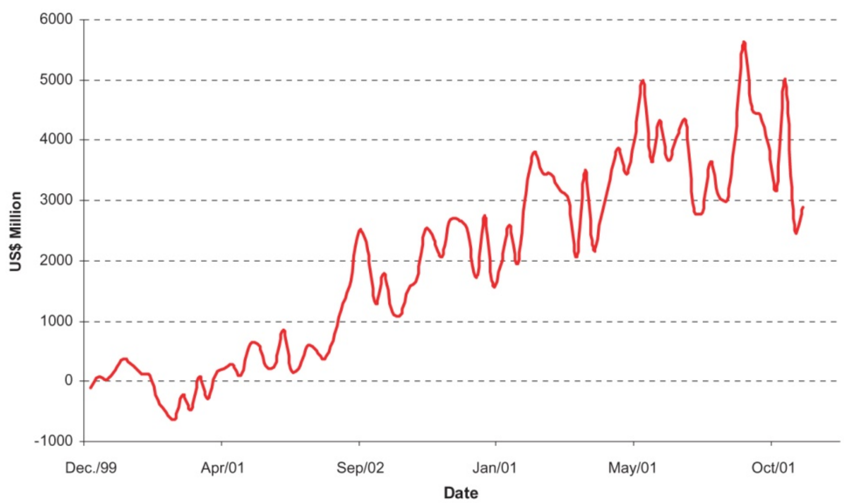

Figure 1. Net international trade of Brazil.

Although most of the world's eyes are currently focused on Asia due to its accelerated development, it is important to have active suppliers in other continents to avoid dependence on one country or region. Sanitary restrictions and political and trade barriers may be imposed quickly to protect local economies so that other supply sources could be readily considered to avoid rising prices and low stock. For instance, it is estimated that over 100 million birds have died or been killed in 2004 as a consequence of avian influenza outbreaks. In particular, the impact of import bans on export-dependent countries, such as Thailand, will increase the income vulnerability of small producers as local prices drop sharply. Both Canada and the USA, in addition to nine Asian countries, have also reported outbreaks of bird fl u. These countries account for 4 million tons or 50% of the world exports of poultry meat (with the USA accounting for nearly 35%). Chinese exports of poultry were estimated to decline 20% as a direct consequence of the bird fl u outbreaks. Similarly, cases of bovine spongiform encephalopathy in the USA and Canada has caused countries around the world to ban beef imports from these countries. The USA and Canada account for more than one-quarter of global beef exports (around 1.6 million tons, valued at approximately $4 billion).[3] In Japan, import bans on beef and chicken have led to pork meat prices surging 40% in 2004. Also, meat shortages have pushed large importers to diversify suppliers globally in order to protect market share.

Truck transport plays a significant role in moving products from the agricultural and resource-rich regions of Brazil to the port cities. The Brazilian truck fleet is estimated at 1 733 300 vehicles.[4] During 2005, 61.1% of the total tonnage of goods transported in Brazil used road transport.[4] It is therefore the most important transport system for the distribution of goods. The volume of goods transported by rail, ships and planes consisted of 20.7, 17.8 and 0.4%, respectively.[4]

There is quite a diversity in the types of road surfaces used by trucks in Brazil. The most common types of road surfaces are asphalt, concrete, dirt (unpaved) and stone. Stone roads are almost exclusively found in the urban environment because their construction is labor intensive. Asphalt and concrete are more common for expressways (highways) connecting major cities. Figure 3 shows the various types of road conditions measured in this study. Toll roads account for 10 803 km and are deemed to be better than public roads because the toll tax is reinvested in the road. Even among paved surfaces, potholes and undulations due to heavy-load traffic and poor construction occur, causing severe impacts or transient shocks during truck vibration. Table 2 shows the distribution of paved and unpaved roads in Brazil.

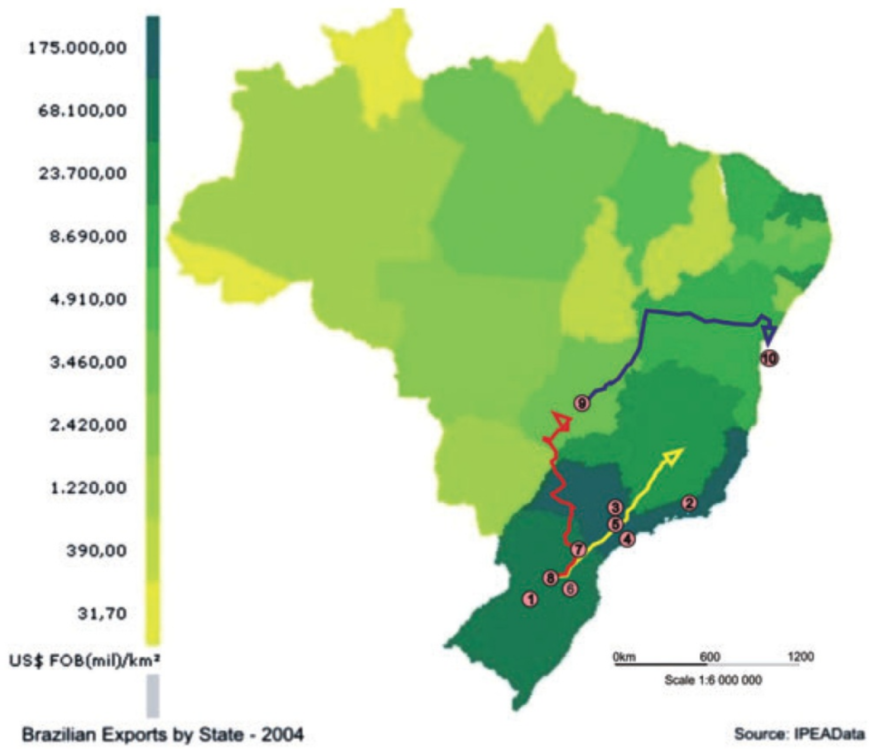

Figure 2. Exports of Brazil by state and locations of measurement of metropolitan distribution and cross-country trips.

For economical and environmental reasons, packaging systems have been reduced to minimal levels in order to provide the required protection. The challenge of surviving the zero-damage goal has become greater as a consequence of the global economy, as most goods are distributed virtually everywhere in the world.[5] Therefore, measuring the distribution environment is a key factor in developing appropriate vibration testing methods that can be used to develop optimum protective packaging. Not designing according to realistic shipping conditions may result in either over-packaging (where the test level is

Figure 3. Types of road surfaces in Brazil: asphalt, concrete, stone and dirt (clockwise from top left).

more severe than the environment) or product damage due to under-packaging (where test levels are lower in intensity than the shipping environment).

Since 2000, vibration measurement studies have been done in various regions around the world (China, Thailand, India and Europe) in order to develop data to define a 'global distribution environment'.[6] Data from Brazil is important, as this is the leading economy in Latin America. Small trucks for metropolitan distribution and larger trucks for cross-country distribution were used in this study to collect data for different payloads, truck types, speeds and road surfaces.

Vibration occurs whenever a spring-mass system (e.g. the truck mass on its suspension) is in motion. A large tractor-trailer has different spring-mass systems acting together. They are the pneumatic tires, the

Table 2. Distribution of road types in Brazil

Road type	Paved	Unpaved	Total	% paved
Federal	57 933	14 777	72 710	79.7
State transitory	17 049	7 277	24 326	70.1
State	98 377	109 963	208 340	47.2
City	22 735	1 281 965	1 304 700	1.7
Total	196 094	1 413 982	1 610 076	12.2

Source: CNT – Brazilian National Transport Confederation.

trailer floor and the suspension. Damage usually occurs as a consequence of magnification of truck vibration caused by cushioned product packages. When the truck bed vibration frequency is close to the product-package natural frequency, the system starts to exhibit a condition called 'resonance', resulting in large vibration forces from the truck bed (input) to the product (output). These conditions often result in damage to the packaged product. Examples of vibration-related product damage from truck shipments include fatigue, mechanical failure, scuffing, static charge buildup, undesirable product settling, phase separation and leaking of fluids.

EXPERIMENTAL DESIGN AND SET-UP

Vehicles and trips

Table 3 shows the various shipments measured. There were large variations in trip distance, gross weight and truck type. All trucks had leaf spring suspensions and insulated trailers. The products transported in these shipments were food products in refrigerated or frozen conditions. The routes are also graphically shown in Figure 2. All metropolitan regions used six-wheeled trucks (two axles), except for measurement 7 (Curitiba – PR), which was done using a 10-wheeled (three axles) trailer. Figure 4 shows the metropolitan distribution trucks, and Figure 5 shows the cross-country trucks.

Table 3. Details of measurements of truck environment in Brazil

Shipment date	Location	Load (kg)	Distance (km)	Vehicle
		Metropolitan regions		
1. 24 August 2006	Passo Fundo – RS	6020	186	Mercedes 1418 (177 h.p. @2200 rpm, maximum net payload of 13 990 kg)
2. 29 August 2006	Rio de Janeiro – RJ	462.68	103	Mercedes-Benz 710 (110 h.p. @2300 rpm, maximum net payload of 3770 kg)
3. 30 August 2006	Campinas – SP	2150	94	Volkswagen 8-150 (150 h.p. @ 2500 rpm, maximum net payload of 8150 kg)
4. 31 August 2006	Santos – SP	1264.24	145	Iveco 50-13 (125 h.p. @3600 rpm, maximum net payload of 3270 kg)
5. 1 September 2006	São Paulo – SP	1997	51	Volkswagen 8-120 (115 h.p. @2400 rpm, maximum net payload of 7750 kg)
6. 6 September 2006	Lages – SC	3423	459	Iveco Daily 70-12 (125 h.p. @3600 rpm, maximum net payload of 4140 kg)
7. 8 September 2006	Curitiba – PR	2921	188	Mercedes 1620 – 10 wheels (231 h.p. @2200 rpm, maximum net payload of 16 460 kg)
8. 19 September 2006	Videira – SC	1180	120	Iveco Daily 49-12 (122 h.p. @3600 rpm, maximum net payload of 3120 kg)
9. 10 October 2006	Goiânia – GO	2700	42	Mercedes-Benz 710 (110 h.p. @2300 rpm, maximum net payload of 3770 kg)
10. 13 October 2006	Salvador – BA	1629	91	Iveco Daily 35-10 (103 h.p. @3600 rpm, maximum net payload of 2390 kg)
		Long distance trips		
Yellow – 20 September 2006	Videira (SC)– Belo Horizonte (MG)	19 260	1306	Tractor Scania 400 (400 h.p.) – year 2003; semi-trailer Recrusul – year 1999
Red – 27 September 2006	Videira (SC)– Rio Verde (GO)	26 150	1481	Tractor Mercedes 1935 (326 h.p.) – year 1997; semi-trailer Randon – year 1997
Black – 10 October 2006	Goiânia (GO)– Salvador (BA)	17 960	1848	Tractor Scania 380 (380 h.p.) – year 2005; semi-trailer – Randon year 2006

Figure 4. Metropolitan distribution truck

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Figure 5. Cross-country transport truck with three axles.

Measurement equipment

The instrument used to measure vibration was a model EDR-3C data recorder manufactured by Instrumented Sensor Technology, Okemos, MI, USA. In addition, an online Global Positioning Satelite tracking system developed by Autotrac (Brasília – DF, Brazil) and OmniSAT (Qualcomm Inc., San Diego, California, USA) was used to reference the actual location of the trailers at any given instant to the measured vibration. This allowed the authors to exclude periods of measurement when the trailer was stationary during loading and unloading. The data recorders were mounted on the undercarriage in the middle section and at the rear location of the trailer (Figure 6).

Figure 6. Mounting location of vibration recorder.

The following set-up parameters were used for all three axes (vertical, lateral and longitudinal):

- Pre-trigger length (samples): 32 ms
- Maximum length (samples): 2730.7 ms
- Dead time after event: 1 s
- Sampling rate: 750 samples per second
- Trigger level: 0.25 G
- Data retention mode: overwrite

All shipments were conducted along normal shipping routes and while delivering actual loads. For metropolitan shipments, the truck speeds ranged from 20 to 60 km/h. For cross-country shipments using expressways, the speeds ranged from 70 to 100 km/h.

DATA AND RESULTS

The data obtained from the recorders were analysed using the Dynamax software package developed by Instrumented Sensor Technology. The results of the vibration data analysis are presented as power density spectra. A power density spectrum is a plot of energy (power density) versus frequency. [5] This is commonly used to measure and compare vibration levels in various global studies.[6,7]

The levels of acceleration occur in a random manner over a range of frequencies. The average power density (PD) within a band of frequencies is calculated as follows:

$$PD = \frac{1}{BW}\sum_{i=1}^{n}(RMS\,G_i^2)/n$$

where G_i is a sampled acceleration value measured in g's within a bandwidth (BW) of frequencies, and n is the number of samples.[8] The corresponding power density levels are then plotted against the centre frequency of the bandwidth to develop the power density spectra for the data set analysed. For this study, a bandwidth of 1.875 Hz was used.

The spectra analysed with the described method can be used to compare levels of vibration and frequencies for different trucks, payloads, geographical regions and logistical systems. The raw data for a shipment consisted of vibration levels sampled and recorded in the vertical, lateral and longitudinal directions above the trigger level. The root mean square acceleration (G_{rms}) was also calculated for each orientation and trip. This is the square root of the area under the Power Spectral Density plot and represents the overall intensity of vibration across all frequencies.

The results from this study are presented in the form of four power density spectra for each measurement. These are shown in Figures 7–19. Figures 7–16 are the various inner city metropolitan shipments. These trips varied significantly in the quality of road surfaces as well as travel speeds. Some of these trips produced significantly higher vertical vibration levels than others. Figures 17-19 represent

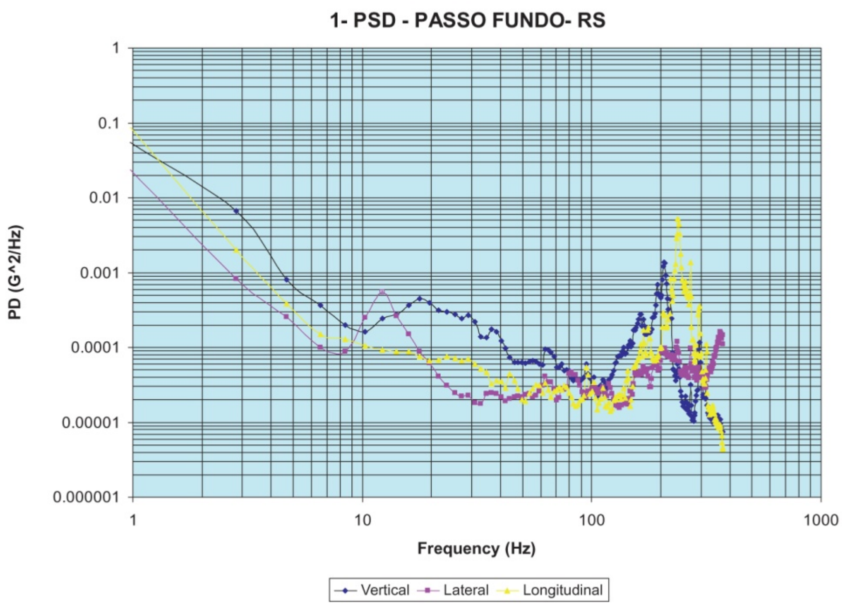

Figure 7. PSD plot for measurement 1 – Passo Fundo (RS). G_{rms}: vertical = 0.3449; lateral = 0.2198; longitudinal = 0.4438

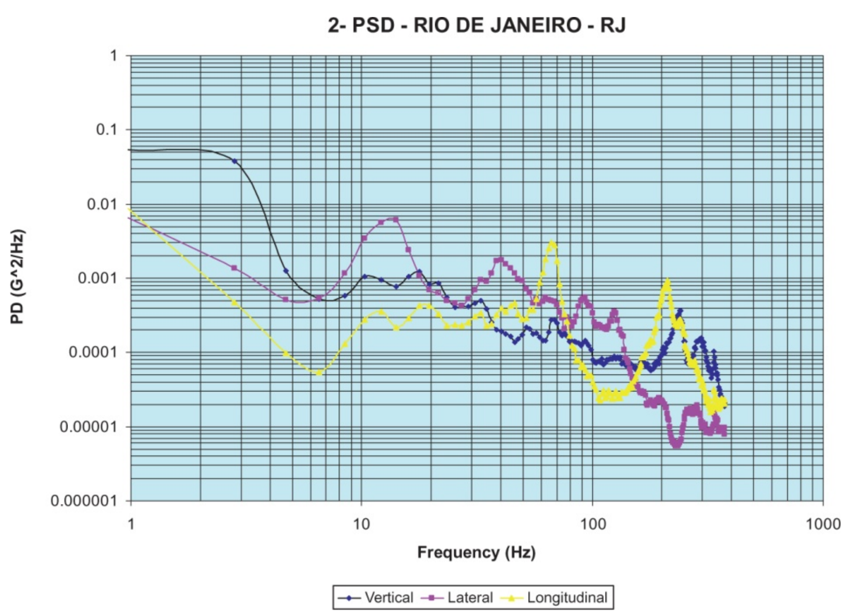

Figure 8. PSD plot for measurement 2 – Rio de Janeiro (RJ). G_{rms}: vertical = 0.4291; lateral = 0.3364; longitudinal = 0.3092.

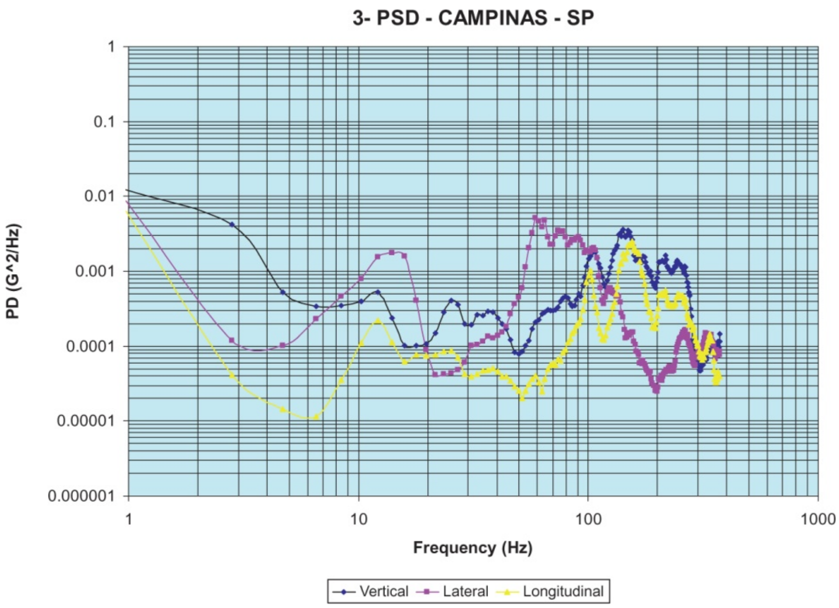

Figure 9. PSD plot for measurement 3 – Campinas (SP). G_{rms}: vertical =0.5591; lateral = 0.4699; longitudinal = 0.3799.

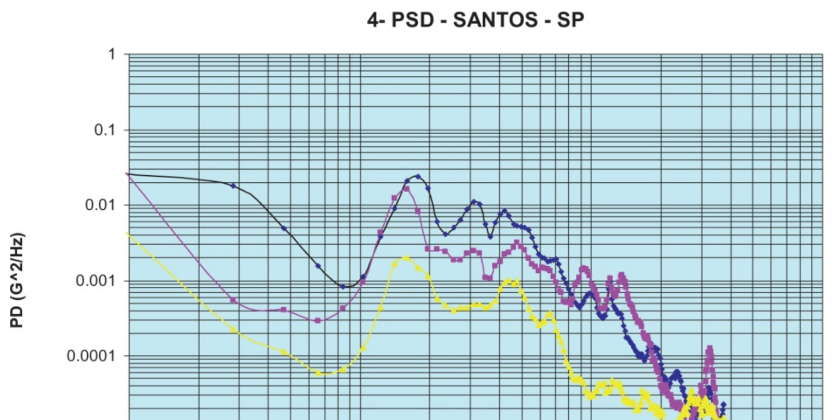

Figure 10. PSD plot for measurement 4 – Santos (SP). G_{rms}: vertical = 0.7206; lateral = 0.5377; longitudinal = 0.2286.

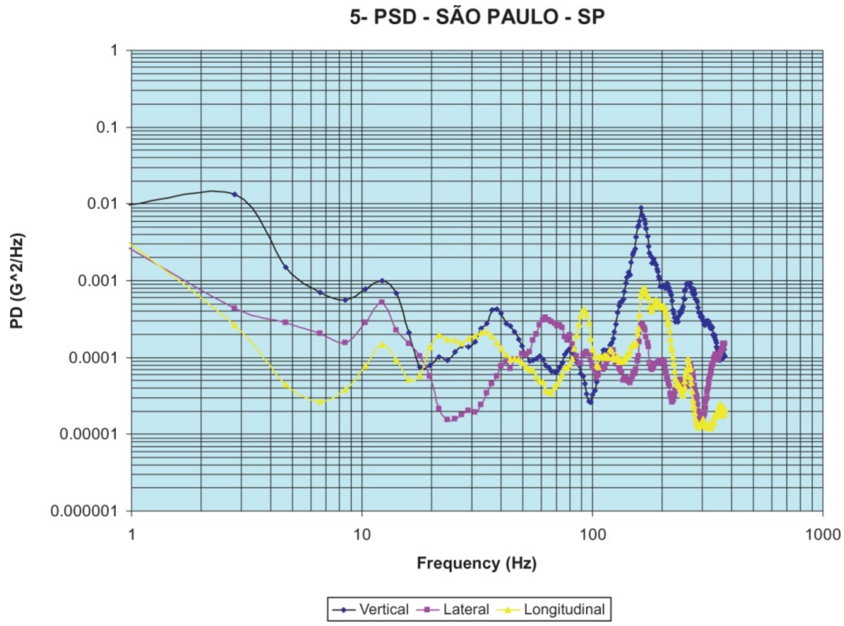

Figure 11. PSD plot for measurement 5 – São Paulo (SP). G_{rms}: vertical= 0.5706; lateral = 0.1958; longitudinal = 0.2400

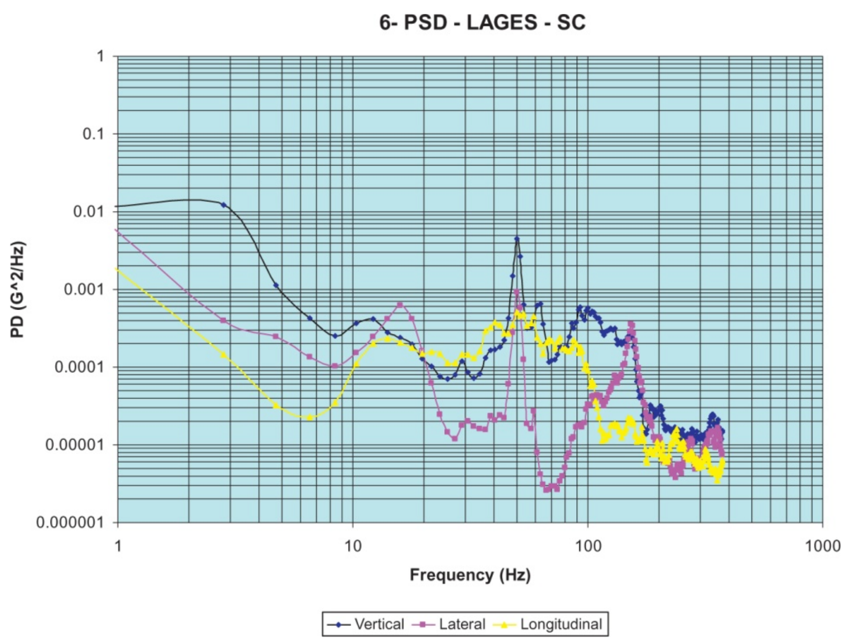

Figure 12. PSD plot for measurement 6 – Lages (SC). G_{rms}: vertical = 0.3142; lateral = 0.1608; longitudinal = 0.1609.

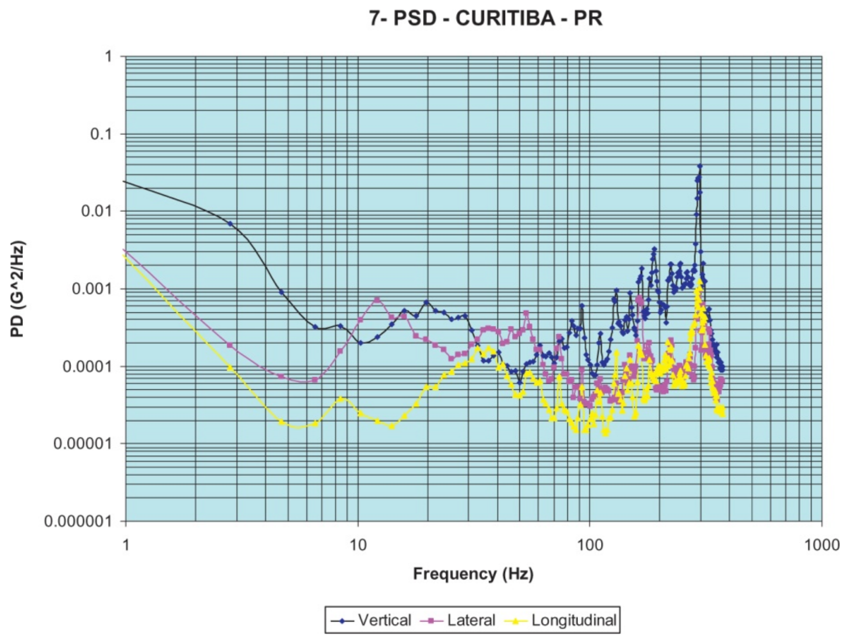

Figure 13. PSD plot for measurement 7 – Curitiba (PR). G_{rms}: vertical = 0.7621; lateral = 0.2462; longitudinal = 0.2172.

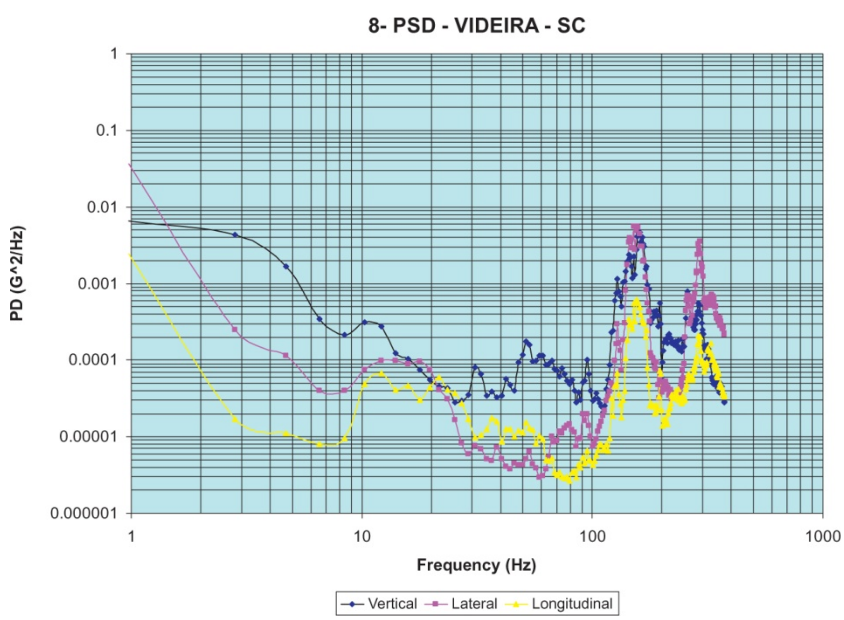

Figure 14. PSD plot for measurement 8 – Videira (SC). G_{rms}: vertical = 0.4193; lateral = 0.5100; longitudinal = 0.1739.

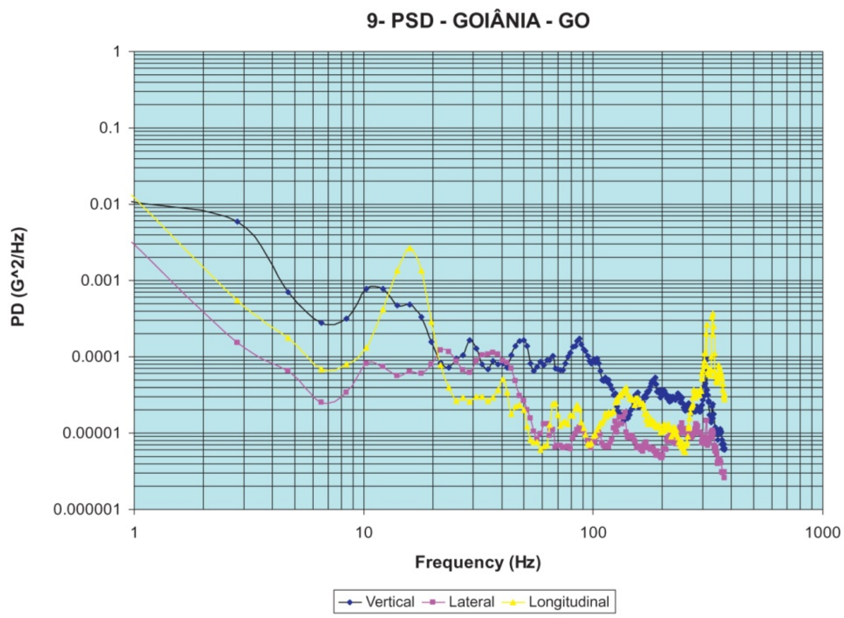

Figure 15. PSD plot for measurement 9 – Goiânia (GO). G_{rms}: vertical = 0.2127; lateral = 0.0995; longitudinal = 0.1993.

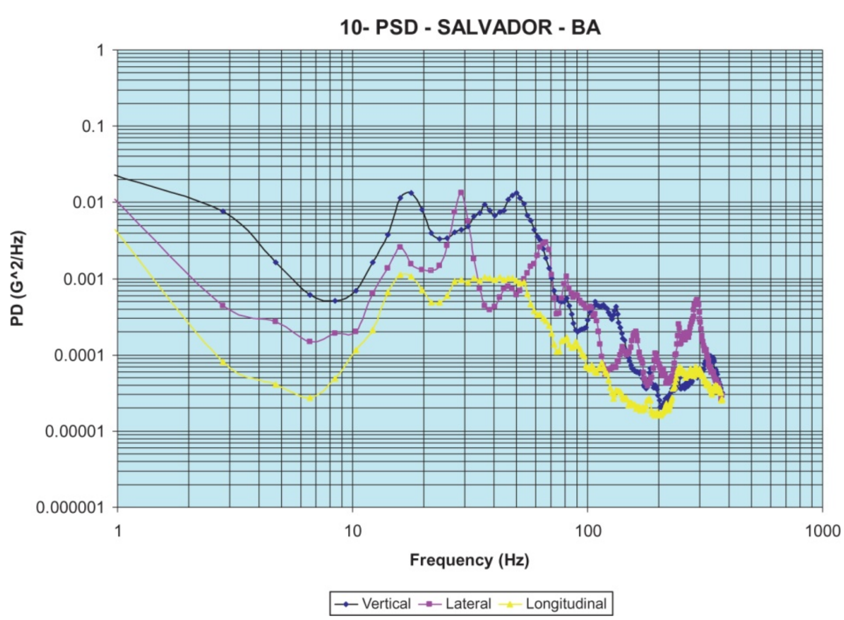

Figure 16. PSD plot for measurement 10 – Salvador (BA). G_{rms}: vertical = 0.6804; lateral = 0.4388; longitudinal = 0.2508.

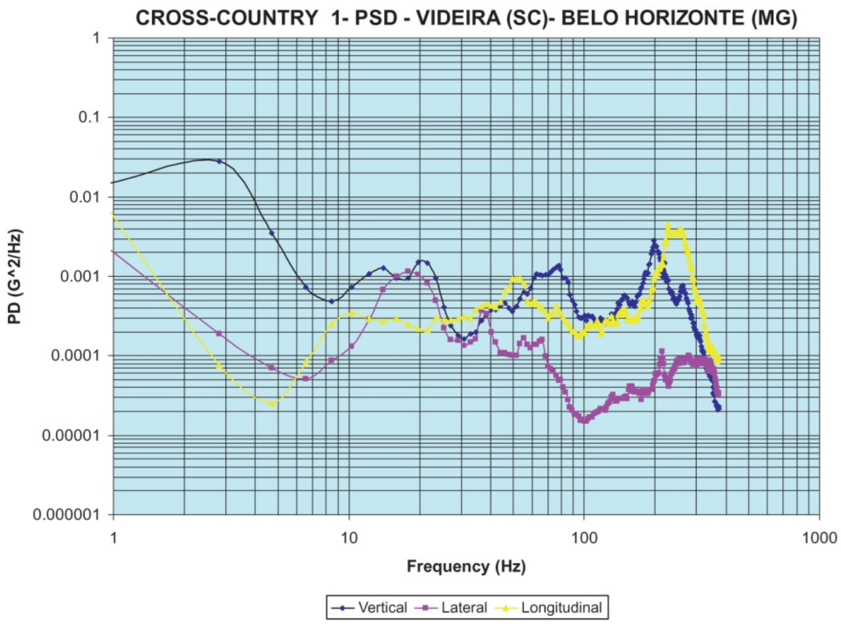

Figure 17. PSD plot for measurement 1 – long distance trip: Videira (SC) to Belo Horizonte (MG). G_{rms}: vertical = 0.5393; lateral = 0.1944; longitudinal = 0.5798.

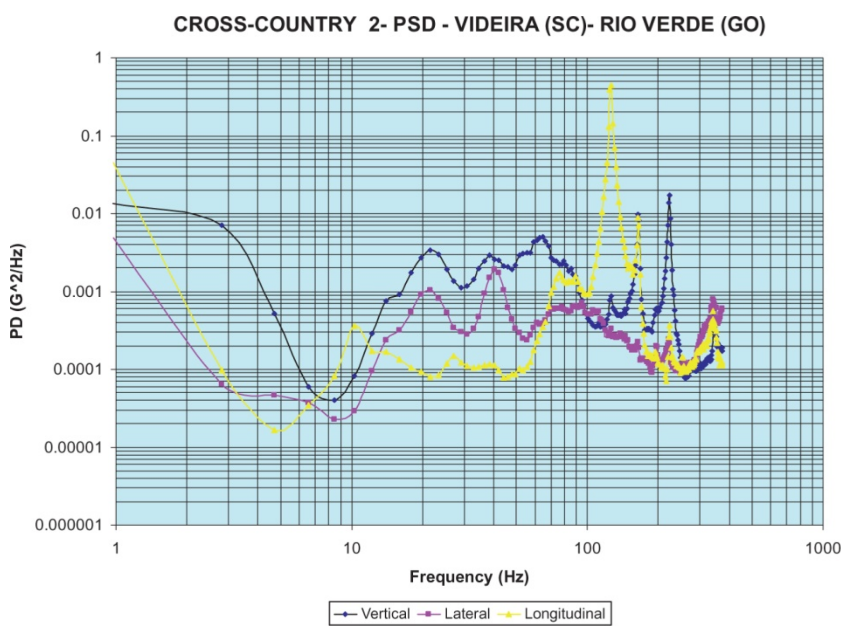

Figure 18. PSD plot for measurement 2 – long distance trip: Videira (SC) to Rio Verde (GO). G_{rms}: vertical = 0.6943; lateral = 0.3625; longitudinal = 1.6828.

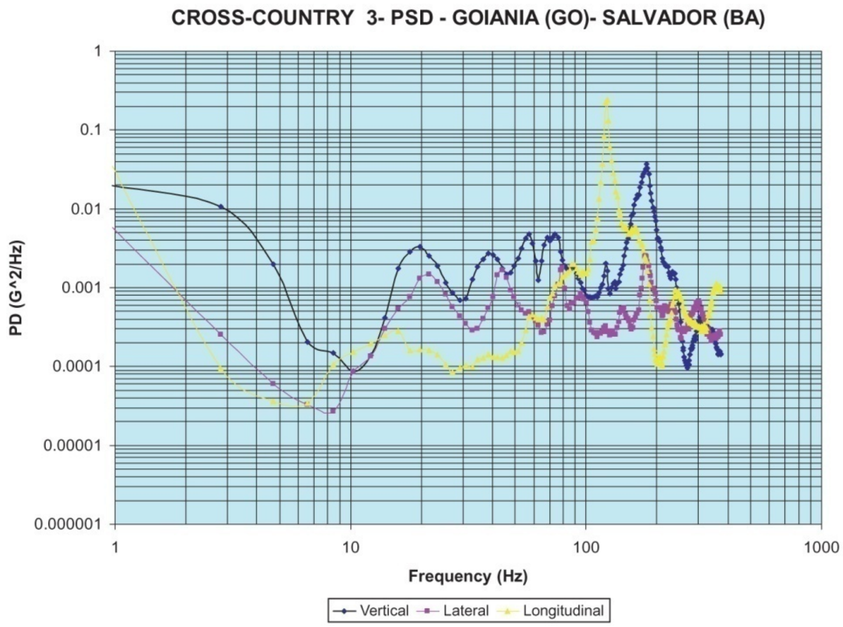

Figure 19. PSD plot for measurement 3 – long distance trip: Goiânia (SC) to Salvador (BA). G_{rms}: vertical = 1.1239; lateral = 0.4601; longitudinal = 1.4917.

the three long distance highway measurements. The data in two of these shipments show extremely high vibration levels in the longitudinal direction at around 110–125 Hz (Figures 18 and 19). These two trailers had low bumpers at the rear of the trailer that produced resonant conditions at these frequencies when contacting the road surface during turns and going over bumps. This is shown in Figure 20.

The data for this study as described earlier uses events that were triggered at 0.25 g intensity or higher, and, also, the recorders were in 'max overwrite' memory mode. What this entails is that the higher intensity vibrations are saved in the recorders' memory for data analysis. This results in vibration spectra that generally are 'more' severe than the 'average' intensity of vibrations that occur during the entire trip. This is a common methodology used by packaging researchers as it also allows to shorten test time as compared with travel time in the vehicle. As a result, most vibration testing for package validation is done at time intervals that are less than the actual trip but at levels representing the higher of the measured vibrations from the entire trip. Based on the time intervals of the recorded data, it is estimated that the analysed spectra represent the highest 10% of the entire trip that was monitored.

The PSD shape varies greatly according to region, truck type and load. Metropolitan measurements resulted in higher vibration intensities in the vertical direction, followed by lateral and longitudinal vibration, as stated in previous studies.[9–11] Based on comparing the G_{rms} for each trip, vibration levels increased with lighter loads, bad road conditions (potholes in asphalt or dirt roads) and higher speeds.

Based on the various PSD plots, a composite spectrum was developed for a vertical vibration simulation of truck vibration in Brazil. This can be used in test methods such as American Society of Testing and Materials D4728 to perform vibration testing of products.[12] The composite spectrum shown in Figure 21 is the average of all previously shown spectra. Table 4 summarizes the G_{rms} values for the vertical, lateral and longitudinal directions, and for the composite as well as for all individual trip PSDs.

CONCLUSIONS

Based on the results of this study, the following conclusions were reached:

1. Road conditions in Brazil vary greatly according to region and type. Metropolitan distribution resulted in lower vibration levels than interstate transport.

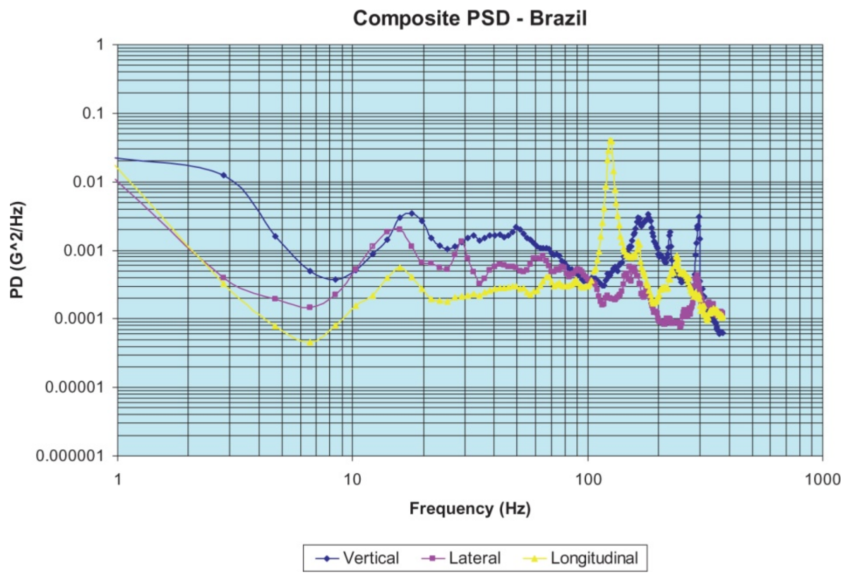

Figure 21. Composite PSD plot for all measurements. G_{rms}: vertical = 0.6284; lateral = 0.3714; longitudinal = 0.7013.

Table 4. G_{rms} values for metropolitan, long distance and the composite PSD profiles

	G_{rms}		
Location	Vertical	Lateral	Longitudinal
Metropolitan regions			
Passo Fundo – RS	0.3449	0.2198	0.4438
Rio de Janeiro – RJ	0.4291	0.3364	0.3092
Campinas – SP	0.5591	0.4699	0.3799
Santos – SP	0.7206	0.5377	0.2286
São Paulo – SP	0.5706	0.1958	0.2400
Lages – SC	0.3142	0.1608	0.1609
Curitiba – PR	0.7621	0.2462	0.2172
Videira – SC	0.4193	0.5100	0.1739
Goiânia – GO	0.2127	0.0995	0.1993
Salvador – BA	0.6804	0.4388	0.2508
Long distance trips			
Videira (SC)–Belo Horizonte (MG)	0.5393	0.1944	0.5798
Videira (SC)–Rio Verde (GO)	0.6943	0.3625	1.6828
Goiânia (GO)–Salvador (BA)	1.1239	0.4601	1.4917
Composite Brazil			
All locations	0.6284	0.3714	0.7013

2. Metropolitan measurements showed the expected behaviour. The G_{rms} values for vertical, lateral and longitudinal vibration were 0.55, 0.37 and 0.3 G, respectively. Long distance measurements showed

similar results up to 100 Hz, which is the range where most products are damaged.

3. Accelerations increased with lighter loads, bad road conditions and higher speeds.

4. Cross-country data shows large amplitude vibrations above 100 Hz. This is due to the low rear bumper contacting the road.

5. The data from this study can be used to program vibration tables to reproduce these vibration conditions for package testing.

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