Measurement of Texture Depth of Pavement Using Potable Laser Profiler

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Abstract: Skid resistance and noise of roads highly depend on the characteristics of pavement texture. Therefore, the estimation of texture characteristics may give an useful information for the skid resistance and noise of road. As an indicator, MTD (Mean Texture Depth) is generally measured by the Sand Patch Test (SPT). Even though the SPT can be simply conducted with very low cost, it has some disadvantages including time-consuming and traffic interruption. There is a strong need to develop a method to quickly estimate characteristics of road surface textures without traffic interruption and implement it in the expressway pavement management system. In this study, an effective measurement way for the texture depth is developed using the MPD (Mean Profile Depth) which can obtained by the Portable Laser Profiler.

Key Words: MPD(Mean Profile Depth), MTD(Mean Texture Depth), Portable Laser Profiler, Sand Patch Test

1. INTRODUCTION

As expressways in Korea have been highly deteriorated with their increased service lives, the skid resistance and noise levels on those expressways have been dropped down with polished and damaged surface condition causing the loss of road functions including driving safety and comfortability. In order to assess the performance conditions of the roads, the evaluation of the pavement distress and road smoothness are being carried out but the direct evaluation of the skid resistance and the noise levels on the road surface are not systematically performed and considered in the pavement management system (PMS). In some developed countries, the research studies to include these functional components of pavement performance in the PMS are being conducted using the information on the mean texture depth (MTD).

In general, the characteristics of the texture are defined according to the extent of Microtexture, Macrotexture, Megatexture, and Roughness, which have effects on the road functions such as the friction, tire-pavement noises, splash and spray, tire abrasion, rolling resistance, and the ride quality according to the characteristics of the pavement texture in wet conditions (Figure 1). In particular, Macrotexture is known to have close relationship with the safety of pavement surface, closely connected with the friction and noise through direct interaction with the tires. To minimize the traffic accidents from the friction decrease, the pavement surface should perform the sufficient friction and drainage functions. The friction of the pavement surface is determined by the surface conditions (apertures, abrasion, aggregate type,

aggregate distribution) and the environmental factors (Panagouli and Kokkalis, 1998), so designing and managing the pavement surface to allow sufficient rolling resistance and texture can be a way to reduce the traffic accidents during the driving on the roads in wet conditions (Hass et al., 1994).

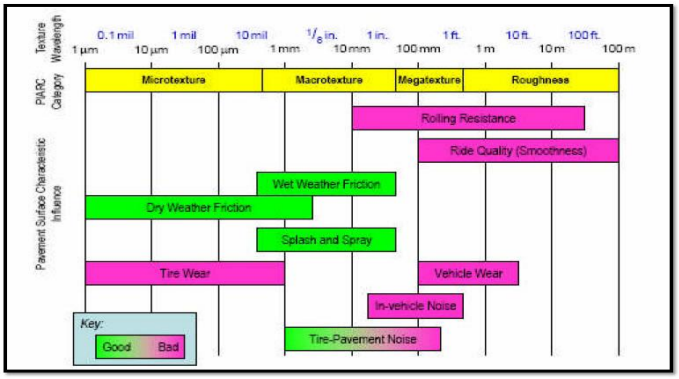
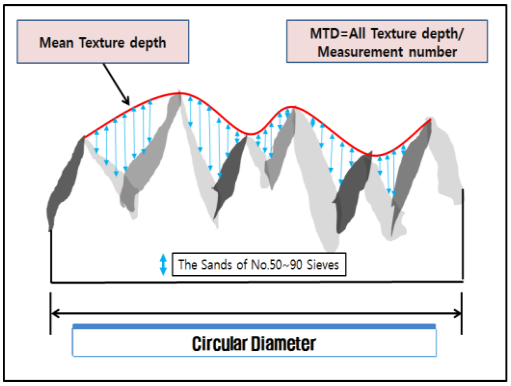
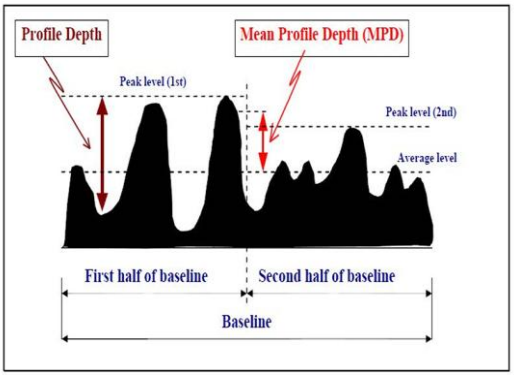


Figure 1. Classifications of pavement surface characteristics and their effects on pavement performance measures (ACPA, 2006a)

There are generally MTD method and MPD method for calculation of mean depth of the pavement texture. As shown in Figure 2(a), MTD is defined as the mean average vertical height differences of the texture, generally calculated through Sand Patch Test (ASTM E – 965). According to the basic principle of Sand Patch Test, MTD is calculated by evenly filling the apertures on the pavement surface with 25 ㎤ of sands that remain 100% in No. 80 sieve after passing through No. 60 sieve for more than 90%, and by dividing it by the spread area. In the case of Sand Patch Test, there are disadvantages that the test can't be performed on the current driving roads, traffic control is necessary to carry out the test, and that a lot of time is required to secure the data. On the contrary, in the case of MPD calculation using the Portable Laser Profiler, MPD is calculated by the difference between the average profile depth of the texture measured at 1mm interval in a total of 100mm distance and the average value of the 'peak level 1st' and the 'peak level 2nd' in 100mm, as shown in Figure 2(b). This method is considered more efficient because it can measure the average texture depth during the driving of the test vehicle and it requires no traffic control and time limit. MPD and MTD have the same goal of calculating the average texture depth but show the different results of measurement of mean texture depth because they have different definitions and different calculation methods. Conceptually, MTD is more suitable than MPD in figuring out the characteristics of mean texture depth, but it has disadvantages that traffic control is necessary and that a lot of time is required to secure the data. So it is necessary to assess the MTD using the MPD measurements. To suggest an equation that can calculate EMTD(Estimated Mean Texture Depth) from the MPD measurements, this study will try to find their correlations by securing the MPD and MTD Data from many asphalt and concrete Sections including the Central Inland Test Roads.



(a) MTD



(b) MPD(Flintsch, 2003)

Figure 2. Definition of MTD and MPD

2. Research trends of pavement texture measuring methods

For the measurement of mean texture depth of the pavement, the domestic researches generally depend only on the Sand Patch Test method. In the foreign countries, however, the research studies are being carried out to evaluate the road functions through the analysis of the characteristics of mean texture depth, and in the case of MPD, the mean texture depth is calculated using various equipment like Laser Profiler, Mobile Profilometer, Ames, CTM, and Portable Laser Profiler, and the researches on the development of EMTD equation through the analysis of the correlation between MPD and MTD is under way to evaluate the road functions. The result of the correlation analysis using the MPD data obtained through various MPD measuring devices and the MTD obtained through Sand Patch Test is shown in Table 1.

Table 1. Collection of Correlations between MTD and MPD

Equipment for MPD	Pavement	Correlation	R^2	Standard
Ames	AP	$EMTD = 1.1743 \times MPD - 0.0127$	0.98	Fisco (2009)
CTM	AP	$EMTD = 1.2587 \times MPD + 0.0762$	0.89	Fisco (2009)
CTM	PCC	$EMTD = 0.947 \times MPD + 0.069$	0.94	ASTM E 965

3.1 Sand Patch Test

The basic principle of quantitatively measuring the texture depth of pavement surface is by calculating the volume of the apertures between the aggregates through MTD method, commonly using Sand Patch Test. Sand Patch Test is a method of calculating MTD by evenly filling the apertures on the pavement surface with 25 ㎤ of sands that remain 100% in No. 80 sieve after passing through No. 60 sieve for more than 90%, and by dividing it by the spread area. The mean texture depth (MTD) through Sand Patch Test is calculated as on Equation (1) below:

$$MTD = \frac{4V}{\pi D^2}, V = \frac{\pi d^2 h}{4} \quad (1)$$

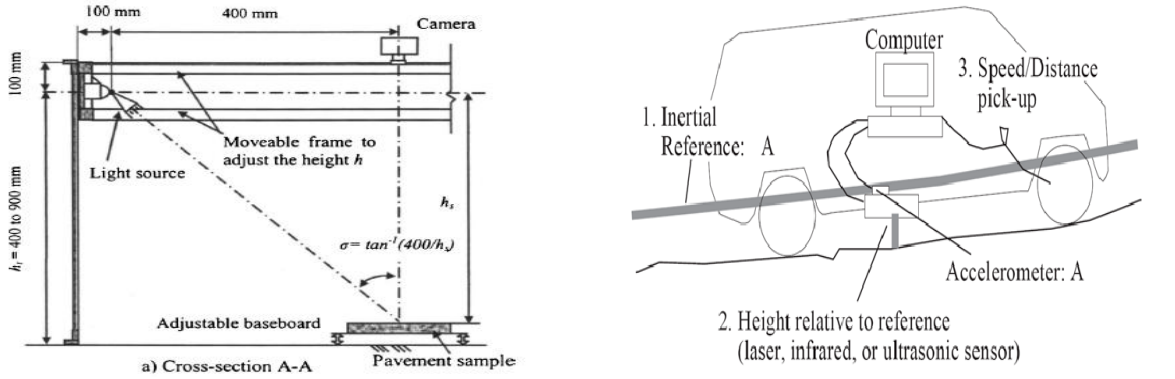
where,

h : Sand Cylinder Height, and
d : Sand Diameter

3.2 Portable Laser Profile Method

As an indirect method to measure the texture depth, there is a Portable Laser Profile method. It is a method of MPD calculation by measuring the time the laser emitted from the Portable Laser Profiler in the test vehicle takes to return after it was reflected from the road surface and transforming it into the texture depth. MPD is calculated by the difference between the average profile depth of the macrotexture measured at 1mm interval in a total of 100mm distance as shown in Figure 3 and the average value of the 'peak level 1st' and the 'peak level 2nd' in 100mm, after removing all texture information except Macrotexture information. The equation for MPD calculation is as follows:

$$MPD = \frac{(Peak\,Level\,1st) + (Peak\,Level\,2nd)}{2} - Average\,Level \quad (2)$$



(a) Principle of MPD Test (b) MPD Measurement Using Portable Laser Profiler

Figure. 3 Measurement Principle of MPD Test Using Portable Laser Profiler

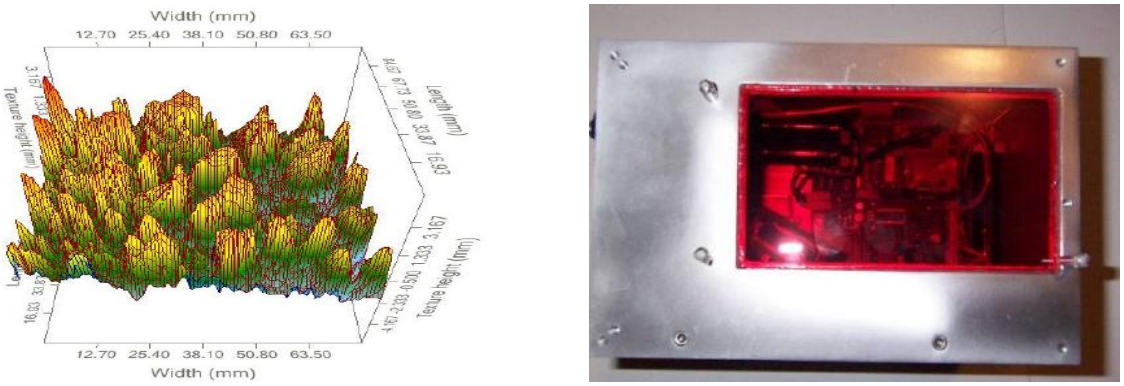
3.3 CTMeter

CTMeter is a method of MPD calculation by measuring the vertical displacement of the pavement surface of 892mm diameter at 0.892mm intervals using the laser displacement sensors. Using these laser displacement sensors, the measurement is possible at the same place where the Sand Patch Test was conducted and the quantitative analysis can be also conveniently conducted through the digitalization of the results of many linear measurements of the mean texture depth. However, this method is difficult to use on Korean expressways due to the heavy weight of the measuring device, traffic control during the test, and long measuring time.

3.4 Ames scanner

Ames scanner is a method of MPD calculation by measuring the 3 dimensional volume in 100mm X 100mm squares using the laser displacement sensors like on Figure 4. Ames Scanner method has an advantage of being able to carry out the measurement at the same place where

Sand Patch Test was conducted but it also has disadvantages that the traffic control is necessary during the test and a lot of measuring time is required.



(a) Three-Dimensional Surface Rendering (b) Ames scanner

Figure 4. Measurement Principle of MPD Test Using Ames scanner (Fisco, 2009)

MTD and MPD calculation can be exactly carried out using Sand Patch Test, CTMeter, and Ames method, but these methods have disadvantages of the difficulty of transportation of the measuring devices, necessity for traffic control, and a lot of measuring time required. However, in the case of Portable Laser Profiler, the traffic control is not necessary though with less precision because it linearly measures the mean texture depth, and the MPD can be easily calculated because the mean texture depth can be measured during the driving of the test vehicle. Accordingly in this study, the analysis of the correlation between the MTD through Sand Patch Test that is commonly used and the MPD using Portable Laser Profiler was conducted, in order to more efficiently test the road functions through the measurement of the mean texture depth.

3. RESEARCH STRATEGY AND RESEARCH RANGE

To carry out the analysis of the correlation between MPD and MTD, the various information on the textures of public roads is necessary for this study. So MTD calculation was conducted through Sand Patch Test on the Central Inland Test Road, Second Joungbu Expressway, Central Inland Expressway, Jungang Expressway, Central Inland Branch Line, and Gangneung-WonJu University Campus, where various surface treatments were applied such as Transverse Tinning, Burlap Drag, Random Tinning, and Asphalt Pavement, calculating the MPD at the same place using Portable Laser Profiler. Though this, the analysis of correlation between the MPD and MTD was carried out using statistical method on the basis of the measurement results on the same 204 places in the asphalt and concrete sections, and the EMTD equation was suggested.

4. CONSTRUCTION OF MPD AND MTD DATABASE THROUGH SITE SURVEY

4.1 Selection of the Sections

To analyze the correlation between the MPD and MTD, the MPD calculation using the Eye Survey, Sand Patch Test, and Portable Laser Profiler, was conducted on the Central Inland Test Roads and Expressways. Data were collected on various pavement treatment methods such as Transverse Tinning, Burlap Drag, Random Tinning, and Asphalt Pavement. Test points were selected from the un-distressed pavement areas through the Eye Survey and the tests were carried out on the right wheel path sections for the safety of the testers. Table 2 below shows the sections where the pavement texture data were collected for the analysis of correlation between MPD and MTD. Information on 10m mean texture depth for each pavement treatment method was collected from the Central Inland Test Roads and the information on each 10m mean texture depth was collected from the Second Joungbu Expressway and Central Inland Expressway. Further, the information on mean texture depth of the transverse tinning and asphalt was collected from the Jungang Expressway and the Central Inland Branch Line, and the information on each 20m mean texture depth of 4 asphalt sections and 1 concrete section was collected from Gangneung-Wonju University Campus.

Table 2. Test Section for Collection of MPD and MPD

Road Routes	Station		Pavement Type
Central Inland Test Road	-	-	Transverse Tinning, Random Tinning Burlap Drag, Asphalt(SMA)
Second Joungbu Expressway	339.0	338.6	Transverse Tinning
Central Inland Expressway	118.0	117.6	Transverse Tinning
Jungang Expressway	130.4	130	Transverse Tinning
Central Inland Branch Line	1.6	2.0	Asphalt(SMA)
Gangneung WonJu University Campus	-	-	Asphalt(SMA), Portland Cement Concrete

4.2 Visual Survey

A visual survey was conducted to survey the pavement distress and to establish the MPD and MTD test points in the test roads and expressway sections. The pavement distress areas were avoided from the test points to measure the mean texture depth properly. The result of the visual survey indicated that most of the pavement distress occurred in the joint parts of the concrete pavement as shown in Figure 5, and these deteriorated areas were excluded from obtaining MPD and MTD data to avoid a bias of analysis results. The Sand Patch Test and MPD calculation were conducted through the visual survey in the right wheel path sections. The tinning interval in transverse tinning sections was identified to be 18×3×3mm which is commonly used.

Figure 5. Eye Survey based on Distress

4.3 Sand Patch Test

The test was conducted in the right wheel sections and Sand Patch Test was also conducted at 1m intervals to collect the various texture information from the Transverse Tinning, Random Tinning, Burlap Drag, and Asphalt Pavement (Figure 6).

(a) Sand Patch Test on the Asphalt pavement Section

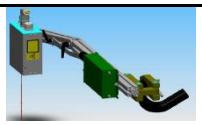
(B) Sand Patch Test on the Concrete Pavement Section

Figure 6. Sand Patch Test for MTD Calculation

4.4 MPD Calculation Using Portable Laser Profiler

The specifications of Portable Laser Profiler used in MPD calculation are specified on Table 3 below. The name of the Portable Laser Profiler model is 2207-155/260-A, with the maximum power of 7.0mW and the measurement range of the texture is 155mm. Using this Portable Laser Profiler, MPD is calculated by the difference between the average value of 'peak level 1st' and 'peak level 2nd' among the 100 data measured at 1mm interval and the mean profile depth in 100mm distance. During the collection of texture data, the texture data except macrotexture data are not used for MPD calculation.

Table 3. Specification of Portable Laser Profiler

Model	Max power	Measurement Range	Portable Laser Profiler
Greenwood Engineering 2207-155/260-A	7.0mW	155.0mm	

MPD calculation method using the Portable Laser Profiler is described on Figure 7. The laser emitted from the Portable Laser Profiler is pointed at the same place where the MTD data from the Sand Patch Test was captured. The MPD data collected with a driving at the speed of 80km/h are compared with the MTD data.

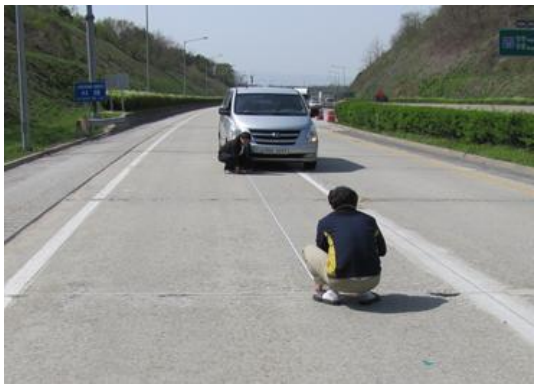


Figure 7. Test Method of MPD

The collected texture data of each surface treatment method are used for MPD calculation through 3 procedures as described in Figure 8. First, the texture information collected by measuring the time the laser from Portable Laser Profiler takes to return after reflection from the pavement surface is transmitted to the main software. Using the collected texture data, the MPD of each 100mm distance is calculated and MPD Database is constructed to conveniently identify one MPD data calculated at each 100mm distance through the program.

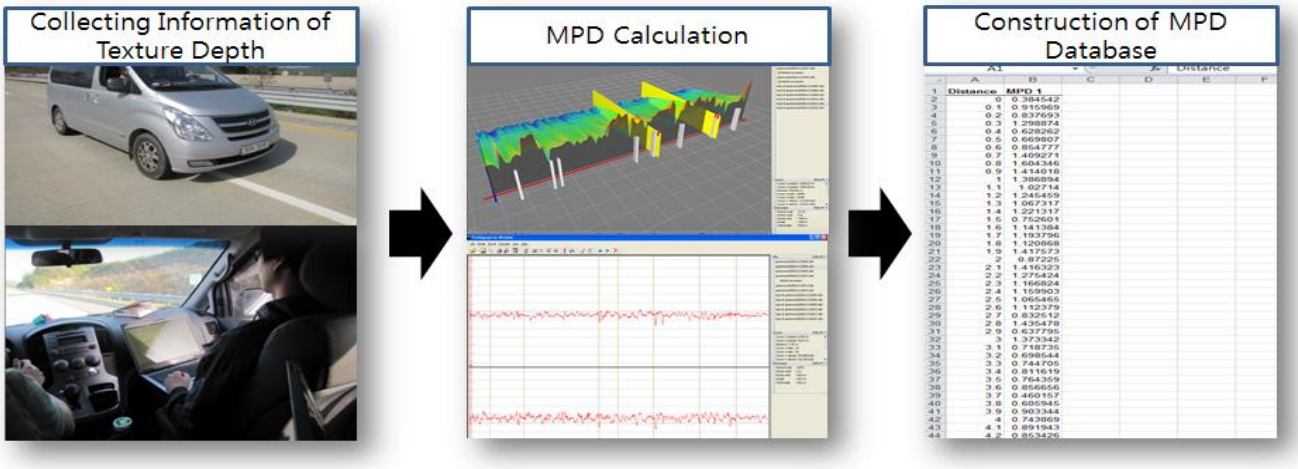


Figure 8. Procedure for MPD Calculation

Through the procedures like Figure 8, MPD using Portable Laser Profiler and MTD through Sand Patch Test were calculated in the asphalt pavement sections (Gangneung-Wonju University Campus, Central Inland Test Road, Central Inland Branch Line), and a total of 87 dataset including 65 data from Gangneung-Wonju University Campus, 15 data from the Central Inland Test Road, and 7 data from Central Inland Branch Line, were established. MPD data in each section were measured at 0.41～1.07mm distances and MTD data at 0.5～1.32mm distances. Table 4 below shows the MPD and MTD data measured in each section.

Table 4. Measuring Result of MPD and MTD on Asphalt Section

Campus in Gangneung WonJu University			**Central Inland Test Road**		**Central Inland Branch Line**				
MPD (mm)	MTD (mm)	MPD (mm)	MTD (mm)	MPD (mm)	MTD (mm)	MPD (mm)	MTD (mm)	MPD (mm)	MTD (mm)
0.71	0.76	1.13	1.07	0.81	0.66	0.72	0.84	0.59	0.80
0.91	0.78	1.13	0.93	0.68	0.51	0.62	0.84	0.72	0.84
0.85	0.82	1.07	1.03	0.73	0.60	0.68	0.74	0.75	0.78
0.96	0.74	0.81	0.69	0.74	0.64	0.73	0.78	0.95	1.04
1.07	0.82	0.82	0.74	0.79	0.45	0.68	0.72	0.68	0.84
1.08	0.78	1.00	0.96	0.94	0.80	0.53	0.65	0.68	0.91
0.86	0.74	0.88	0.89	1.01	0.91	0.77	0.72	0.66	0.88
0.89	0.71	0.77	0.84	1.26	0.91	0.74	0.82		
0.84	0.69	0.92	0.80	0.66	0.47	0.75	0.71		
0.80	0.69	0.98	0.79	0.61	0.62	0.88	0.88		
0.72	0.67	0.77	0.81	0.59	0.53	0.60	0.73		
0.92	0.71	1.04	0.71	0.58	0.54	0.66	0.83		
0.87	0.66	0.88	0.74	0.77	0.66	0.96	0.84		
0.86	0.67	1.08	0.71	0.84	0.69	0.92	0.75		
0.89	0.67	0.76	0.73	0.85	0.76	0.62	0.69		
0.98	0.71	0.84	0.76	0.92	0.72				
0.75	0.59	1.32	0.93	0.95	0.62				
1.19	1.07	0.57	0.41	0.75	0.58				
1.29	0.97	0.69	0.44	0.67	0.66				
0.75	0.66	0.75	0.62	0.68	0.66				
0.85	0.51	0.69	0.45	0.76	0.59				
0.84	0.50	0.62	0.53						

MPD using Portable Laser Profiler and MTD through Sand Patch Test were calculated in the concrete sections (Gangneung-Wonju University Campus, Second Joungbu Expressway, Central Inland Test Road, Central Inland Test Road, Central Inland Expressway, Jungang Expressway), and a total of 174 Databases such as 11 Data from Gangneung-Wonju University Campus, 35 Data from Second Joungbu Expressway, 89 Data from Central Inland Test Road, 22 Data from Central Inland Expressway, and 17 Data from Jungang Expressway, were constructed. MPD data in each section were measured at 0.31～2.17mm distances and MTD data at 0.32～1.68mm distances. Table 5 below shows the MPD and MTD data measured in each section.

5. MPD AND MTD DATA ANALYSIS

5.1 Data Correlation Analysis Method of MPD and MTD

Through Sand Patch Test, the mean diameters of circular MPD and MTD in concrete and asphalt pavement sections are generally measured to be about 25～30cm. MPD data which calculate 1 data due to 100 measurements at each 100mm distance was made to fall within the range of MTD diameter for the analysis of correlation. Correlation analysis was conducted using the average value of 3 MPD and 1 MTD data as shown in Figure 9.

Table 5. Measuring Result of MPD and MTD on Concrete Section

Concrete Pavement													
Gangneung WonJu University Campus		Second Joungbu Expressway		Central Inland Test Road						Central Inland Expressway		Jungang Expressway	
MPD (mm)	MTD (mm)	MPD (mm)	MTD (mm)	MPD (mm)	MTD (mm)	MPD (mm)	MTD (mm)	MPD (mm)	MTD (mm)	MPD (mm)	MTD (mm)	MPD (mm)	MTD (mm)
1.34	0.96	0.71	0.84	0.71	0.89	0.62	0.88	0.56	0.60	0.68	0.88	0.74	0.56
1.99	1.68	0.69	0.62	0.60	0.70	0.47	1.01	0.63	0.72	0.76	0.84	0.59	0.51
1.99	1.46	0.52	0.64	0.58	0.91	0.65	1.07	0.73	0.72	0.77	0.92	1.00	0.49
1.79	1.57	0.78	0.63	0.72	0.61	0.76	1.04	0.73	0.78	1.02	1.07	0.62	0.45
1.87	1.28	0.79	0.42	0.72	1.01	0.50	0.91	0.86	0.69	0.91	0.78	0.81	0.44
1.70	1.24	0.44	0.40	0.78	0.94	0.56	1.01	0.73	0.67	0.92	0.93	0.70	0.58
2.17	1.21	0.54	0.49	0.69	0.87	0.50	0.78	0.82	0.76	0.96	1.07	0.93	0.64
1.58	0.93	1.26	0.58	0.67	1.02	0.39	0.80	0.82	0.67	0.79	1.07	0.73	0.59
1.69	1.33	0.91	0.72	0.76	1.05	0.51	0.78	0.75	0.71	0.84	1.21	0.66	0.52
1.67	1.46	0.52	0.86	0.67	0.92	0.35	0.91	0.79	0.55	0.76	1.14	0.61	0.66
0.84	0.96	0.58	0.53	0.71	1.11	0.35	0.82	0.87	0.64	0.89	1.17	0.74	0.55
		0.62	0.49	0.55	0.92	0.34	0.86	0.92	0.62	1.17	1.17	0.99	0.56
		0.44	0.60	0.64	1.13	0.37	0.91	0.55	0.78	0.75	0.84	0.95	0.51
		0.62	0.53	0.62	0.99	0.37	0.98	1.04	1.07	0.52	0.91	0.70	0.50
		0.46	0.54	1.04	0.77	0.60	0.62	1.10	1.14	0.83	0.89	0.85	0.44
		0.64	0.58	1.01	1.08	0.54	0.72	1.10	1.17	0.73	0.80	0.74	0.98
		0.74	0.66	1.07	0.96	0.45	0.64			1.14	1.28	0.53	0.32
		0.71	0.66	1.04	1.07	0.67	0.76			1.42	1.33		
		0.71	0.67	1.10	1.14	0.78	0.71			1.30	1.05		
		0.71	0.62	1.10	1.17	0.67	0.60			0.78	1.12		
		0.82	0.62	1.04	0.77	0.74	0.58			1.29	1.22		
		0.43	0.48	1.01	1.08	0.41	0.58			1.16	0.91		
		0.41	0.67	1.07	0.96	0.96	1.22						
		0.70	0.63	1.04	1.07	0.88	1.08						
		0.31	0.54	1.10	1.14	0.91	0.90						
		0.52	0.40	1.10	1.17	1.04	0.77						
		0.59	0.39	1.04	0.77	1.01	1.08						
		0.46	0.41	1.01	1.08	1.07	0.96						
		0.68	0.34	1.07	0.96	1.04	1.07						
		0.53	0.36	1.04	1.07	1.10	1.14						
		0.49	0.37	1.10	1.14	1.10	1.17						
		0.37	0.34	1.10	1.17	0.91	1.10						
		0.37	0.32	1.04	0.77	0.62	0.91						
		0.57	0.40	1.01	1.08	0.72	0.98						
		0.83	0.45	1.07	0.96	0.76	0.72						

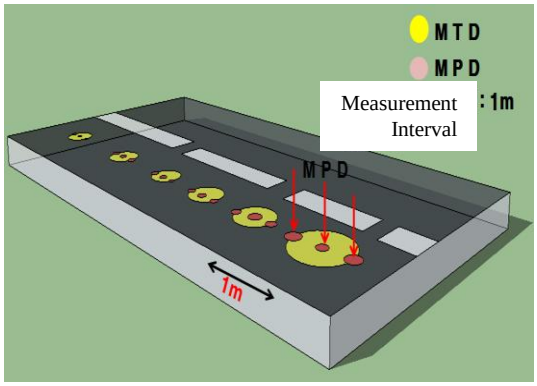


Figure 9. Data Correlation Method of MPD and MTD

5.2 Correlation Analysis of MPD and MTD

Estimated Mean Texture Depth (EMTD) equation was developed in this study through the correlation analysis of MPD and MTD in the asphalt and concrete sections. In the case of concrete sections, correlation analysis was conducted by imposing a certain weighting on the mean texture depth data of more than 1mm to find a method to enhance the reliability of MPD and MTD.

Correlation Analysis of MPD and MTD in Asphalt Pavement Sections

The correlation analysis result on the basis of MPD data using Portable Laser Profiler and MTD data using Sand Path Test showed that MPD and MTD linearly increase as specified on Figure 10 below, with the determination coefficient of 0.51 and p-value of 0.

$$EMTD(AP) = 0.56 * MPD + 0.27,\ R^2 = 0.51, P-value = 0 \quad (3)$$

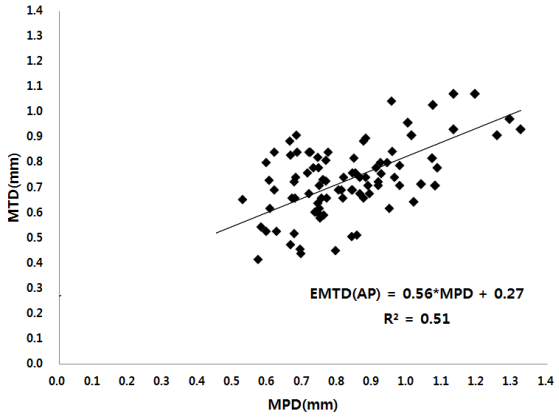


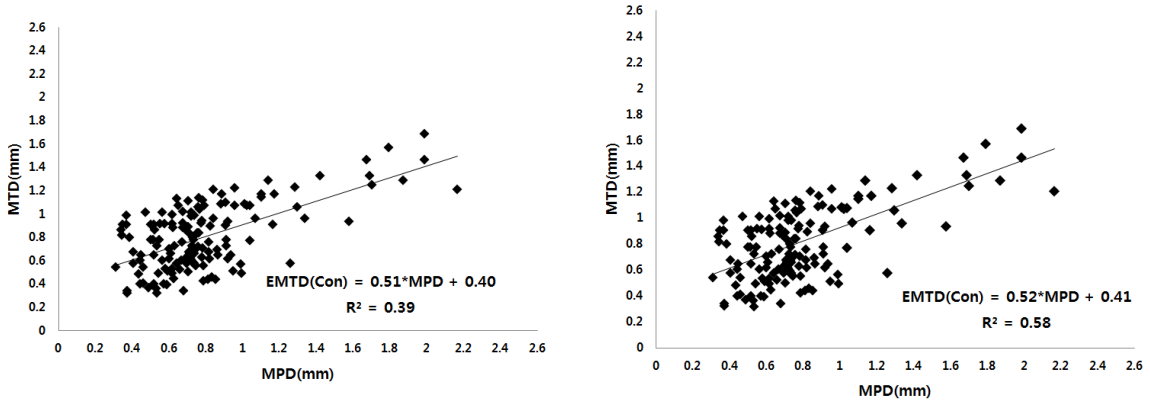
Figure 10. Correlation of MPD and MTD Data on Asphalt Pavement

Correlation Analysis of MPD and MTD in Concrete Pavement Sections

The correlation analysis result on the basis of MPD data using Portable Laser Profiler and MTD data using the Sand Path Test in the concrete sections showed that MPD and MTD linearly

increase as specified on Figure 11(a) below. But the mean texture depth data of 1.0mm~2.4mm range were considered very insufficient compared to that of 0.3mm~1mm. So a certain weighting for data equity was imposed on the mean texture depth data of 1.0mm~2.4mm range to conduct the correlation analysis, and its result is shown on Figure 11(b) below, with the determination coefficient of 0.58 and significance p-value of 0. Considering that the determination coefficient increased from before the weighting was imposed, the further data in 1mm~2.4mm range needs to be additionally secured. The correlation of MPD and MTD with the weighting in concrete sections is described on following Equation 4.

$$EMTD(Con) = 0.52 * MPD + 0.41,\ R^2 = 0.58,\ P-value = 0 \quad (4)$$



(a) Non-imposing of Weighting on Concrete Pavement (b) Imposing of Weighting on Concrete pavement

Figure 11. Correlation of MPD and MTD Data on Concrete Pavement

5.3 Comparison of this Study Result with Foreign EMTD Equation

The comparison of this research result with the foreign research result showed the higher correlation of the MPD and MTD in foreign researches. This may be because the different devices were used in each different research method for MPD and MTD calculation. In particular, Ames Scanner is method of MPD calculation using 3D Laser that can measure the 3-dimensional volume in square sizes using the laser displacement sensors, by dividing the texture volume by the area like the Sand Patch Test. But as the Portable Laser Profiler calculates MPD with the linearly measured texture depth, there is a possibility of some errors during the process of correlation analysis due to the differences of MPD calculation methods and definitions of the measuring devices. Further, the considerably lower equity of the mean texture depth data of more than 1mm than other data seems to produce the lower correlation of MPD and MTD. In foreign researches, the mean texture depth of various ranges of about 0.2mm~3mm was measured with the determination coefficient of 0.89~0.98. In this study, MTD using Sand Patch Test and MPD data using Portable Laser Profiler were intensively measured at about 0.31~1mm range, and comparatively less number of the mean texture depth data was measured at the range of more than 1mm. Accordingly, the domestic research result showed lower correlation than foreign research result.

Table 6. Comparison of EMTD Equation with Result of Other Research

Equipment for MPD	Pavement	Correlation	R^2	Researcher
Ames	AC	$EMTD = 1.1743 \times MPD - 0.0127$	0.98	Fisco (2009)
CTM	AC	$EMTD = 1.2687 \times MPD + 0.0762$	0.89	Fisco (2009)
CTM	PCC	$EMTD = 0.947 \times MPD + 0.069$	0.94	ASTM E 965
Portable Laser Profiler	AC	$EMTD(AP) = 0.66^* MPD + 0.27$	0.51	This Study
	PCC	$EMTD(Con) = 0.62^* MPD + 0.41$	0.58	

6. CONCLUSION

In this study, MPD data were collected using Portable Laser Profiler and MTD data were collected using Sand Patch Test, from the Central Inland Test Road, Second Joungbu Expressway, Central Inland Expressway, Jungang Expressway, Central Inland Branch Line, and Gangneung-Wonju University Campus. The result of correlation analysis of MPD and MTD data collected from the asphalt and concrete pavement sections showed the trend of linear increase of MPD and MTD. To enhance the data reliability of the concrete section, a weighting was imposed on a certain range of mean texture depth data to conduct the correlation analysis, producing following results.

- The result of correlation analysis in the asphalt and concrete sections showed the trend of linear increase of MPD and MTD, which produced the result of $EMTD(AP) = 0.66^* MPD + 0.27$, $R^2 = 0.61$, $P-value = 0$. In the foreign researches, the correlation analysis of MPD and MTD was conducted by variously measuring the mean texture depth data of about 0.2mm~2mm range, but this study carried out the correlation analysis of MPD and MTD by measuring the mean texture depth of 0.6mm~1.4mm range. Therefore, the correlation of MPD and MTD was analyzed to be lower than in foreign researches. Accordingly, the various ranges of the mean texture depth data in the asphalt pavement sections need to be added to the correlation analysis of MPD and MTD.

- The result of correlation analysis in the concrete sections showed the trend of linear increase of MPD and MTD. But the correlation of MPD and MTD showed lower result because of the considerably less number of the mean texture depth data in 1mm~2.4mm range in the concrete sections, so the correlation analysis of MPD and MTD was conducted by statistically imposing a certain weighting, which produced the result of $EMTD(Con) = 0.62^* MPD + 0.41$, $R^2 = 0.58$, $P-value = 0$. Accordingly, the various ranges of the mean texture depth data in the concrete pavement sections need to be added to the correlation analysis of MPD and MTD.

- The correlation analysis of MPD calculated through the Portable Laser Profiler and MTD calculated through Sand Patch Test showed the lower correlation result than the foreign literature, due to following 2 reasons. First, the correlation of the MPD and MTD showed the lower result due to the differences of the measuring methods because, while the Ames Scanner calculates the MPD by dividing the 3-dimensional volume of the mean texture depth that was

measured for many times by the area using the laser displacement sensors, through the similar method as Sand Patch Test, the Portable Laser Profiler method used in this study linearly conducts the MPD calculation during the driving of the test vehicle at the same place where the Sand Patch Test was conducted. Second, the correlation of MPD and MTD showed the lower result because of the lower equity resulting from the considerably less number of the mean texture depth data of more than 1mm than other mean texture depth data. The correlation of the EMTD equation suggested in this study also showed the lower results than the foreign researches, but it is considered to be the statistically safe correlation of MPD and MTD with the very high p-value of 0. If the higher correlation analysis result can be achieved by adding the various ranges of MPD and MTD data to enhance the reliability of MPD and MTD correlation analysis, the estimation of skid resistance and the noises of the tires and roads using the mean texture depth will contribute to the improvement of efficiency of road management.

ACKNOWLEDGEMENT

The study was conducted under the support of a Research Program funded by Korea Institute of Construction & Transportation Technology Evaluation and Planning.

REFERENCES

Kim, Y.G., Lee, S.W., Yoo, T.S. (2008) A Study on optimum mix and exposure skill of the fine-size exposed aggregate concrete pavement, Paper presented at the Annual Conference of Korean Society of Road Engineers, Seoul, Korea, September 30.

Hong, S.H., Kim, J.B., Kim, H.G., Kwon, B.G. (2003) *A study on establishment of pavement function standard and skid control standard.* Korea Expressway Corporation, Seoul

Panagouli, O. K., Kokkalis, A. B. (1998) Skid resistance and fractal structure of pavement surface. *Chaos Solutions and Fractals*, 9(3), 493-505.

Haas, R., Hudson, A. B., Zaniewski, J. (1994) *Modern Pavement Management*. Krieger Publishing Company, Florida.

Snyder, M. B. (2006) *Pavement Surface Characteristics: A Synthesis and Guide. American Concrete Pavement Association Draft Report.* ACPA, Chicago.

ASTM E 961. (2001) Standard Test Method for Measuring Pavement Macro-texture Depth Using a Volumetric Technique.

Flintsch, G. W., Le, E. D., McGhee, K. K., Al-Qadi, I. L. (2003) Pavement surface macrotexture measurement and application, Paper presented at the Annual Meeting of Transportation Research Board, Washington, D.C., January 13-18.

Hoerner, T. E., Smith, K. D. (2002) *PCC pavement texturing: effects on tier-pavement noise and surface friction.* FHWA , Washington, D.C.

Amin, E. G., Shalaby, A. (2007) Mean profile depth of pavement surface macrotexture using photometric stereo techniques. *ASCE,* 0733-947X 133:7(433)

Jackson, N. M. (2008) *Harmonization of texture and skid-resistance measurements,* A Research Report 08-BDH-23, Florida Department of Transportation.

Fisco, N. R. (2009) *Comparison of macro-texture measurement methods.* Master's Thesis, Department of Civil Engineering, Michigan State University.

Mohamed, A.A., Muniandy, R., Hamzah, M.O. (2004) Texture depth determination for stone mastic asphalt. Paper presented at the 3rd Eurasphalt & Eurobitume Congress Vienna.