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Measurement and Analysis of Truck and Rail Vibration Levels in Thailand

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SUMMARY

Worldwide increase in trade, foreign direct investment, capital flows, migration and the spread of technology has caused an increased focus to be put on designing packages that can protect goods shipped globally. This requires a wide-ranging understanding of the distribution environments on a global basis. Several past studies have mapped the vibration levels for surface transportation along the most popular shipment routes in countries such as Brazil, Canada, China, India and the USA. This study was conducted to provide a comprehensive understanding of the vibration levels observed for truck and rail shipments for major transportation routes in Thailand, one of the leading economies in the Southeast Asia region. Data recorders were used to collect the vibration data which were then analysed in terms of power spectral densities. Vibration levels observed from various segments of transportation are presented in the form of power density spectrums. Composite spectrums that can be used to simulate the measured vibration conditions in Thailand are presented.

KEY WORDS: vibration; transportation; Thailand; truck; rail

INTRODUCTION

The ever-evolving global manufacturing trends require goods to flow throughout the world in what may be considered poorly understood distribution environments and channels. This lack of a thorough understanding has triggered comprehensive, yet complimentary global data acquisition studies. These studies are intended to establish comprehensive awareness of relatively new and unfamiliar distribution channels, while also providing the basis for proper testing that can better simulate those channels. The variation in distribution hazards is attributed to a complex interaction between packages, humans, material handling equipment, logistical vehicles and transfer systems. As the global shipping environment develops, where companies produce products at a few locations and market and distribute on a worldwide basis, the impact of the distribution hazards around the world needs to be better quantified and simulated.

Several past studies have measured and analysed the vibration levels for truck and rail shipments in various continents. In a recent study that observed the vibration levels for trucks with leaf-spring and air-ride suspensions across Spain,[1] it was noted that the vibration intensity was lower as compared with the levels measured in North America,[2,3] Brazil[4] and India.[5] In a previous study done on comparing road conditions from rural un-surfaced roads to highways for shipments of fruits in Thailand, it was found that road surface and truck speed played a significant role in the severity of vibration levels and damage to fruits.[6] A similar study conducted using small local trucks and larger tractor-trailer in 10 different regions in Brazil[4] concluded that the truck transport environment showed lower vibration levels in metropolitan areas than interstate highways. This study also noted that acceleration levels increased with lighter loads, bad road conditions and higher speeds.

Another recent study provided results of a 2 year study that measured and analysed truck and rail transport vibration for major freight distribution routes between five major metropolitan areas in India.[5] Comparison of the data collected by this study for both truck and rail vibration showed that the measured vertical vibration levels were more severe than levels recommended in existing American Society of Testing and Materials (ASTM) and International Safe Transit Association (ISTA) vibration test methods. This study also showed that there was a difference between vibration levels in truck versus rail shipments and that the most severe levels occurred at different frequencies than those observed in North America and Europe.

Studies conducted in the USA and Canada on vibration levels in truck transport showed that higher vibration levels occurred in the rear of the trailer, and were a function of the suspension and payload.[2,3] All these studies listed above observed that the vertical vibration levels were higher than the lateral and longitudinal levels for truck transportation.

Although a recent study measured the vibration levels for two of the commonly used types of leaf-spring suspension trucks used in Thailand,[6] the authors could not find any published comprehensive research that measures the vibration levels for both truck and rail transportation over the four major geographically divided regions, north, north-east, east and south (Figure 1). The increasing interna-

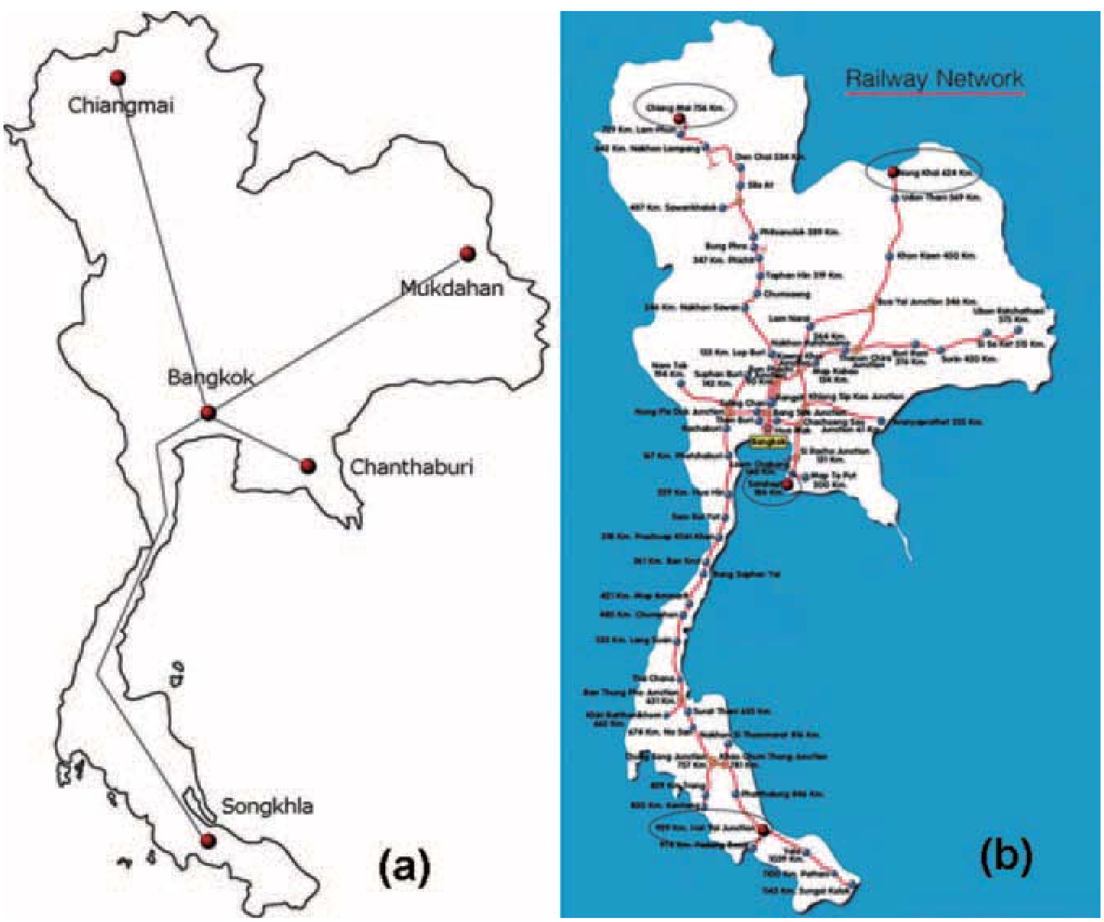

Figure 1. Thailand map indicating truck (a) and rail (b) transportation routes investigated.

tional trade between Thailand and North America, Europe and the Pacific Rim warrants a better understanding of the distribution environment present in this leading and exporting economy of Southeast Asia.

TRUCK AND RAILWAY NETWORK IN THAILAND

Thailand road network

Transportation of goods by truck is significant in Thailand as most regions are connected by roads. Thailand's government has focused for decades to increase the road network in order to foster and promote economic growth in the country. The road network in Thailand is approximately 218 000 km. The highways account for approximately 63 062 km,[7] of which more than 40% meet international standards.[8] Several road development projects are underway to enhance the capability of delivering goods and services throughout Thailand and provide trade across the country.[7] The second bridge across the Thailand–Laos border, linking Thailand's Mukdahan province with Laos' Savannakhet province, has been recently completed to enhance trade and investment in the Mekong Subregion.[9] The road systems in Thailand can be categorized as motorways, national highways, rural highways, municipal roads, urban roads and concession roads. A numbering system indicates the highway locations. The single-digit National Highways are the major highways connecting four geographical regions in the country from the Central region (mostly from Bangkok) to the North (1); North-East (2); East (3); and South (4).[9]

Approximately 95% of the highways in Thailand are concrete. Paving 65 000 km of currently unpaved rural road by resurfacing laterite (unpaved roads) with asphalt is among the core ongoing road improvement projects of Thailand's Ministry of Transport. However, at present some unpaved roads connecting major highways to rural areas are poor in performance. Most highways are four lanes or more, with the average vehicle speeds of approximately 80–90 km/h. Roads in the rural areas are predominantly two lanes or less, where vehicle speeds rarely exceed 30–40 km/h.[7] Road systems in Thailand are similar to other global regions like India,[5] Spain[1] and Brazil[4] and as reported by previous studies. As Southeast Asia's gateway, Thailand plays a key role in the Asian highway network linkage. The highways throughout the country support the Greater Mekong Sub-region transport network, including the East-West Economic Corridor (EWEC),[10] the North-South Economic Corridor (NSEC)[11] and the Southern Economic Corridor (SEC).[12] The highly efficient transport systems hold the promise to accelerate global commercialization and regional development by facilitating the movement of goods and people around the region and other areas of influence.

The EWEC is a continuous road approximately 1450 km long that links the Indian Ocean (Andaman Sea) to the South China from Mawlamyine–Myawaddy in Myanmar to Lao Bao–Hue-Dong Ha-Da Nang in Vietnam through Thailand.[10] The NSEC projects include the road connection between Chiang Rai (Thailand) and Kunming (China) via Lao PDR and Myanmar, which will subsequently link Singapore to Kunming.[11] The NSEC shows some of the best sections of highway as this also serves as the biggest movement of goods and allows for the significant trade between regions. The SEC among others will improve links in the Asian Highway from Bangkok (Thailand) to Ho Chi Minh City (Vietnam) via Phnom Penh.[12]

Truck transportation in Thailand

Trucks account for the major freight transportation in Thailand. As of December 2006, the total number of registered trucks was 718 562. Tables 1 and 2 show the numbers of registered trucks, classified by types and number of wheels under the Land Transport Act.[13] Non-fixed route trucks are referred to as trucks providing services in transporting goods on any requested route, while private trucks refer to the trucks used in transporting goods weighing over 1600 kg.[13]

Thailand's railway network

Railways are another important means of transporting passengers and goods in Thailand. Thailand's railway network (Figure 1) links the major cities in all regions of the country with a total route length

Table 1. Number of registered vehicles, classified by types in Thailand (as of December 2006).[8]

Truck types	Non-fixed route truck	Private truck	Total
Pick-up truck	34 571	448 814	483 385
Van	9285	31 533	40 818
Liquid bulk vehicle	1699	12 256	13 955
Dangerous goods vehicle	4221	5881	10 102
Special purpose vehicle	8448	34 231	42 679
Trailer	10 090	30 001	40 091
Semi-trailer	31 765	15 790	47 555
Long-loading semi-trailer	126	728	854
Truck tractor	24 684	14 439	39 123
Total	124 889	593 673	718 562

Table 2. Number of registered vehicles, classified by number of tires in Thailand (as of December 2006).[8]

Number of wheels	Non-fixed route truck	Private truck	Total
Four-wheel truck	1932	44 188	46 120
Six-wheel truck	19 721	308 467	328 188
Eight-wheel truck	37 987	43 810	81 797
10-wheel truck	60 891	192 463	253 354
12-wheel truck	2737	3551	6288
14-wheel truck	–	–	–
16-wheel truck	1	1	2
18-wheel truck	–	–	–
20-wheel truck	25	11	36
Others	1595	1182	2777
Total	124 889	593 673	718 562

of 4041 km.[14] Approximately 80% of the route is single track and constructing double tracks is a primary focus of the railway development plan.[15] In addition, rail freight shipments are available through Thailand–Malaysia border via Sugnai Kolok (East border) and Padang Besar (West border) stations. Transportation of large volumes of goods by railroad routes is also available to and from Singapore. Cross border rail freight offers competitive inter-modal logistic solutions for Southeast Asian trade to move containers into high-volume ports such as Singapore.

This research attempts to measure and analyse the vibration levels that occur in truck and rail shipments in Thailand using data recorders with tri-axial accelerometers that were mounted on truck and railcar floor beds. It had the following objectives:

1. Measure the vibration levels in the truck and rail shipments along major distribution routes in Thailand.
2. Analyse the collected vibration data and present them in the form of power density (PD) spectrums.
3. Develop test methods to simulate vertical truck and rail vibration levels in Thailand using vibration test equipment.

INSTRUMENTATION AND METHODOLOGY

Figure 1 shows the various road and rail track networks monitored in this study. Shock and Vibration Environmental Recorder (SAVER)^{TM} Model 3X90 (Lansmont, Corp., Monterey, CA, USA) data recorders were used to collect the data in this study. The SAVER consists of a piezoelectric tri-axial accelerometer with an integrated microcomputer. The data recorder is a battery-powered instrument capable of measuring and recording shock (impact/drop), vibration, temperature and humidity conditions during transportation. For truck shipments, the recorders were mounted at the rear floor position as this location produces the highest vertical vibration levels.[3] This is particularly important when measuring poor road conditions. In the railcars, the recorders were mounted in the midsection of the cargo holds on floor. The following settings were used in this study:

- Time triggered sampling: 10 min
- Trigger threshold level: 2.4 G
- Sampling rate: 500 samples per second (Hz)
- Recording window: 2.048 s
- Sample size: 1024

Six-wheel trucks (Table 2) account for the highest percentage of commercial trucks used for distributing goods in Thailand. Most commercial trucks in Thailand are equipped with leaf-spring suspensions. Figure 2 shows the various types of six-wheel trucks with leaf spring suspensions used for this study. Figure 3 shows the type of railcars monitored during this study.

Truck shipments for this study were monitored along the major distribution routes in the country. Table 3 describes the various truck shipping routes studied. The speeds of the trucks were in the range of 30–90 km/h, where the average speed on good highway conditions was 80–90 km/h, while on the poor road conditions (mostly two-lane roads) it was 30–40 km/h. The average truck speeds for this study were maintained by supervising the truck drivers, maximum speed limits allowed on these highways and driver log records that are required for government-sponsored shipments. The different types of road surface conditions are shown in Figure 4. The data were collected using duplicate

Figure 2. Various trucks used in the vibration measurement study.

Figure 3. Railcars used in the study.

Table 3. The details of truck and rail shipment routes studied.

Route		Distance (km)
Truck	National highway	
Bangkok–Chiang Mai (North)	1	700
Bangkok–Mukdahan (North-East)	2	642
Bangkok–Chanthaburi (East)	3	245
Bangkok–Songkhla (South)	4	950
Rail	Station	
Bangkok–Chiang Mai (North)	Bangkok–Chiang Mai	756
Bangkok–Nong Khai (North-East)	Bangkok–Nong Khai	624
Bangkok–Chon Buri (East)	Bangkok–Sattahip	184
Bangkok–Songkhla (South)	Bangkok–Songkhla	929

shipments between each route. The trucks in this study have shorter trailer beds (approximately 8 m long) as compared with truck trailers used in North America and Europe for a majority of product shipments. The truck shipments consisted of fresh fruits and vegetables in shipping containers, weighing approximately 10 000 kg, and were similarly loaded in the two duplicate shipments. The rail shipments were also similar and done using dry products.

Railcar measurements were conducted along the major rail routes covering all four regions in Thailand as previously shown in Figure 1. The details of these routes monitored are shown in Table 3. The vibration data for all shipments were measured in all three axes (vertical, lateral and longitudinal) using the data recorders and then analysed using the SaverXware™ (Lansmont Corporation) software. PD spectra of the transport vibration measurements were developed.

The recorded acceleration amplitudes of the measured random vibration were analysed as a function of frequency to determine the PD levels. The average PD within a narrow band of frequencies of the spectrum is calculated as follows:

$$PD = \frac{1}{BW}\sum_{i=1}^{n}\left(RMS\ G_i^{2}\right)/N \quad (1)$$

Where, $RMS\ G_i$ is the root mean square acceleration value measured in g's within a bandwidth (BW) of frequencies, and N is the number of instants sampled. The corresponding PD levels are then plotted against frequency of the bandwidth to develop a power spectrum density (PSD) plot.

For this study, the data are presented from 1 to 100 Hz as this frequency band represents the most damage-causing component for packaged goods.[3] The PSD data derived from truck measurements can also be used as input data in simulating vibration distribution environments on electro-hydraulic

Figure 4. Various road conditions measured in the study.

vibration test machines. The comparison of the vibration profiles created through this study can be drawn with test levels recommended in ASTM D4169[16] and ISTA Test 4AB[17] for leaf-spring truck vibration levels.

DATA AND RESULTS

Truck vibration measurement

The average PSD plot developed for Thailand truck shipments in all axes is summarized in Figure 5. Vibration levels in the lateral, longitudinal and vertical modes are shown in Figure 5. These spectra show the average PSD plot, the highest 20 percentile of events PSD plot, the lower 80% of events PSD plot and a PSD plot representing all measured events greater than 1 G. The average spectrum represents analysing all recorded events. The 20 percentile spectrum is made using the top 20% of the most severe recorded events, and 80 percentile spectrum uses the remaining 80% of the recorded data.

As shown in the data spectrums, measured vibration pattern was similar to that of previous studies in Asia.[4,6] In the low-frequency range (1–5 Hz), the measured vibration levels were similar to those of other international studies. Lower intensity vibrations were observed in the 10–20 Hz as compared with the recommended levels recommended in the ASTM and ISTA vibration test methods. The measured data are also less severe in high-frequency regions (40–60 Hz), representing the structural responses and road roughness regions. The reason for this is that while there are similarities in the ‘suspension’ response, the higher frequencies data from North America and Europe is attributed to longer trailers (40–53 ft, 12.2–16.2 m), as compared with the short bed structures of trailers that were

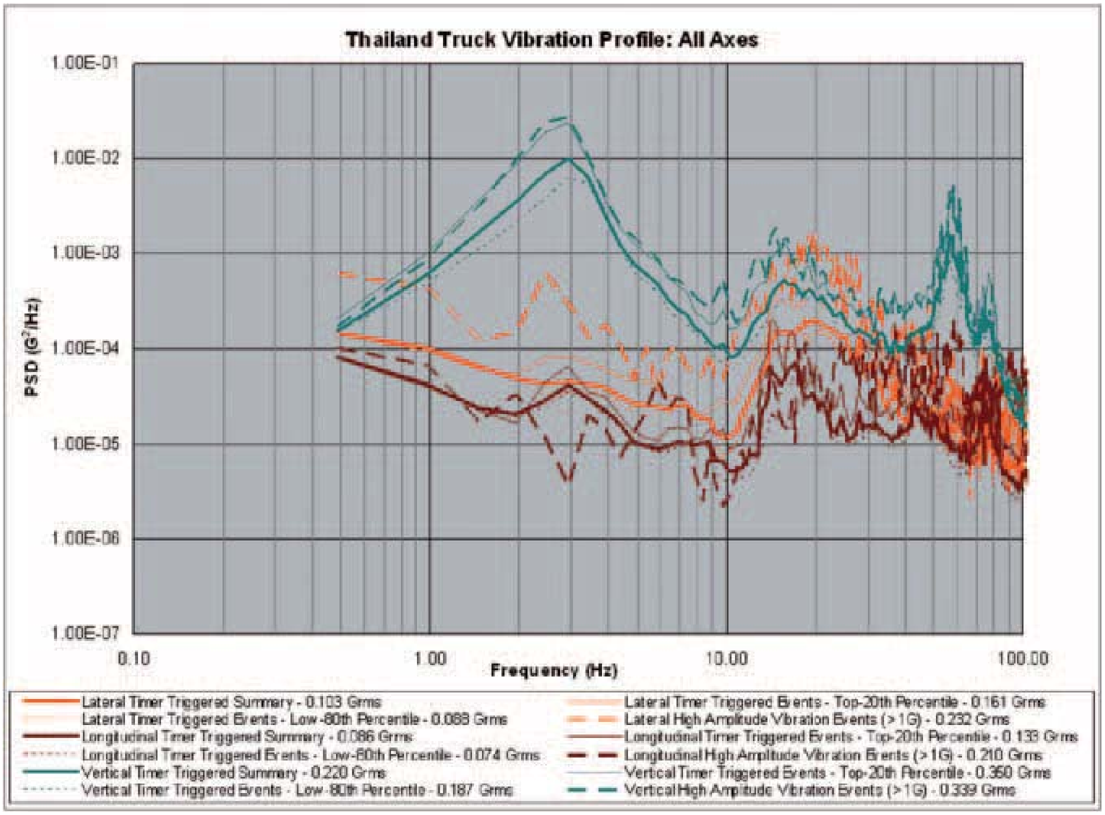

Figure 5. Power spectrum density (PSD) plots for truck vibration in Thailand in all axes.

used in this study (less than 20 ft or 6.1 m) and the slower vehicle speeds in this study as compared with those measured for North America and Europe. Longer trailers have stiffer support structures. When moving on similar road deformations, short bed trailers moving at slower speeds produce longer strokes and lower frequency vibration cycles (producing lower accelerations), while longer trailers moving at higher speeds result in slightly shorter strokes at higher frequency vibration cycles (producing higher acceleration).

The analysed data showed that the vibration levels in the vertical modes were the highest in truck shipments. The lateral vibration levels were higher than the longitudinal modes in the 1–40 frequency range. This should be taken in to account as product damage can be attributed to lateral vibrations during horizontal movements. This could be significant when there are void spaces in the loaded trailers.

Rail vibration measurement

Figure 6 represents the average PSD plot of rail vibration in all axes. The PSD plots for lateral, longitudinal and vertical vibration levels for rail measurements are also shown in Figure 6. The results showed that the measured spectrums for rail vibration were generally lower than the existing test methods. The pronounced differences were shown in the high frequency range between 10 and 50 Hz. Similar to the truck PD spectra, vibration levels in the lateral modes were higher than those in the longitudinal modes. This is significant in rail shipments, where loads are not generally packed tightly. Hence, load shifting can easily occur during railcar impact and cause product/package damage.

The data in this study show that in general when comparing PD spectra from previous studies,[1,2,4,5] the PD levels measured for shorter bed trailers in Thailand are similar between 1 and 5 Hz., and lower between 10 and 100 Hz.

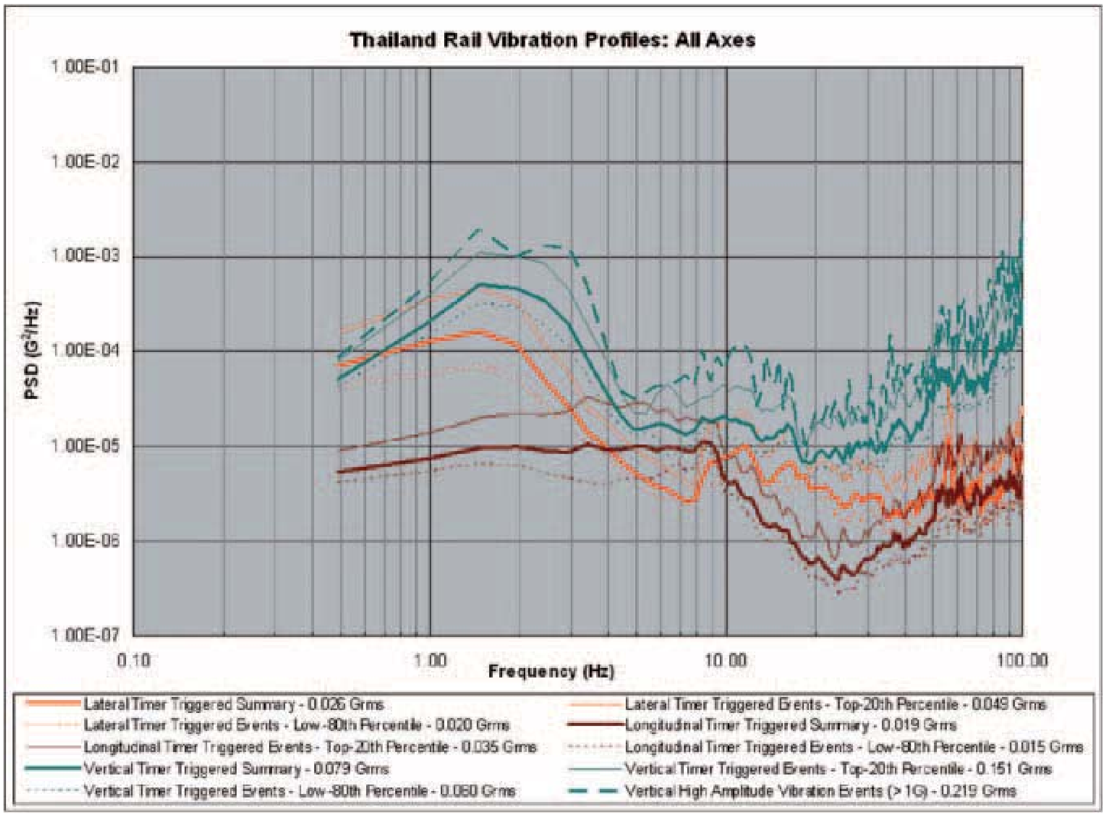

Figure 6. Power spectrum density (PSD) plot for rail vibration in Thailand in all axes.

Table 4. Composite spectrum for truck vertical vibration.

Break point no.	Frequency (Hz)	Power density (G^2/Hz)
1	1	0.0008
2	2	0.007
3	3	0.007
4	5	0.0003
5	50	0.0003
6	100	0.00003

Table 5. Composite spectrum for rail vertical vibration.

Break point no.	Frequency (Hz)	Power density (G^2/Hz)
1	1	0.0002
2	2	0.0004
3	5	0.00001
4	30	0.00001
5	50	0.00008
6	100	0.00008

Recommended composite spectrums

The composite spectrums were developed using the averaged values of PD obtained from the various truck shipments and road conditions between 1 and 100 Hz. The recommended composite spectrums for truck and rail vibration are shown in Tables 4 and 5, respectively. The available data could be informative and is recommended to be used for simulating the transport vibration in Thailand.

CONCLUSIONS

The following conclusions were reached:

1. The vertical vibration levels measured in both truck and rail shipments were the highest, followed by lateral and longitudinal levels.
2. The levels in vertical vibration as shown in respective PD spectrums are similar to those of other international studies and test methods in the low frequency region (1–5 Hz), but are significantly lower in the higher frequency regions (10–100 Hz) representing structural response and vehicle speeds.
3. New vibration PD spectrums are recommended based on measured data from this study that can be used to simulate the vibration conditions in truck and rail shipments for shorter bed trucks in Thailand.

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