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A TRIAL PLAN REGARDING THE EVALUATION METHOD OF ROAD ROUGHNESS ON THE BASIS OF A MAN-VEHICLE-ROAD SYSTEM CONCEPT

By Akira KAWAMURA and Terutoshi KAKU***

The evaluation of road roughness has been examined by various authors from different points of view : riding quality, pavement serviceability, structural design of the vehicle and the pavement. Nevertheless, there are a number of unclarified points regarding a correlation between them.

The authors have obtained a significant result through examining a linear relationship between the inputs and the outputs of the vibratory system of a vehicle induced by road roughness. Based on the result, the method of road roughness evaluation synthesizing the standards used in the related fields is proposed by simulation method of a vehicle mathematical model.

Keywords : *road roughness, riding quality, pavement serviceability, man-vehicle-road system*

1. INTRODUCTION

It has been suggested by many researchers that the traffic system of today is composed of three subsystems : 1) man-vehicle system, 2) environment system, and 3) information system. If it is limited to the road traffic, the vehicle and environment are equal to the car and road condition, respectively. Furthermore, it is generally accepted that the solution of the problem on road accident casualties is necessary to understand the correlations about the road traffic elements of man, vehicle and road. Thus, we think that further analysis with a view to the synthesis of man, vehicle and road elements is essential to deal with the road traffic problem.

On the other hand, the evaluation standards of road roughness differ with the engineers' positions. For example, pavement engineer evaluates road roughness from serviceability regarding pavement performance, bridge engineer evaluates it from structural design especially in the vibration of highway bridge and automotive engineer evaluates it from design of the suspension of a car and the strength of car components such as a body and a frame.

Therefore, at present stage, there are many unclarified points on the correlation between the evaluation standards in their respective positions. This research aims at presenting basic data on the evaluation method of road roughness synthesizing those standards. When progressing with our study, a measurement of road roughness provides a rich source of information to aid in the evaluation process. As more roughness measuring methods have been developed[1),2)], the focus has shifted toward the purpose of measurements.

* Member of JSCE, Associate Professor, Department of Civil Engineering, Hakodate National College of Technology (Tokura-cho, Hakodate, 042)
** Member of JSCE, Dr. Eng., Professor, Department of Civil Engineering, Hokkaido University (Kita-ku, Sapporo, 001)

We used the measuring method based on dynamic response of the vehicle to the road surface, which is useful to study about a man-vehicle-road system. In this case, the response-type measuring system requires a linear vehicle response system. Accordingly, we also study the linear relationship between acceleration response of the vehicle and road roughness.

This research process includes the following steps : 1) Evaluation of linearity between inputs and outputs on the vehicle vibratory system. 2) Correlation analysis between characteristics relating road surface conditions (i. e., pavement serviceability, riding quality of the vehicle, vehicle motion and road roughness, etc.). 3) Development of a synthetic index on a man-vehicle-road system.

2. ACCELERATION RESPONSE OF THE VEHICLE INDUCED BY ROAD ROUGHNESS

As for a vehicle vibratory system, the existence of the linear relationship between vehicle response and road roughness is not only necessary for measuring road roughness but useful for clarifying the complex distributed character of their approximate inputs, and facilitating the numerical calculation. Although a true vehicle vibratory system consists of many nonlinear elements : tire, suspension, sheet and so on, the response characteristics for the system has been therefore assumed to be linear at least over some limited range of inputs[3]. The present report is concerned with the results of our investigation of the influence of the input wheel vertical acceleration of unsprung mass, and the output acceleration of sprung mass on the responses of the vibratory system of a four-wheeled vehicle in rectilinear vibrations.

We have investigated the distribution of the input-output acceleration first and then multiple linear regression analysis was performed. The multiple regression equation is shown below :

$$Y=\alpha_0+\alpha_1x_1+\alpha_2x_2+\alpha_3x_3+\alpha_4x_4+\varepsilon \qquad (1)$$

where Y is normal (side) acceleration at C. G. (center of gravity) of the vehicle at natural frequency of the unsprung mass system, $x_{1\sim4}$ are vertical acceleration of each wheels at the natural frequency, $\alpha_{1\sim4}$ are partial regression coefficients, α_0 is the intercept and ε is the residual. The data used in this investigation were measured by a normal passenger car under various road surface conditions as in Table 1[3].

Fig. 1 shows boxplots on the typical data. Computations for the analysis were performed using SAS program[4]. In the figure, SR 5 is an average dry road surface and WR 7 is a snow covered surface that is classified as a poor minor road.

The skewness $\sqrt{\beta_1}$ and the kurtosis β_2 are given by

$$\sqrt{\beta_1}=\mu_3/\mu_2^{1.5}, \quad \beta_2=\mu_4/\mu_2^2$$

where μ_r is the r-th central moment. $\sqrt{\beta_1}$ and β_2 are specified as nonsymmetric tendency and long tailness of the data, respectively. If it is assumed that the sample is normally distributed, the kurtosis and the skewness are as follows : $\beta_2=3$, $\sqrt{\beta_1}=0$. The analysis generally shows that the acceleration levels of

Table 1 Details of Test Routes.

Ref. Code	Measure-ment Speed Km/h	Route Length m	Note (road surface condition, vehicle motion etc.)	Ref. Code	Measure-ment Speed Km/h	Route Length m	Note (road surface condition, vehicle motion etc.)
SR1	40	120	Manhole, vehicle rolling	WR1	30	90	Urban street
SR2	40	120	Extremely smooth surface	WR2	20	60	Urban street
SR3	40	120	Bridge	WR3	40	120	Compacted snow covered
SR4	50	150	Bridge	WR4	50	150	Compacted snow covered
SR5	40	120	Intersection	WR5	50	150	Compacted snow covered
SR6	40	120	Urban street	WR6	20	60	Culd-de-sac, vehicle rolling
SR7	40	120	Urban street	WR7	20	60	Slushy, extremely rough
SR8	40	120	Relatively smooth	WR8	30	90	Rutted
SR9	30	90	Underpass	WR9	20	60	Rutted
SR10	40	120	Patched, vehicle rolling	WR10	20	60	Slushy, extremely rough

SR = Dry surface (asphalt), WR = Snow covered surface

* The test vehicle is a normal passenger car.

(wagon-type, total weight = 198 kgf·s^2/m, wheel base = 2.69 m and inflation pressure = 1.9 kgf/cm^2)

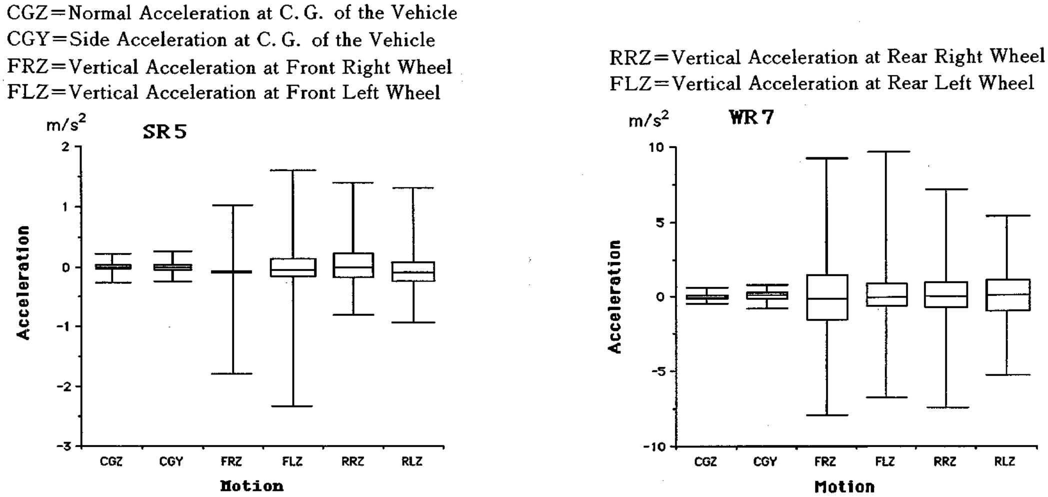


Fig. 1 Typical Results of Box Plots for Acceleration of the Vehicle.

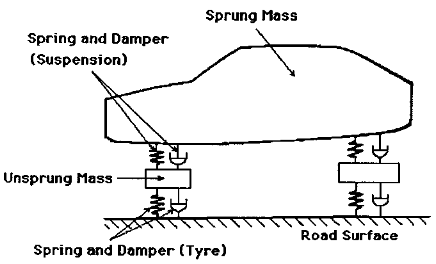


Fig. 2 Vehicle Mass-Spring-Dashpot Model.

Table 2 Analysis of Variance for Acceleration of the Vehicle.

Ref. Code	Motion	Number	Skewness	Kurtosis	Prob >D
SR5	CGZ	1024	0.0089	3.6797	< 0.01
	CGY	1024	0.2141	3.6934	< 0.01
	FRZ	1024	-0.8453	19.5344	< 0.01
	FLZ	1024	-0.5112	11.6774	< 0.01
	RRZ	1024	0.7432	5.2187	< 0.01
	RLZ	1024	0.4819	6.1898	< 0.01
WR7	CGZ	1024	-0.1457	1.0407	< 0.01
	CGY	1024	0.1333	0.6162	< 0.01
	FRZ	1024	0.0391	0.6883	< 0.01
	FLZ	1024	0.4213	3.6117	< 0.01
	RRZ	1024	-0.2839	3.2532	< 0.01
	RLZ	1024	0.0348	0.8688	< 0.01

unsprung mass system measured in winter are extremely higher than those in summer, and the acceleration levels of front wheel system are higher than those of rear wheel system. From **Table 2**, the kurtosis values of the unsprung system in winter are greater than those in summer and the skewness values are between +1.0 and −1.0. Although I can not say so definitely, the general tendency of a normal distribution is understood. Next, the typical results of multiple regression analysis are shown in **Table 3** and **Table 4**.

Table 3 shows the analysis of variance table for normal acceleration (vertical component of the vector of acceleration at C. G. of the vehicle) and **Table 4** shows that for side acceleration (lateral component of the vector of acceleration at C. G. of the vehicle). From the tables, it is seen that the inputs normal acceleration of unsprung mass system, and the output acceleration of sprung mass system, display a relative strong correlation of over 0.9.

The investigation on the vehicle vibratory system response properties is summarized above and these results confirm that the vehicle vibratory system can be considered a linear system when studying the general tendency of the vibration for the vehicle traveling at constant speeds realistic.

3. EVALUATION ON RIDING QUALITY OF THE VEHICLE

In a broad sense, riding quality is not only concerned with the vibration that crew receives but vehicle size, noise, temperature, air conditioning, lighting, color and so on.

In case of evaluating riding quality exerted from road surfaces, it is mainly evaluated from the standpoint of vibration standards which have been previously reported[3),5),6)].

This paper provides a comparative study of the band pass filter method (by use of ISO Standard)[7)] and

Table 3 Analysis of Multiple Linear Regression for Normal Acceleration at C. G. of the Vehicle.

DF:	R:	R-squared:	Adj. R-squared:	Std. Error:
19	.982	.964	.955	6.843E-3

Analysis of Variance Table

Source	DF:	Sum Squares:	Mean Square:	F-test:
REGRESSION	4	.019	4.729E-3	101
RESIDUAL	15	7.024E-4	4.6826E-5	p = 1.0000E-4
TOTAL	19	.02		

Residual Information Table

SS[e(i)-e(i-1)]:	e ≥ 0:	e < 0:	DW test:
1.606E-3	14	6	2.287

Table 4 Analysis of Multiple Linear Regression for Side Acceleration at C. G. of the Vehicle.

DF:	R:	R-squared:	Adj. R-squared:	Std. Error:
19	.977	.955	.943	7.889E-4

Analysis of Variance Table

Source	DF:	Sum Squares:	Mean Square:	F-test:
REGRESSION	4	1.9714E-4	4.9285E-5	79.193
RESIDUAL	15	9.3351E-6	6.2234E-7	p = 1.0000E-4
TOTAL	19	2.0647E-4		

Residual Information Table

SS[e(i)-e(i-1)]:	e ≥ 0:	e < 0:	DW test:
2.0121E-5	7	13	2.155

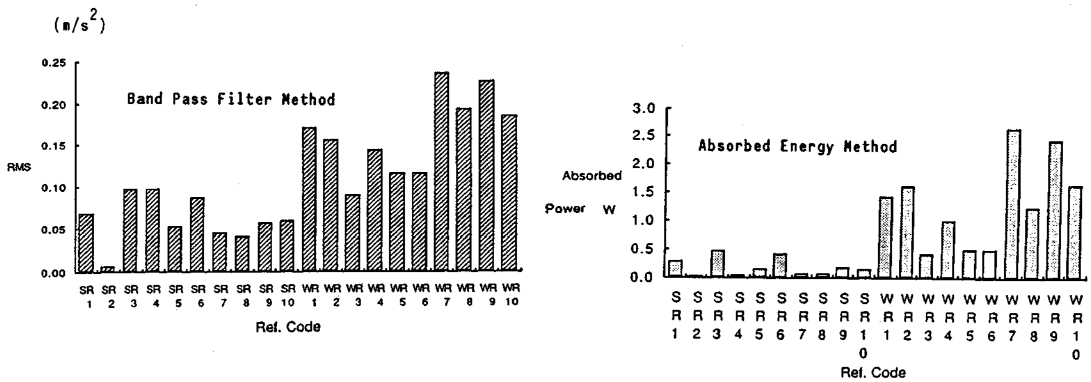


Fig. 3 Comparison of Evaluation Methods of Riding Quality for Normal Acceleration (4-8 Hz).

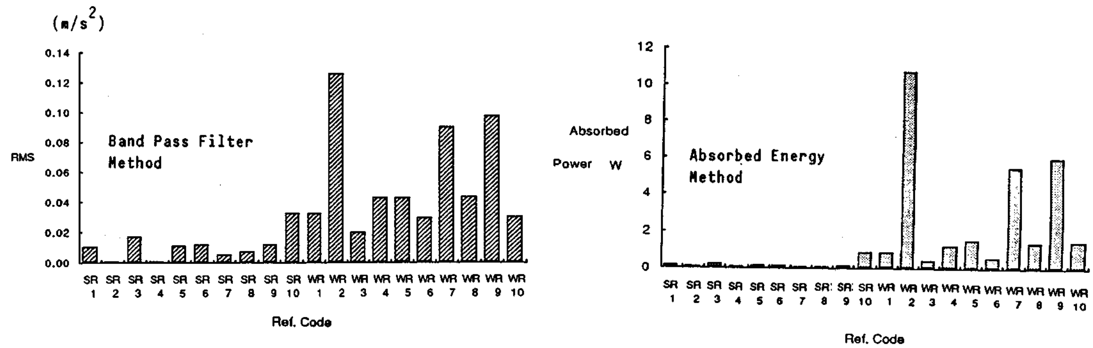


Fig. 4 Comparison of Evaluation Methods of Riding Quality for Side Acceleration (1-2 Hz).

the absorbed energy method[8]. Indices which can be useful for quantitative processing of riding quality are also examined. The data used for the evaluation are identical with those of the previous chapter.

(1) Evaluation of riding quality by the band pass filter method and the absorbed energy method

The band pass filter method is the evaluation method which considers the intensity, the direction, the exposure time of the vibration and the effect of human exposure to vibration for the rms (root mean square) value of acceleration within specified-band.

The absorbed energy method is the method which examines the rate of flow of energy taking place as a result of the complex damped elastic properties of the anatomy from human dynamics.

In this chapter, based on the facts that the effects of vibration to the physiological reaction of a human body is reducing beyond 10 Hz and considering the labor and cost of calculations, we deal with tha most sensitive frequency range on human body, namely 4-8 Hz for longitudinal acceleration and 1-2 Hz for lateral one.

Fig. 3 shows the typical examples of comparison of both methods for normal acceleration at C. G. of the vehicle in the 4-8 Hz band and **Fig. 4** shows those for side acceleration in the 1-2 Hz band.

Although these results can be anticipated to some extent on the shape of the evaluation standard curves, it is confirmed that the general tendency of the difference between dry road surface and snow covered surface regarding riding quality, and the measured values according to road surface conditions and driving conditions of the vehicle, are similar.

(2) Development of riding quality evaluation index

In this section, as for the standard to clarify the correlation between indices, we used ISO Standard 2631 based on the results in the previous section and the application to riding quality.

When considering the evaluation of various characteristics of the vehicle dynamics such as the direction and the frequency range, the duration and the human acceptable level of vibration, we have developed the performance index of riding quality (PIR) as the evaluation function and it can be expressed as follows :

$$PIR=\frac{1}{n}\sum_{i=1}^{n}\frac{A_i}{E_i} \qquad (2)$$

where A=integrated value of acceleration on the object i of evaluation within the frequency band
E=integrated value of ISO Standard curve on the object i of evaluation within the frequency band
n=number of the objects of evaluation.

The objects of evaluation of equation (2) are normal and side acceleration at C. G. of the vehicle in various significant frequency bands. The equation represents that the value of PIR is greater than 1.0 when vibration acceleration on the subject exceeds the evaluation standard.

As a few examples, Fig. 5 shows the PIR of normal acceleration of sprung mass by "Reduced Comfort (RC)"[9] standard at one hour exposure time for the analytical frequency range 0.2-2.0 Hz and 4-8 Hz. Furthermore, Fig. 6 shows the PIR of side acceleration of sprung mass by "Fatigue Decreased Proficiency (FDP)"[9] standard at 24 hours exposure time for the analytical frequency range 1-2 Hz. When considering levels for various strengths of perception of vibration, these figures show that "1 hr Reduced Comfort" boundary on normal acceleration of sprung mass corresponds "24 hr Fatigue Decreased Proficiency" boundary on side acceleration of it.

From these results, road surface conditions according to the evaluation standard of riding quality can be observed and we think the PIR is helpful when the dominant frequency and the direction of vibration concerning about riding quality are examined.

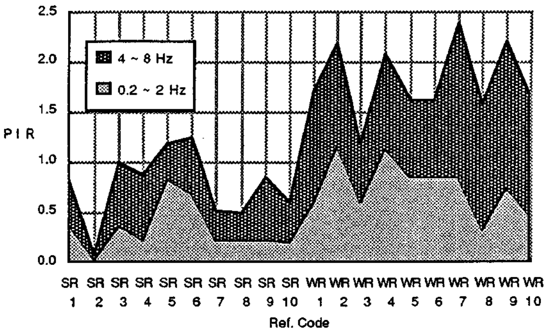


Fig. 5 PIR of Normal Acceleration of Sprung Mass (1 hr RC).

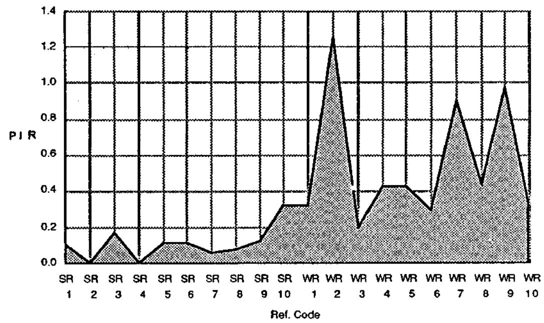


Fig. 6 PIR of Side Acceleration of Sprung Mass (24 hr FDP).

4. EVALUATION OF ROAD ROUGHNESS BY PAVEMENT SERVICEABILITY

In case of considering road traffic, the serviceability of pavement is concept of service that the vehicle can travel on road surface safely and comfortably and an attempt at quantitative grasping the serviceability has been made in various countries since AASHO Road Test[10] was reported[11].

In this chapter, we calculate the Present Serviceability Index (PSI)[10),11)] by use of PSD of road roughness. PSD of road roughness[12)] is used to measure and evaluate road roughness by a statistical method and it can be represented by the function $S(n)$, where n is spatial frequency.

We have discussed characteristics of the PSD function about various road surfaces[3)]. According to Stenschke[13)], the slope variance (SV) of road profile can be calculated with

$$SV=\int_0^{\lambda} F^2(\lambda)A(\lambda)d\lambda \cdots\cdots (3)$$

where

$F(\lambda)=(2/l)\{\sin(\pi l/\lambda)-(1/L)\sin(\pi l/\lambda)\}$

$l=2.23$ m, $L=7.77$ m

$A(\lambda)$ is energy density at wave length λ and $F(\lambda)$ is transfer function of AASHO profilometer. PSI can be calculated easily using the following equation[14)]:

$$PSI=3.27-1.37(\log SV-0.78) \cdots\cdots (4)$$

Furthermore, a relation between the energy density function and the PSD function can be described with

$$A(\lambda)=(1/\lambda^2)S(\lambda) \cdots\cdots (5)$$

From these relations, the value of PSD function can be converted to the value of PSI. The PSI is now widespread among the various countries of the world as the measure associated with the pavement serviceability concept and riding quality of the vehicle.

In this study, we use the PSI as the serviceability index since it has been considered to possess high practical value compared with the other similar indices at present. The PSI of actual road surfaces are calculated from equation (4) and the results are shown in Fig. 7. According to the AASHO Road Test, it is recognized that pavements should be resurfaced when the value of PSI fell to 2.5 for primary roads. Therefore, poor surface conditions of roads in winter can be recognized from the figure and the results agree approximately with those expected.

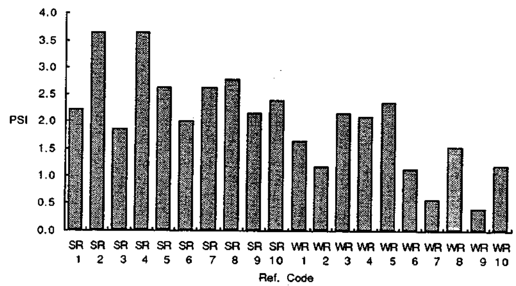


Fig. 7 Calculation Results of PSI

5. SIMULATION ON VEHICLE RESPONSE TO ROAD ROUGHNESS

(1) Calculation of power spectral density by mathematical model of the vehicle

Vibration of the vehicle induced by road roughness contain vibration regarding sprung mass, unsprung mass, steering system, body frame, power transfer system and so on. Research on this vibration has been extensively studied[3)]. In case of handling a complex vibration system and requiring the general tendency of vibration, it would be more suitable to improve or use mathematical model of the vehicle which has been used.

In this study, the model, which is mainly applicable to the evaluation of vehicle vibratory characteristics, is related to the following:

① Vibration of sprung mass, unsprung mass and suspension system
② Acceleration at relatively low frequencies
③ Model of a low degree-of-freedom as would influence the fundamental characteristics of vibration of the vehicle
④ Vibration modes on the coupled vertical and lateral motion
⑤ Acceleration response of the linear system with road roughness as inputs

As for the mathematical model satisfying these requirements, a seven degree-of-freedom model which is composed from a spring-dashpot-mass system, is selected and it is shown in Fig. 8. When using this model, equations of motion for the vehicle are derived from the Lagrangian and Newtonian mechanics.

A seven-second order differential equation for each motion is obtained and it can be recasted into a set of fourteen state space equations. The state equation is given by

$$\dot{\boldsymbol{x}}=\boldsymbol{A}\boldsymbol{x}+\boldsymbol{B}\dot{\boldsymbol{u}}+\boldsymbol{C}\boldsymbol{u} \quad \cdots\cdots (6)$$

where $\boldsymbol{A}$ is the system matrix composed of the coefficients and parameters of the system and $\boldsymbol{B}$, $\boldsymbol{C}$ are the distribution matrices, which are affected by road roughness input vector $\boldsymbol{u}$. The state vector $\boldsymbol{x}$ and the input vector $\boldsymbol{u}$ are expressed in the next formulas :

$$\tilde{\boldsymbol{x}}^T=[z, \dot{z}, \theta_x, \dot{\theta}_x, \theta_y, \dot{\theta}_y, z_3, \dot{z}_3, \theta_3, \dot{\theta}_3, z_1, \dot{z}_1, z_2, \dot{z}_2] \quad \cdots\cdots (7)$$

$$\boldsymbol{u}^T=[\eta_1, \eta_2, \eta_3, \eta_4] \quad \cdots\cdots (8)$$

where z = vertical displacement of the sprung mass

θ_x = roll displacement of the sprung mass

θ_y = pitch displacement of the sprung mass

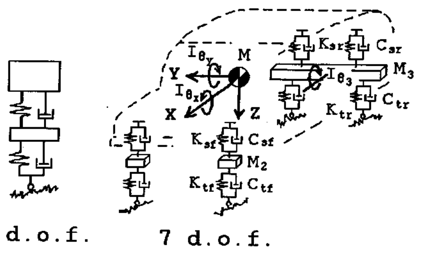
z_3 = rear axle vertical displacement

θ_3 = rear axle angular displacement

z_1 = right front wheel vertical displacement

z_2 = left front wheel vertical displacement

$\eta_{1\sim4}$ = road roughness input at each tire



M = 172·5 kgf·s²/m
M_2 = 5.4 kgf·s²/m
M_3 = 14.79 kgf·s²/m
K_{sf} = 2400 kgf/m
K_{tf} = 20000 kgf/m
K_{sr} = 2200 kgf/m
K_{tr} = 20000 kgf/m
C_{sf} = 270 kgf·s/m
C_{tf} = 220 kgf·s/m
C_{sr} = 60 kgf·s/m
C_{tr} = 60 kgf·s/m
I_{θ_x} = 65 kgf·s²·m
I_{θ_y} = 200 kgf·s²·m
I_{θ_3} = 4 kgf·s²·m

Fig. 8 Vehicle Dynamics Simulation Model.

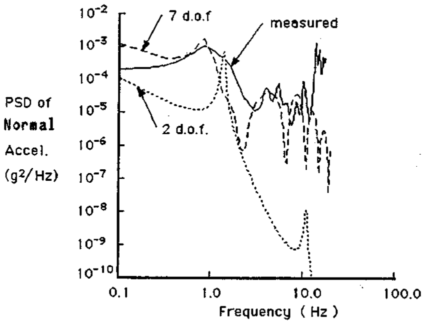


Fig. 9 Typical Normal Acceleration by Simulation Method.

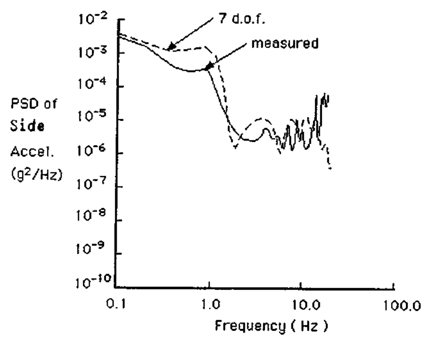


Fig. 10 Typical Side Acceleration by Simulation Method.

By Laplace transforming $\ddot{x}$ and Y and substituting equations $x=x'+Cu$ and $B'=AC+B$ into equation (6), the following transfer function yields :

$$G(s)=\frac{Y(s)}{u(s)}=\frac{C^T s\,(C+B)}{sI-B} \quad \cdots\cdots (9)$$

where

$\ddot{x}=Ax+B'$, $Y=C^Tx'$ and I is the unit matrix.

Y is scalar quantity as an output variable of the system and $Y(s)$ is therefore given by

$$Y(s)=G(s)u(s) \quad \cdots\cdots (10)$$

PSD of acceleration P is obtained by

$$P=TY(j\omega)\,Y^*(j\omega) \quad \cdots\cdots (11)$$

where ω is angular frequency and T is the total simulation time.

(2) Comparison of power spectral density of measured and simulated acceleration

In order to examine vibration of the model used in the previous section, PSD of the acceleration of mass sprung for normal and side directions are obtained by solving system equations and PSD of the simulated acceleration is compared with that of the measured acceleration on road surface (SR 5).

Fig. 9 shows a typical example of a comparison for the normal acceleration and Fig. 10 shows that for the side acceleration. The simulation using a two degree-of-freedom model is also shown for reference in Fig. 9. As may be seen in the figures, the predicted acceleration levels differ from the measured ones beyond 10 Hz.

This problem has been discussed by Healey[15] and Nathoo[16] et al. and it has been suggested by them that vibration due to nonlinearity, structural flexture, and tire and drive train unbalance may contribute significantly above 10 Hz.

As stated in the introduction, the main discussion of this study is examination of the correlation between the evaluation standards of road roughness in the related fields synthetically and it is generally accepted that the effect of vibration to the physiological reaction of a human body is reducing beyond 10 Hz.

From the facts, it is considered that the seven degree-of-freedom model is suitable for estimating riding quality as discussed in the following chapter.

6. EVALUATION OF ROAD ROUGHNESS WHEN CONSIDERING A MAN-VEHICLE-ROAD SYSTEM

Based on the results discussed in the previous chapter, we will outline a systematic method for evaluating road roughness.

As for the index regarding this object, we consider it necessary to be able to do : (1) quantitative grasping, (2) clarifying the correlation between indices, and (3) relating with elements of a man-vehicle-road system. Accordingly, the following indices were selected :

① Present Serviceability Index (PSI)
② Basic Roughness Coefficient ($S(n_0)$)
③ Performance Index of Riding Quality (PIR)

It has been known that the basic roughness coefficient gives the amplitude when road roughness expressed in terms of PSD and PSD function $S(n)$, can be described the coefficient[17].

And $S(n)$ at the spatial frequency n of the road is

$$S(n)=S(n_0)\ (n_0/n)^{w_1},\quad n\leqq n_0$$
$$S(n)=S(n_0)\ (n_0/n)^{w_2},\quad n>n_0$$

where n_0 is a fixed datum spatial frequency $(=1/2\pi)$, w_1 is 2.0 and w_2 is 1.5.

A relation between PSI and PIR is estimated by simulation method in chapter 5. Vehicle parameters used here and the damping constant are those of normal passenger cars and the damping constants which affect riding quality of the vehicle are taken to the range from 30 to 300 kgf · sec/m (294 to 2 940 N · s/m).

Based on the results, we will introduce a figure in order to examine the relation among three indices and we call it PPS diagram using the first letters of PSI, PIR and $S(n_0)$. Fig. 11 shows an example of the usage on PPS diagram and PIR in the figure is calculated for the vibration of sprung mass of the vehicle under the

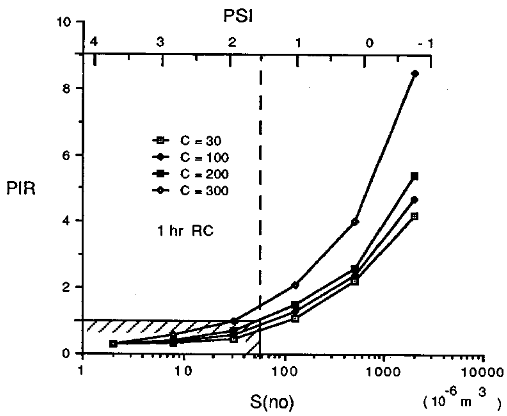


Fig. 11 Example of PPS Diagram.

conditions : one hour "Reduced Comfort (RC)" level in the frequency range of 4 to 8 Hz for the vertical direction and the level in the frequency range of 1 to 2 Hz for the lateral direction. From the figure, It is recognized that the value of $S(n_0)$, which simultaneously satisfy two levels in order to maintain the riding quality and prevent pavement disruption (i. e., PIR is less than 1.0 and PSI is greater than 1.5), is required to be $64.0 \times 10^{-6}\ m^3$. That value of $S(n_0)$ corresponds to the road that is equal or better than "Average Principal Roads" of ISO Standard[18].

Accordingly, it is estimated that the evaluation level of road surface by PSI is higher than that of ISO Standard. Furthermore, it is found that "Reduced Comfort" level at one hour exposure time can be maintained when using the passenger car with shock absorber that suspension damping constant is less than 200 kgf · sec/m (1 960 N · s/m), and traveling over "Average Principal Roads".

Calculation was repeated for other riding quality criteria and the following results were also obtained : As for one hour exposure time and PSI=1.5, the road class which reaches "Fatigue Decreased Proficiency (FDP)" level and the class which reaches "Exposure Limit (EL)" level, are "Poor Minor Road" and "Very Poor Minor Road", respectively. Thus, the evaluation of riding quality and serviceability under various road surface conditions, can be done schematically by PPS diagram.

7. CONCLUSION

The main results of this study are summarized as follows :

(1) The characteristics of the kurtosis and the skewness show that acceleration of sprung mass and unsprung mass generally follow a normal distribution in case of vehicle traveling at a constant speed.

(2) The results of multiple regression analysis for estimating a linear relationship between acceleration of sprung mass show that significant correlation exists between normal acceleration of sprung mass and that of unsprung at natural frequency of sprung mass vibratory system.

(3) PIR as the function based on the ISO Standard enables us to evaluate riding quality quantitatively. That is, the effects of direction, frequency, intensity and duration of vibration relating to riding quality can be estimated by the function in quantity.

(4) Present Serviceability Index is calculated using the slope variance obtained from the power spectral density of road roughness.

(5) When using a seven degree-of-freedom mathematical model of the vehicle for predicting acceleration response, it was confirmed that PSD of the simulated response compares well with those obtained experimentally in a frequency range of 0.1-10 Hz.

(6) PPS diagram is useful for considering road roughness, riding quality and pavement serviceability synthetically. And, we can state that the diagram is one of the countermeasures answering the request for the evaluation of road roughness from the standpoint based on a man-vehicle-road system.

As for the method of analysis and the theory used in this study, various reports in the related fields have been given over a long time. It is the purpose of this paper to point out that an approach in due consideration of the relation between those fields is necessary for the evaluation of road roughness.

This promising field of research has just begun and we should be happy if anyone who has considerable knowledge about the evaluation method of road roughness from the standpoint based on the man-vehicle-road system would give me his advice.

In addition, we used the large-capacity computer of Hokkaido University to calculate the numerical values in this study.

8. ACKNOWLEDGEMENT

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