トラック輸送中の振動計測に及ぼすサンプリング間隔の影響

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Original

Effects of Sampling Intervals on Truck Transport Vibration Levels

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Abstract

Truck transport plays an important role in the distribution of goods. Although the lab-simulated truck vibration test has been developed, the vibration wave pattern was different in different measurement condition of truck vibration. To obtain the appropriate sampling intervals condition for the consecutive measurement during truck transport, the effects of sampling intervals on truck transport vibration levels were analyzed. The vibration through the transport trip was measured consecutively in the rear platform of 20-ton loaded truck for the peach distribution from Nagano to Tokyo. The vibration data was sampled with different intervals, and was analyzed with power spectrum density (PSD). With a longer sampling interval, gap with consecutive wave patterns become bigger, and the real vibration cannot be reproduced. It was found that intermittent 60 s sample periods with 4 s and 2 s sub-recorded lengths were sufficient for reproduce local roads and highways vibration. The reason for this difference was that shocks occurred more frequently on local roads than highway.

Keywords: truck transport, sampling interval, shock, vibration

1. Introduction

Truck transport plays an important role in the distribution of goods. In Japan, almost 100% of fruits and vegetables are transported by truck. However, mechanical damage sustained during truck transport can reduce the quality of such products. Therefore, it is important to understand the nature of the shocks and vibrations encountered during truck transport to reduce damage to transported goods.

Numerous studies have been conducted on truck transport environments, including the effects of truck vibration levels (Li and Jansen, 1991; Jones *et al.*, 1991; Pierce *et al.*, 1992; Hinsch *et al.*, 1993; Singh and Marcondes, 1992; Singh *et al.*, 1992, 1995, 2006, 2007; Jarimopas *et al.*, 2005; Usuda *et al.*, 2006a; Garcia-Romeu-Martinez *et al.*, 2008; Rissi *et al.*, 2008), vibration analysis, assessment and simulation methods (Sek, 1996; Rouillard and Sek, 2000; Usuda *et al.*, 2006b; Rouillard and Richmond, 2007; Kipp, 2008), and damage to perishable fruits and vegetables caused by transport vibration (Vergano *et al.*, 1991; Hinsch *et al.*, 1993; Slaughter *et al.*, 1993, 1995; Barchi *et al.*, 2002; Berardinelli *et al.*, 2005; Jarimopas *et al.*, 2005; Zhou *et al.*, 2007, 2008).

The effects of sampling and recording parameters on the outcomes of distribution vibration surveys, including the sample periods, have also been studied (Saito and Morita, 2006; Rouillard and Lamb, 2008) and trigger levels (Rouillard and Lamb, 2009). Saito and Morita (2006) found that the statistical results of vibration measured by a shock recording unit were nearly identical to the results obtained by a continuous vibration recording unit when intermittent measurements were recorded properly. Furthermore, Rouillard and Lamb (2008) discussed the effect of sampling and recording parameters on truck transport. They concluded that a natural lower limit (approximately 1/8) exists for the proportion of data that is required to produce a valid statistical representation (average PSD, peak-hold PSD and RMS distribution function) of vibrations generated by road vehicles (Rouillard and Lamb, 2008). A year later, Rouillard and Lamb (2009) recommended that while conducting vibration surveys with level-triggered sampling, whenever possible, the trigger level should be set to ensure that at least 30% of all vibrations are recorded.

Because both vibrations and shocks occur continuously during the transportation of packaged goods, they are often associated with damage to goods being transported by truck (Li and Jansen, 1991; Rouillard and Richmond, 2008; Lu *et al.*, 2008; Ishikawa *et al.*, 2009). We measured shock occurrences during truck transport, which were recorded simultaneously with vibrations, and found that the probability distribution function (PDF) of the combined shock and vibration data

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does not follow a standard normal distribution. Therefore, such recordings cannot be considered random vibration (Lu *et al.*, 2008). However, when the shocks are removed, the PDF becomes normal and the vibrations can be considered random. Thus, we concluded that shocks and vibrations must be separated before conducting laboratory simulations. We also analyzed the effects of truck speed on shock and vibration levels (Lu *et al.*, 2010). As a result, this may offer an improved method of simulating truck transport and indicates that it is feasible to develop vibration and shock simulating methods, respectively (Lu *et al.*, 2008, 2010). In this paper, we separately analyze the effects of sampling intervals on vibration and shock levels to further clarify the nature of shocks and vibrations during truck transport.

2. Experimental Design

2.1. Vehicle and routes

A 20-ton loaded truck (Super Dolphin Profia, Hino Motors Ltd, Japan) with leaf-spring suspension was used to monitor transport conditions. The truck was fully loaded with peaches during transport. Transport routes included local roads and highways (Fig. 1). Peach transport scheduling was roughly as follows. Truck left packing house in Nagano at 12:20 on September 1, 2006, entered the highway at ShinshuNakano IC at 12:43, left the highway at Nerima IC at 15:17 and arrived at Ohta market at 16:40. The truck was monitored for a total of 260 min, including approximately 23 of local road travel in Nagano prefecture, 154 min of highway travel, and about 83 min of local road travel in Tokyo city. The vehicle speeds on local road and highway were about 0-60 km/h and 60-69.9 km/h, respectively.

2.2. Measurement equipment and data analysis

Vibration levels were measured continuously over the transport routes using three AS-10 GB accelerometers

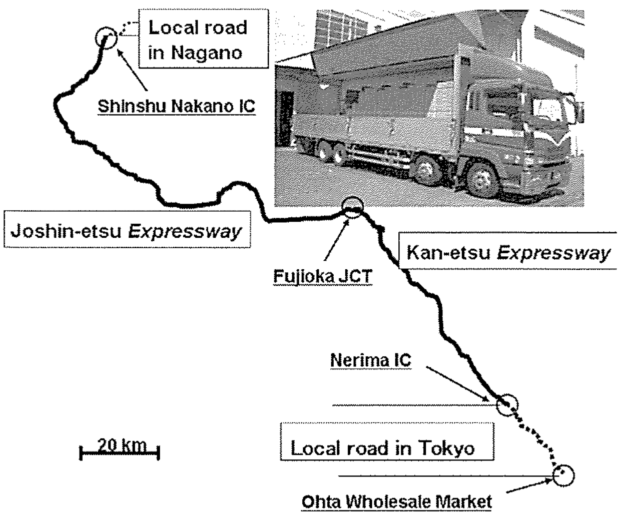

Fig. 1 Transport route used in this study.

(Kyowa Electronic Instruments, Tokyo, Japan) attached to the floor of the truck's trailer, and computer-based data acquisition. Accelerometers monitored acceleration vertically, longitudinally and laterally. Acceleration level signals were recorded using a DS-2100 multichannel data station (Ono Sokki, Yokohama, Japan), after setting sampling to 2 ms and A/D conversion to 16 bits.

To study the effect of sampling intervals on acceleration during truck transport, including shock and vibration, the acceleration spectrum was separated and connected by using Oscope software (Ono Sokki). Oscope is time-series data analysis software for extracting necessary partial data from excessive amounts of time-series data. With this software, actual acceleration waveforms can be extracted, separated, connected and Fast Fourier Transform analyzed. In the case of both local roads and highways, the sampling interval was set with three different sampling periods and sub-recorded lengths: a 120 s sample period (1 s sub-recorded length), a 60 s sample period (2 s sub-recorded length) and a 60 s sample period (4 s sub-recorded length).

To study the effect of sampling intervals on vibration acceleration during truck transport, shocks above 0.7 G were removed using Oscope software. Our previous paper indicated that the probability distribution function (PDF) of the combined shock and vibration data does not follow a standard normal distribution, and it cannot be considered truly random vibration (Lu *et al.*, 2008). But when the shocks are removed, the PDF becomes normal and the vibration can be considered random. In this study, it was found that the waveform, which the shocks above 0.7 G was removed, can be considered as random. The shock was removed by using the Oscope software (Ono Sokki, Japan). Oscope software is time-series data analysis software for extracting necessary partial data from huge amount of time-series data. The actual acceleration waveform can be extracted, separated, connected and FFT analyzed by using this software (Lu *et al.*, 2010). In this study, these shocks were removed according peak G using the Oscope software; the shock above 0.7 G was removed. After removed shocks, the waveform was connected using the Oscope software. The sampling interval was then set to three different sampling periods and sub-recorded lengths: a 120 s sample period (1 s sub-recorded length), a 60 s sample period (2 s sub-recorded length) and a 60 s sample period (4 s sub-recorded length).

The results obtained were based on an analysis of continuous shock and vibration records from actual truck transportation in Japan during September 2007. Vibration level results are presented as PSD. A PSD function represents the strength of the energy as a function of frequency (Jarimopas *et al.*, 2005; Singh *et al.*, 1992; Singh and Marcondes, 1992; Rissi *et al.*, 2008). The average power density (PD) within a band of frequencies is calculated as follows (Jarimopas *et al.*, 2005; Singh *et al.*, 1992; Singh and Marcondes, 1992; Rissi *et al.*, 2008):

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

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.

3. Results and Discussion

3.1. The acceleration level in truck transport

In this study, continuous acceleration data in the vertical, longitudinal and lateral directions during actual truck transport in Japan were obtained. Fig. 2 shows the total acceleration data sequence for 260 minutes of actual truck transport, including 23 minutes for a local road in Nagano, 154 minutes for highway travel and 83 minutes for local roads in Tokyo. By careful observation of the acceleration data recorded from actual truck transport, it was found that severe shocks occurred frequently in the vertical direction (Fig. 2a). Our previous work reported that shocks were caused by such factors as road roughness, joints in the road, joints in paved roads, pedestrian crossings, manholes, road curves, left or right turns, and railway crossings (Lu *et al.*, 2008). The shock status was monitored using a video camera (Lu *et al.*, 2008). Fig. 3 shows the vertical PSD, including vibrations and shock, measured on a local road in Nagano, local roads in Tokyo, highways and the entire data obtained from Fig. 2. As shown in Fig. 3, PSD highway value is significantly higher than that of local roads. This is attributable to the fact that vehicle speeds on highways are significantly higher than those of local roads (Lu *et al.*, 2010). No significant PSD difference was observed between local roads in Nagano and local roads in Tokyo.

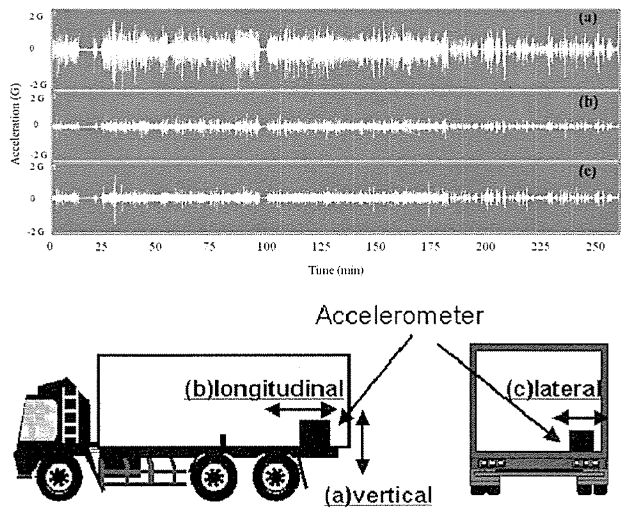

Fig. 2 Acceleration history versus time in actual truck transport (total 260 min). (a) Vertical; (b) longitudinal; (c) lateral.

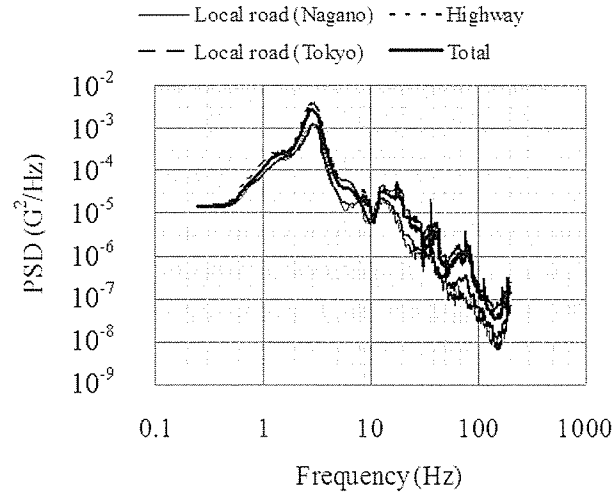

Fig. 3 PSD plot of the continual vertical acceleration data obtained during actual truck transport.

3.2. Effects of sampling interval on acceleration including shock and vibration on local roads and highways

In some reports, vibration frequencies are divided into a number of major ranges to analyze road conditions and transport data (Singh and Marcondes, 1992; Jarimopas *et al.*, 2005; Singh *et al.*, 2006, 2007): (1) 3-4 Hz, representing the truck suspension response, (2) 15-20 Hz, representing the tire response, (3) 40-55 Hz, representing the structure (floor) response. Hinsch et al. (1993) found that the highest PSD levels were found at about 3.5 Hz in semi-trailers with steel-spring suspension systems. Similar results were found in trailers equipped with air-ride suspension. In such cases, PSD levels were attenuated at 3.5 Hz. PSD values in the vertical direction were higher than those in longitudinal and lateral directions (Singh *et al.*, 1992). Therefore, only the vertical PSD in the first frequency range (3-4 Hz) was discussed in this study.

Fig. 4 shows the PSD levels of vertical acceleration including shock and vibration on a local road in Tokyo. The sample periods of Fig. 4a, 4b and 4c were 120 s sample period (1 s sub-recorded length), 60 s sample period (2 s sub-recorded length) and 60 s sample period (4 s sub-recorded length), respectively. In Fig. 4a, the correlation coefficients between the PSD curve of consecutive acceleration data and that with three different sample periods were 0.9216, 0.9536 and 0.9252, respectively. The correlation coefficient was calculated by Microsoft Excel 2003. In this study, the significance level of 0.05 was decided. Two curves were difference at the 0.05 level with the consecutive curve. In Fig. 4b, the correlation coefficients between the PSD curve of consecutive acceleration data and that with three different sample periods were 0.9223, 0.9788 and 0.9445, respectively. Two curves were also difference at the 0.05 level with the consecutive curve. In Fig. 4c, the correlation coefficients between the PSD curve of consecutive acceleration data and that with three different sample periods were 0.9766, 0.9957 and 0.9922, respectively. These three curves were no different at 0.05 level with the consecutive curve. These data indicated that intermittent measurement using the 60 s sample period (4 s sub-recorded length) was sufficient for assessing truck transport conditions on local roads.

Fig. 5 shows the PSD levels of vertical acceleration including shocks and vibrations on highways. The sample periods of Fig. 5a, 5b and 5c were also 120 s sample period (1 s sub-recorded length), 60 s sample period (2 s sub-recorded length) and 60 s sample period (4 s sub-recorded length),

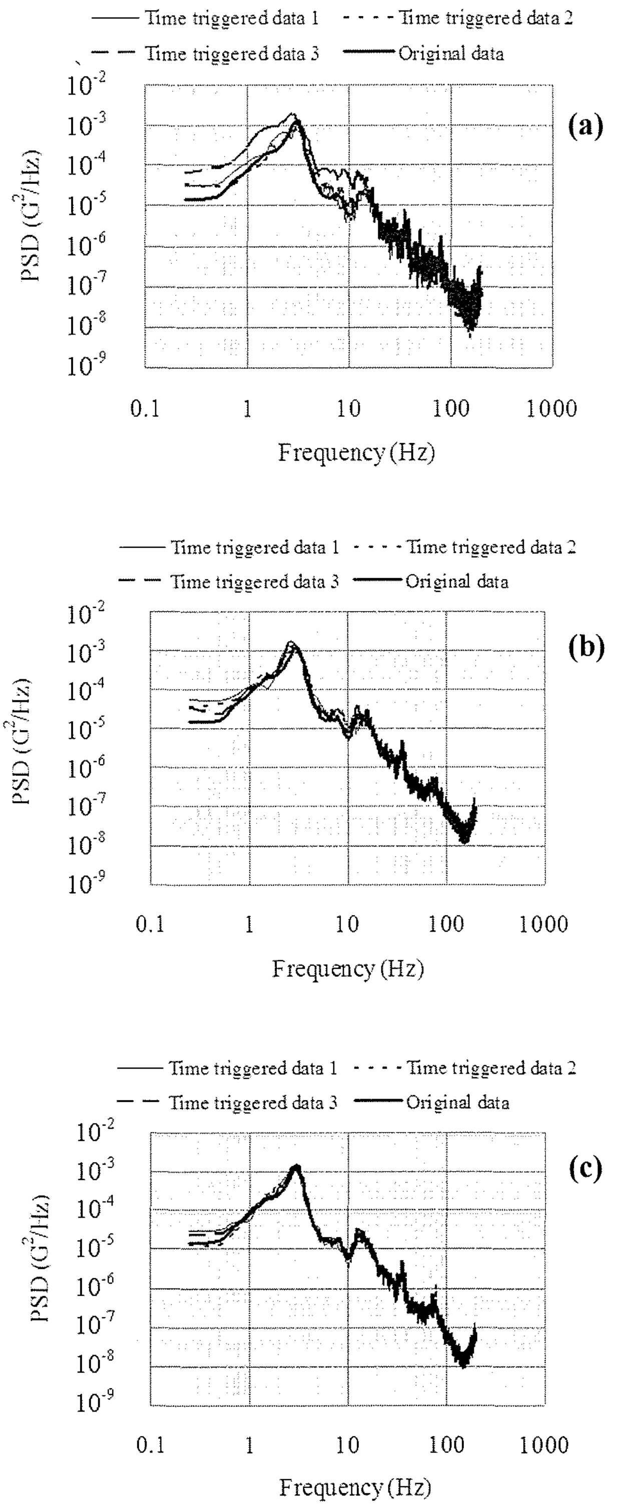

Fig. 4 Vertical PSD plot of the time-triggered data recorded during travel on a local road in Tokyo. (a) 1 s sub-recorded length, 120 s sample period; (b) 2 s sub-recorded length, 60 s sample period; (c) 4 s sub-recorded length, 60 s sample period.

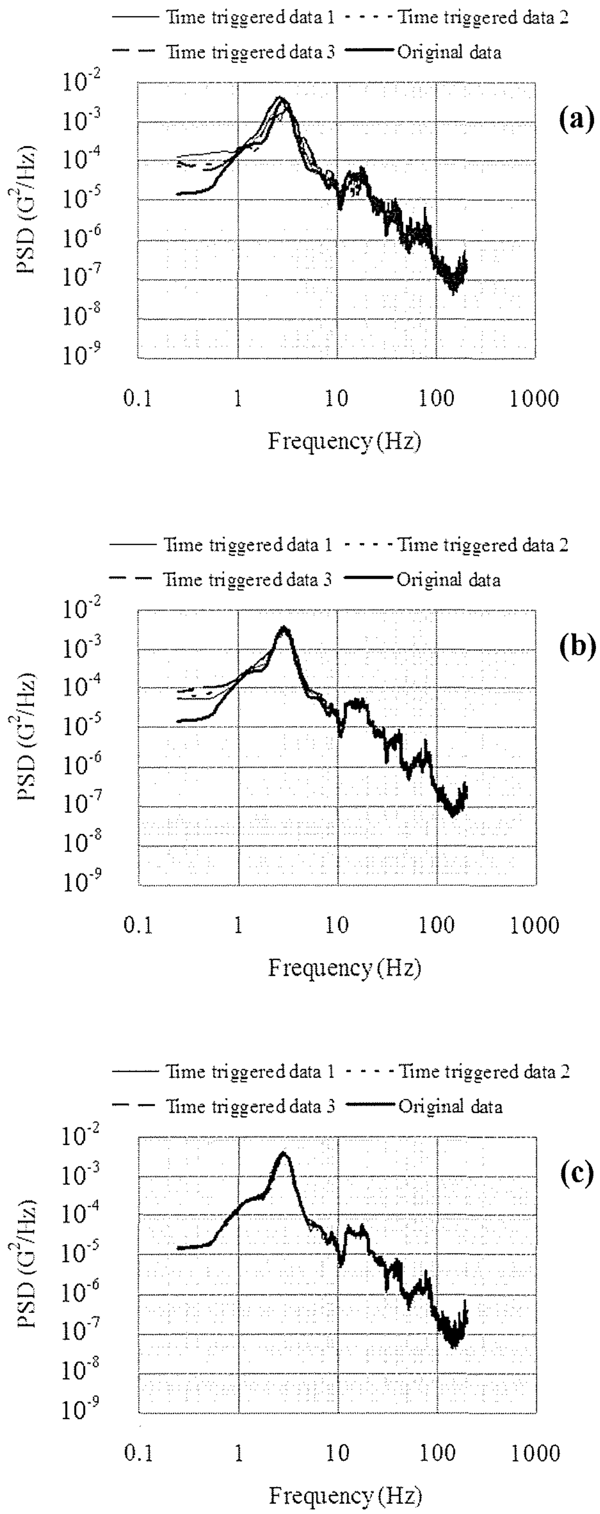

Fig. 5 Vertical PSD plot of the time-triggered data recorded during highway travel. (a) 1 s sub-recorded length, 120 s sample period; (b) 2 s sub-recorded length, 60 s sample period; (c) 4 s sub-recorded length, 60 s sample period.

respectively. In Fig. 5a, the correlation coefficients between the PSD curve of consecutive acceleration data and that with three different sample periods were 0.8652, 0.9268 and 0.9128, respectively. The three curves were also difference at the 0.05 level with the consecutive curve. In Fig. 5b, the correlation coefficients between the PSD curve of consecutive acceleration data and that with three different sample periods were 0.9894, 0.9772 and 0.9812, respectively. In Fig. 5c, the correlation coefficients between the PSD curve of consecutive acceleration data and that with three different sample periods were 0.9973, 0.9923 and 0.9979, respectively. In both the case of the 60 s sample period (2 s sub-recorded length) and the 60 s sample period (4 s sub-recorded length), the three curve were no different at 0.05 level with the consecutive curve. These data indicated that intermittent measurement using the 60 s sample period (2 s sub-recorded length) was sufficient for assessing truck transport on local roads.

In our previous work (Lu *et al.*, 2008), we concluded that shock and vibration must be separated before conducting laboratory simulations. It indicates that it is feasible to develop a vibration and shock simulation method, respectively. In this study, shocks above 0.7 G were removed using Oscope software. Fig. 6a shows a typical continuous vertical acceleration data sample taken from actual truck transport records. Fig. 6b shows vibration acceleration spectra separated from the acceleration data in Fig. 6a using Oscope software. Fig. 6c shows the acceleration connecting separated vibration in Fig. 6b to be more or less random. After removing shock waves over 0.7 G, the waveform was connected using Oscope software, and the changes in vibration acceleration were seen to be nearly identical to a random wave (Lu *et al.*, 2008).

3.3. Effect of sampling interval on the vibration acceleration

Fig. 7 show the PSD levels of the intermittent measurement data after removal of shocks above 0.7 G from the entire transport route. The sample periods of Fig. 7a, 7b and 7c were also 120 s sample period (1 s sub-recorded length), 60 s sample periods (2 s sub-recorded length) and 60 s sample periods (4 s sub-recorded length), respectively. In Fig. 7a, the correlation coefficients between the PSD curve of consecutive acceleration data and that with three different sample periods were 0.9729, 0.9441 and 0.8993, respectively. Two curves were difference at the 0.05 level with the consecutive curve. In Fig. 7b, the correlation coefficients between the PSD curve of consecutive acceleration data and that with three different sample periods were 0.9831, 0.9868 and 0.9739, respectively. In Fig. 7c, the correlation coefficients between the PSD curve of consecutive acceleration data and that with three different sample periods were 0.9995, 0.9985 and 0.9986, respectively. In both the case of the 60 s sample period (2 s sub-recorded length) and the 60

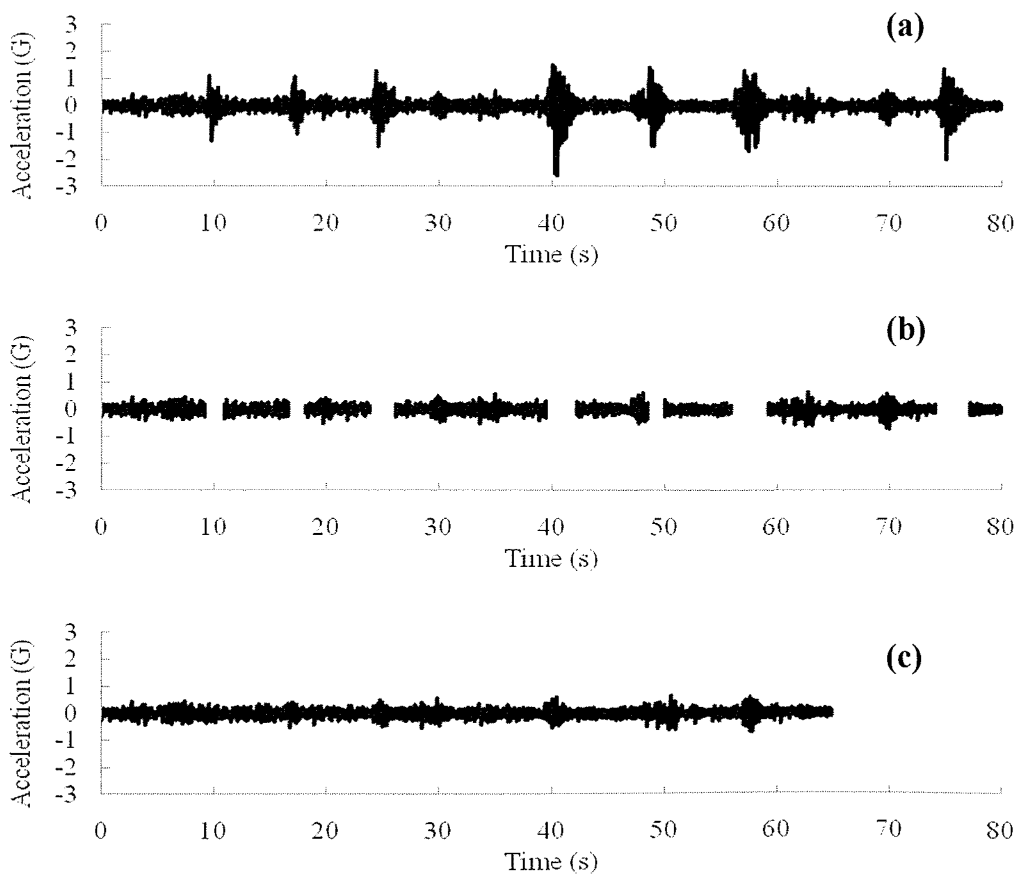

Fig. 6 Vertical acceleration recorded during actual truck transport. (a) Overall. (b) vibration. (c) connected vibration.

s sample period (4 s sub-recorded length), the three curve were no different at 0.05 level with the consecutive curve. These data indicated that intermittent measurement using the 60 s sample period (2 s sub-recorded length) was sufficient for assessing truck vibration with shock data removed.

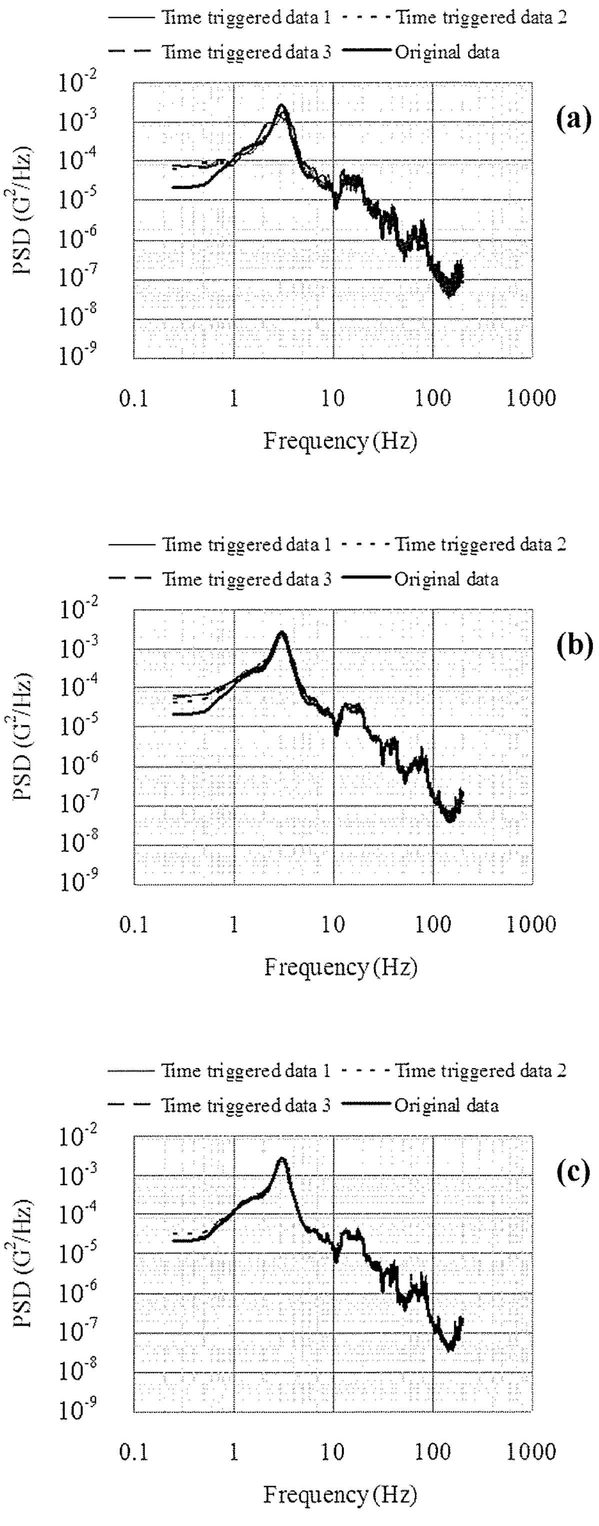

Fig. 7 Vertical PSD plot of the time-triggered data after shocks above 0.7 G were removed. (a) 1 s sub-recorded length, 120 s sample period; (b) 2 s sub-recorded length, 60 s sample period; (c) 4 s sub-recorded length, 60 s sample period.

As shown in the data mentioned above, it is clear that the intermittent measurement results of 60 s sample periods with 4 s and 2 s sub-recorded lengths were sufficient for use when assessing truck transport on local roads and highways, respectively. By careful observation of the acceleration data recorded from actual truck transportation, it was found that shocks occurred more frequently on local roads than on highways. This may be the reason that it needs more recorded data for local road assessment. In this study, when shock data was removed using Oscope software, the intermittent measurement with the same proportion of recorded data for highway was sufficient for assessing truck vibration. Rouillard and Lamb (2008) found a natural lower limit (approximately 1/8) to be the proportion of data necessary for producing a statistically valid representation of vibrations generated by road vehicles in Australia. After comparing our results with the data from Rouillard and Lamb (2008), we concluded that less recorded data is needed to assess truck transport in Japan. The reason for this may be that roads in Japan are paved better than those in Australia. Saito and Morita (2006) also found that the statistical results for vibrations measured by the shock recording unit were almost equal to the result produced by the continuous vibration recording unit when the intermittent measurement was recorded properly. That is, when the number of acceleration waves is more than 20, the recording period per "one window" is about 1 s.

These results indicate that data on intermittent measurements of shocks and vibrations in truck transport are useful for measuring truck transport environments and for developing vibration and shock simulation methods.

4. Conclusion

This paper concludes with a discussion on the effect of sampling interval on the shock and vibration levels during truck transport. The results of continuous acceleration data can be reflected by proper intermittent measurement selection. It was found that intermittent measurements using 60 s sample periods with 4 s and 2 s sub-recorded lengths were sufficient for assessing truck transport on local roads and highways, respectively. When the shock data was removed, the proper sampling condition was a 60 s sample period with a 2 s sub-recorded length. These results indicate that data about intermittent shock and vibration measurements in truck transport are useful for measuring truck transport environments and for developing vibration and shock simulation methods.

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トラック輸送中の振動計測に及ぼすサンプリング間隔の影響

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要　旨

わが国の青果物輸送のほとんどはトラックによるものである。輸送中の振動を計測することにより実験室内での再現試験が可能となるが，振動計測の条件により，得られる振動波形が異なったものになることが報告されている。本研究では，トラックの振動を間欠計測する際のサンプリング間隔が振動特性に及ぼす影響を解析し，連続計測と同等の振動特性を得るための条件について検討した。長野から東京までモモ輸送中の 20t トラックの荷台後部において輸送行程全振動を連続計測した。ここから一定間隔で振動をサンプリングし，パワースペクトル密度（PSD）解析を行った。サンプリング間隔が長い場合には連続波形とのずれが大きくなり，実際の振動を再現できないことが明らかとなった。一般道路，高速道路ではそれぞれ 60 秒毎に 4 秒および 2 秒以上のサンプリングを行うことによりトラックの輸送環境を再現できることがわかった。この違いは，一般道路が高速道路に比べて輸送中の路面凹凸などによる衝撃波発生の頻度が多いためと考えられた。

キーワード：トラック輸送，サンプリング間隔，衝撃，振動