Derivation of PSD Profiles for Random Vibration Test Based on the Field Data Obtained in Japan

ISO/TC 122 Japanese Mirror Committee
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A procedure to derive the acceleration power spectral density (PSD) profiles for the random vibration test based on the transport scenario and classification method of vibration severity was proposed. By using the proposed method, a PSD profile for the random vibration test which simulates the transport conditions was also derived using the field data obtained in Japan. Furthermore, a PSD profile which enables to shorten the testing time (one tenth of the original one) was developed by employing two types of time compression methods. In addition, the time for random vibration test should be selected in accordance with the transport distance considering.

（http://www.jpi.or.jp/report/data/report2014_jp.pdf)

1. Introduction

A simple sinusoidal vibration test or a sweep mode test has been replacing by random vibration test[1)] because of rapid evolutions of transport environments logger, vibration test equipment and its controlling system, computers for measuring test parameters and conditions and for controlling equipment, and software for testing and data analyzing system.

In the random vibration test method, as in the case of other vibration test method, testing conditions including the vibration time history derived using reverse fast Fourier transformation (FFT) from a test PSD profile should reflect the damage level of the packaged products/packaging materials occurred during the actual transport condition. To put this phenomenon into practice, it is necessary to obtain actual transport data, analyze transport conditions (vibration acceleration or PSD profile, testing time, stacking method, etc.), and develop test conditions based on the analysis of acquired data[2)].

However, because of the limitations of testing equipment of individual organization, only limited personnel can perform this type of test.

On the other hand, international standard (such as ISO 13355[3)]) or domestic standards (such as ASTM D4169[4)] and JIS Z 0232[5)]) provide the PSD profiles as a reference or a recommendation in their standards. However, it is not possible for personnel to judge whether the profile is suitable for the testing condition of their transport scenario or destination.

In this report, we proposed the method to derive a test PSD profile by using the field data and established the PSD profile for simulating transport condition in Japan. Furthermore, a PSD profile which enables to shorten the testing time was developed by employing two types of time compression methods.

2. Theory and experimental methods

2.1 Method of averaging transport environment

In the recent data acquisition of transport environment, many data with small data frame such as 1,024 points per frame are obtained and converted to the PSD profile by FFT method. Additionally, several methods for deriving a test PSD profile for the random vibration test by using these PSD profiles have been proposed6-15). In this report, a scenario based averaging method for deriving a unified PSD profile was employed. By using this method, vibration acceleration conditions were classified to several levels depending on the primary mode PSD level, and averaged PSDs for each vibration classes were obtained. Then, a unified PSD was derived by averaging the PSDs for each classes based on the ratios of each category among the data obtained from the transport test.

2.2 Definition of transport scenario

Transport route includes Factory – Delivery center, Deliver center – Distributor company, Distributor company – Dealer. The types of vehicle, road condition, and the running speed are shown in Table 1.

Table 1 Transport scenario defined

<table>
<tr><td>Transportation route</td><td>Factory</td><td>⇒</td><td>Delivery center</td><td>⇒</td><td>Distributor company</td><td>⇒</td><td>Dealer</td></tr>
<tr><td colspan="2">Transportation mode</td><td colspan="2">Large-sized vehicle</td><td colspan="2">Large-sized vehicle</td><td colspan="2">Large and medium sized vehicle</td></tr>
<tr><td colspan="2">Running road (Running speed)</td><td colspan="2">Expressway (80km/h)</td><td colspan="2">Expressway (80km/h)</td><td colspan="2">General road (40km/h or below)</td></tr>
</table>

*1: The average running speed of the transport scenario ≅ 80 km/h.
Running duration = 0.75 min/km.

2.3 Classification of vibration severity

The vibration condition depends on the road roughness, suspension type of the vehicle, and the driving condition even in the fixed transport scenario. In this report, therefore, we employed the method to classify the transport condition based on the PSD level referring the method of five levels road condition classifications[16,17] based on International Roughness Index (IRI)[18,19]. Table 2 shows the three vibration severity levels (A, B, C) and their PSD levels.

Table 2 Classification of vibration severity based on the PSD level

Vibration severity level		PSD (g^2/Hz)
A	Good vibration	Less than 0.005
B	Usual vibration	0.005 to 0.03
C	Bad vibration	Higher than 0.03

2.4 Acquisition of vibration data

Time history vibration data on the truck bed and their PSDs were obtained by using the actual transportation based on the transport scenario as shown in Table 3.

Table 3 Conditions of the vibration data acquisition under three transport conditions

Vibration severity level	Vehicle type and the position of vibration measurement	Loading ratio	Running road	Data acquisition method
A	Type: Large size truck with leaf spring suspension (13 t in capacity) Position: Rear truck bed	Full	Expressway in Western Japan	Full time recording by using original system (Mitsubishi Electric Logistics Corporation)
B	Type: Large size truck with leaf spring suspension (13 t in capacity) Position: Rear truck bed	Full	Expressway in Western Japan	Full time recording by using original system (Mitsubishi Electric Logistics Corporation)
C	Type: Large size truck with leaf spring suspension (11 t in capacity) Position: Rear truck bed	Full	National road with snow covered in Hokkaido	Recording by acceleration trigger (0.087 G) using the EDR-3 (Instrumented Sensor Technology, Inc.)

2.5 Averaging PSDs and derivation of a unified PSD

The representative PSDs for each vibration severity levels (A, B, C) were obtained by averaging the PSDs within the level. A unified PSD was derived by weighted averaging of the representative PSDs based on the ratio of each vibration severity classes obtained from the transport test as shown in Table 4.

2.6 Time compression method No.1

In the fatigue failure, it is considered that the low level of vibration has less effect on the total fatigue level. In this report,

Table 4 Ratio of three vibration severity classes

Vibration severity level		Distribution ratio (%)
A	Good vibration	30
B	Usual vibration	69
C	Bad vibration	1
	Total	100

therefore, we employed the time compression method No.1, namely peek number reduction method, by removing the waves of low level time history data which were recorded more than $10^5 - 10^6$ times during actual transport time period. After deriving the new unified PSD profile by removing the low level vibration, a simplified PSD with limited break points was developed for the convenience of the vibration test.

2.7 Time compression method No.2

The stress–strain (S-N) curve is the basis of the fatigue failure. Therefore, we employed the time compression method No.2, namely S-N method, by multiplying the acceleration factor (more than 1.0) to the PSDs in the profile.

In the fixed frequency, the following equation can be derived from S-N curve ($N \cdot G^{\alpha} = \beta$).

$$T_2 / T_1 = (G_1 / G_2)^{\alpha} \qquad (1)$$

, where T_1 is the test time before time compression, T_2 is the test time after time compression, G_1 is the acceleration before time compression, G_2 is the acceleration after time compression.

Equation (1) can be converted as follows:

$$T_2 = T_1 \cdot (G_1 / G_2)^{\alpha} \qquad (2)$$

3. Results and discussion

3.1 PSD profiles in each classes

PSD profiles fell in each vibration severities (bad, usual, and good) were shown in Figure 1.

3.2 Representative PSD profiles for each categories

The representative PSD profiles for each vibration severity levels (bad, usual, and good) were shown in Figure 2.

3.3 Fatigue equivalent unified PSD profile

A unified PSD profile which is fatigue equivalent was derived by weighted averaging based on the Table 4 as shown in Figure 2.

3.4 Time compression method No.1

The histogram-A of the vibration acceleration obtained by using zero-cross peek count method was shown in Figure 3. Figure 4 shows the Histogram-B obtained by removing the low level vibration from Histogram-A.

Total number of vibration peek in Figure 3 and 4 is 756 and 373, respectively.

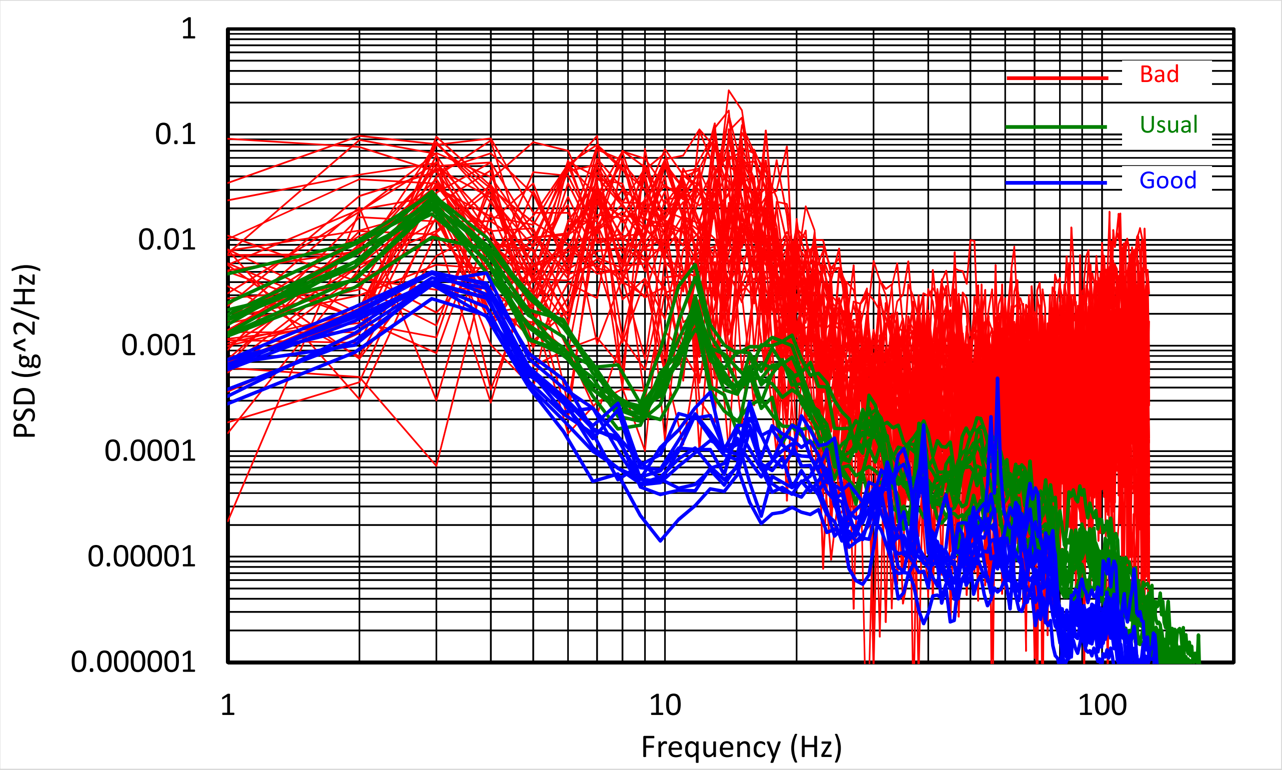
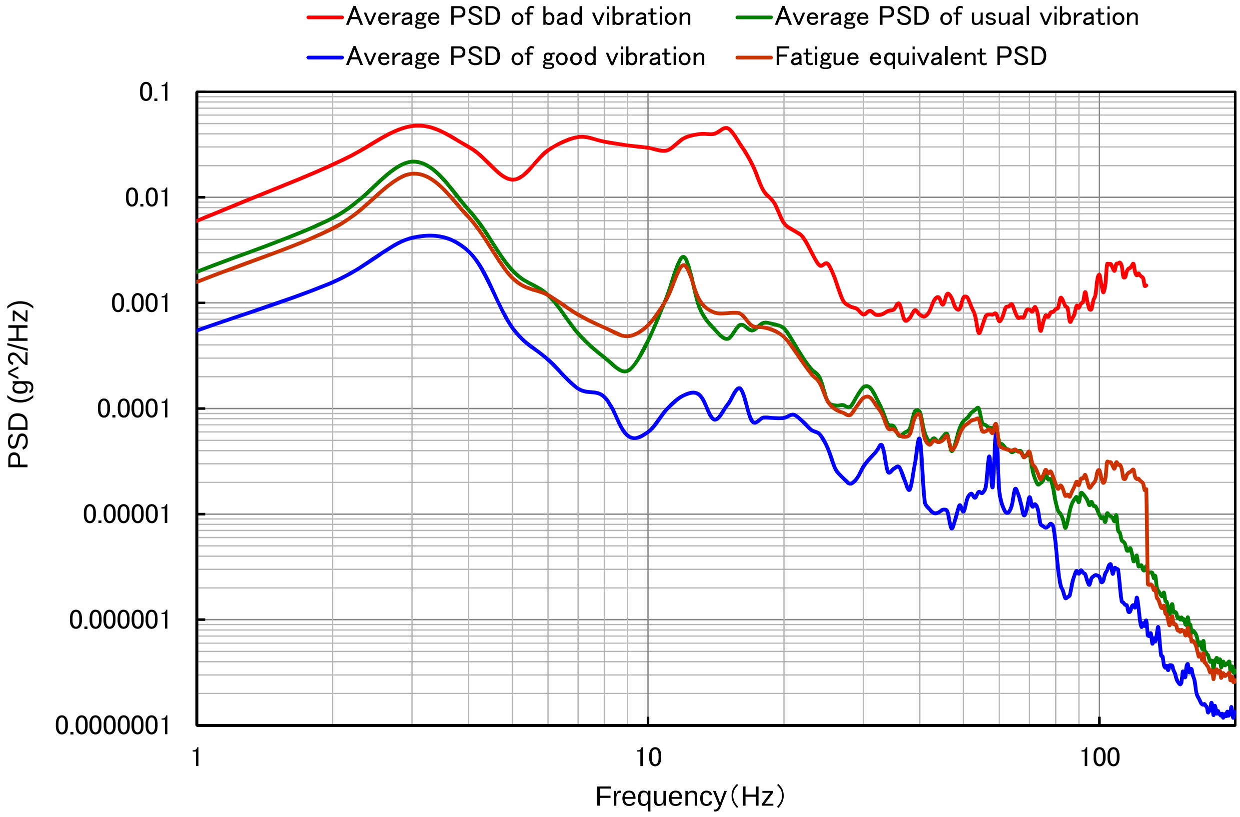


Figure 1 PSD profiles fell in three vibration severity classes



Figrure2 Representative PSD profiles and fatigue equivalent unified PSD profile

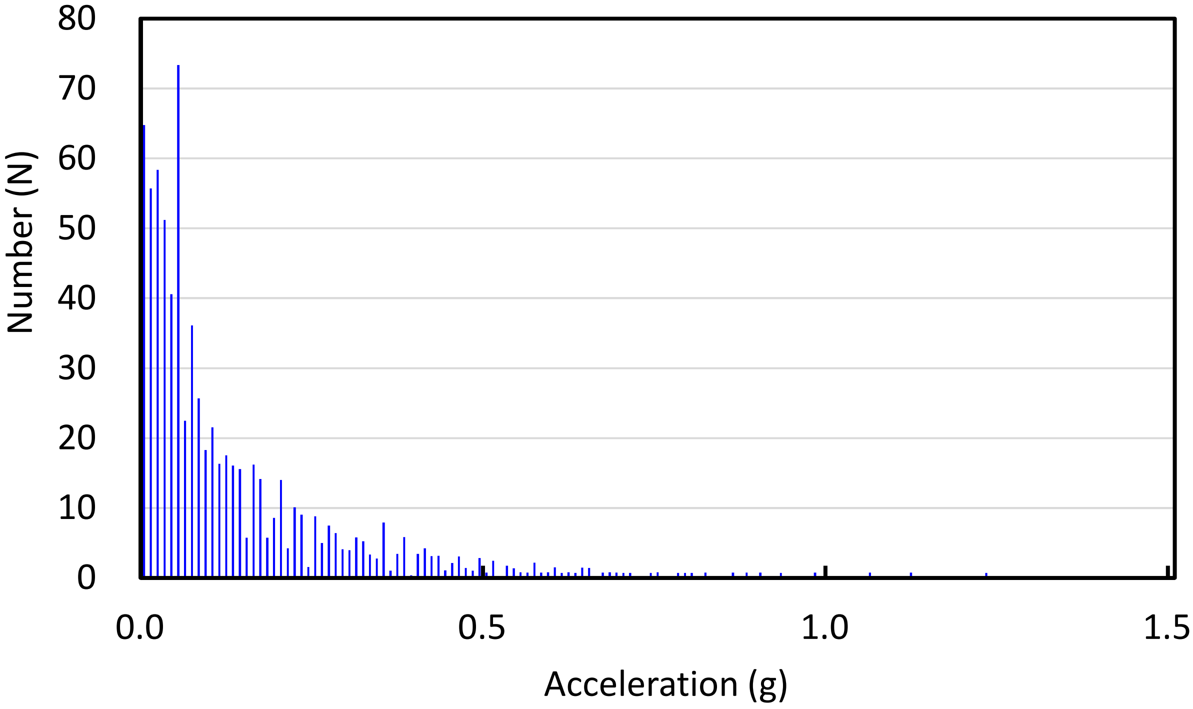


Figure 3 Histogram A (acceleration range is about 3 g)

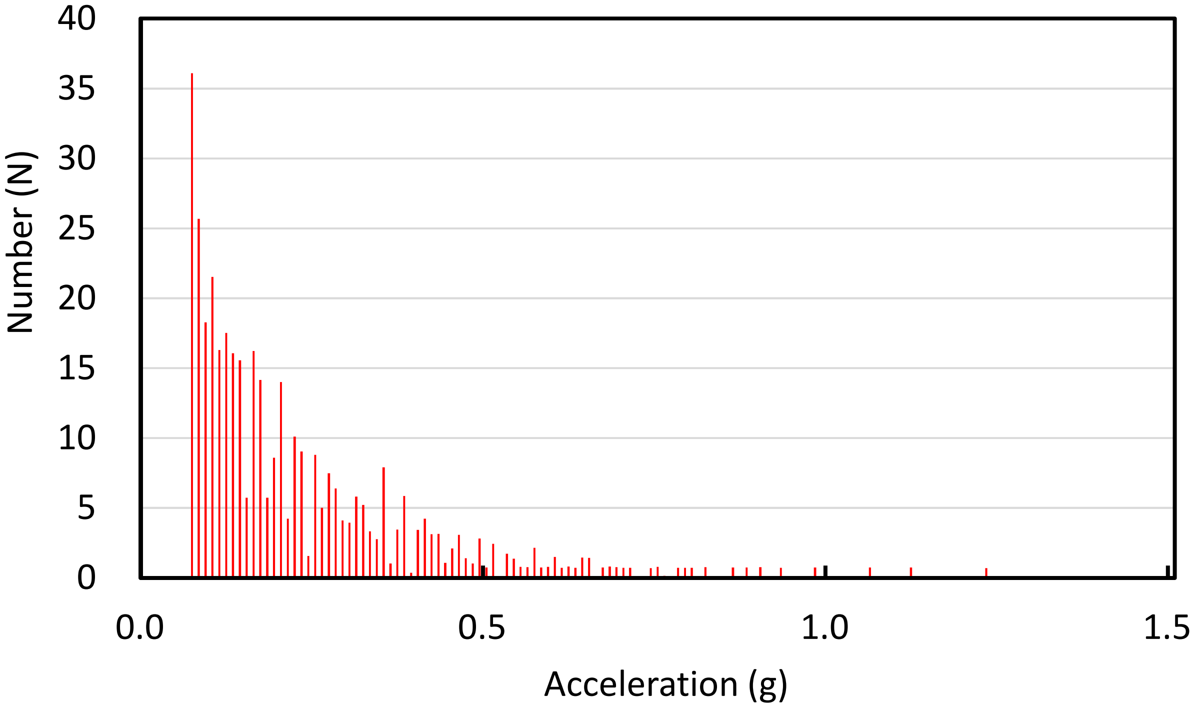


Figure 4 Histogram B (after removing low level of vibration from Histogram A)

Time compression of 1/2 (373/756=0.5) can be achieved by using the time history vibration data from Figure 4 or by using the PSD derived.

PSD_A is the PSD profile derived from original time history by removing the low level vibration (Figure 5).

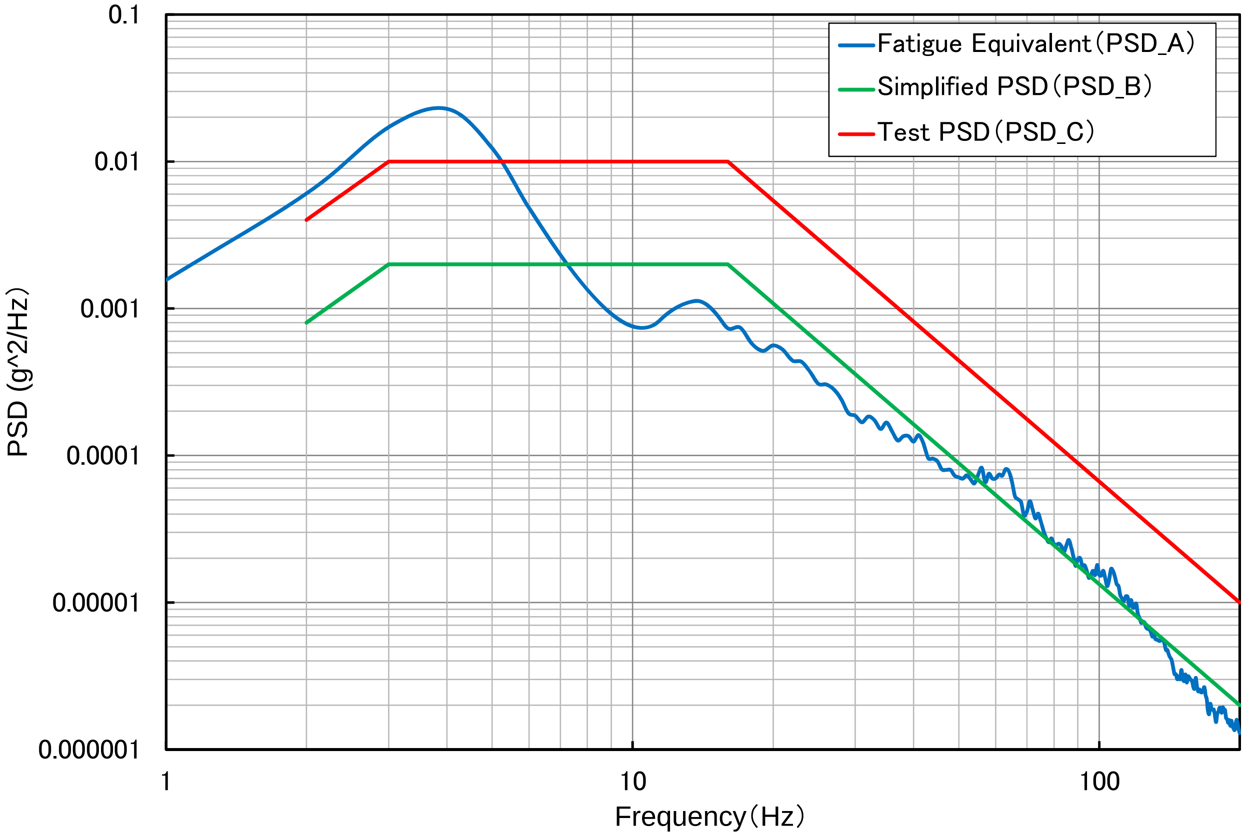


Figure 5 Fatigue equivalent PSD (PSD_A), Simplified PSD (PSD_B), S-N method time compressed PSD (PSD_C)

PSD_B is the fatigue equivalent PSD profile obtained by simplifying the PSD_A based on the performance availability of the test equipment and on the ease of the operation of the test PSD (Figure 5).

3.5 Time compression method No.2

The S-N method for time compression was applied to obtain feasible testing time period. The value of 2.0 for α in the S-N curve was selected to avoid the over/less estimation of the fatigue level by considering wide range of test specimen to be tested.

PSD_C is the time compressed PSD of PSD_B by using S-N method with the value of 2.0 for α in the S-N curve (Figure 5).

3.6 Time for testing

The time for random vibration

test should be selected in accordance with the transport distance as shown in Table 5.

Table 5 Relationship between transport distance and time for testing

Transport distance, l (km)	Test Duration, T_{test} (min)
$l \leq 200$	15
$200 < l \leq 500$	30
$500 < l \leq 1000$	60
$1000 < l \leq 1500$	90
$1500 < l \leq 2000$	120
$2000 < l \leq 2500$	150
$2500 < l$	180

4. Concluding remarks

Proposed PSD profile (PSD_C) can be used to simulate the transport condition in Japan (relatively good condition among the world) in the random vibration testing for packaging.

The use of proposed PSD profile will enhance the optimization of the packaging for cushioning and lead to eliminate the accident of transporting goods and to reduce the use of packaging materials and environmental load. Active utilization is highly expected.

5. Acknowledgement

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