A Study on the Slip Resistance of Pavement on Pedestrian Facilities

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ABSTRACT

The development of paving technology in Japan has focused mainly on road pavement. The stages of development, including planning, design, construction, maintenance and repair, and evaluation of serviceability, are compiled in the "Pavement Management System", which meets high technical standards. On the other hand, the paving laid on pedestrian facilities such as walkways, bicycle paths, parkways and bridge walkways is used not only by able-bodied people, but also by the elderly, the visually challenged, wheelchair-bound people and occasionally bicycle riders. Due to the wide range of users, performance characteristics based on the universal design philosophy are required, such as slip resistance for pavement for pedestrian use. Slipping and falling accidents while walking are a serious issue particularly for elderly people, and victims may end up bedridden or even die as a result of such accidents. Therefore, it is important to quantitatively evaluate the property of "hard-to-slip" or slip resistance in order to reduce such accidents, as well as assure walking comfort.

Accordingly, as members of the Subcommittee on the Pavement on the Pedestrian Facilities, the Japan Society of Civil Engineers, we studied the slip resistance of pavement on pedestrian facilities. This paper reports the following two results of our study:

1. *The relationship between the slip resistance measurements of various types of pavement constructed on public housing premises and the results of a questionnaire survey conducted among pedestrians*
2. *Discussion on the guidelines for the standard value for slip resistance to be used for pavement on pedestrian facilities*

Keywords: *Pedestrian facilities slip resistance, slip resistance tester, questionnaire survey, standard value*

1. STANDARD VALUE FOR SLIP RESISTANCE FOR THE PAVEMENT ON PEDESTRIAN FACILITIES IN JAPAN

The Tokyo Metropolitan Government has set the standard value for slip resistance by relating the "slipperiness sensed by pedestrians" on various types of pavement on pedestrian facilities to the values measured using the British Pendulum Tester (BPT), as follows. Many local governments across the nation set standard values based on the Tokyo method.

a. At least BPN 40 when wet, as a guideline
   "Design Standard for Highway Works 2012, Tokyo Metropolitan Government, Bureau of Construction" [1)]
b. Preferably BPN 40 or more when wet
   "Ordinance on Planning for a Comfortable Tokyo", Planning and Maintenance of Facilities Manual 2009" [2)]

For interlocking block pavement (IL pavement), the slip resistance value for pedestrian facilities is also set to "BPN 40 or more" in line with the Tokyo method (Interlocking Block Pavement Engineering Design and Build Guidelines, 2007[3)]).

Although there are various slip resistance testers available for testing the pavement on pedestrian facilities other than the BPT, a standard value has not been established for the pavement on pedestrian facilities in Japan.

2. ASSESSING THE SLIP RESISTANCE FOR THE PAVEMENT ON PUBLIC HOUSING PREMISES

Past studies have indicated that it is necessary to assess the slip resistance by using the results from both testers and pedestrian sensory tests. To evaluate the effectiveness of the combined assessment of slip resistance measurement values and the pedestrian sensory tests at a site, we selected a public housing area (located in Toride City, Ibaraki Prefecture) characterized by various types of pavement used on the pedestrian facilities. The measurement using various slip resistance testers was conducted on the pavement on these pedestrian facilities, and a questionnaire survey of users was also conducted. The results were analyzed to determine the relationship between the measured slip resistance values and how the users actually felt when they walked on the pavement.

2.1 Overview of the pavement on public housing premises

Table 1 below shows an overview of the pavement constructed on the public housing premises and surrounding area located in Toride City, Ibaraki Prefecture. Seven types of pavers are shown in **Photos 1** to 7.

Table 1 Overview of the pavement on pedestrian facilities in public housing area

Paver	Symbol	Description	Photo
Colored asphalt	CAs	Reddish	**Photo 1**
Interlocking blocks	ILB	98 (W) × 198 (L) mm Two types of laying patterns	**Photo 2**
Flag blocks	FL1	450 (W) × 600 (L) mm	**Photo 3**
	FL2	Decorative type 300 (W) × 300 (L) mm	**Photo 4**
Tiles	TL	100 (W) × 100 (L) mm	**Photo 5**
Rubber chips	GM1	Block type (factory manufactured)	**Photo 6**
	GM2	Site- installed	**Photo 7**

Photo 1 CAs

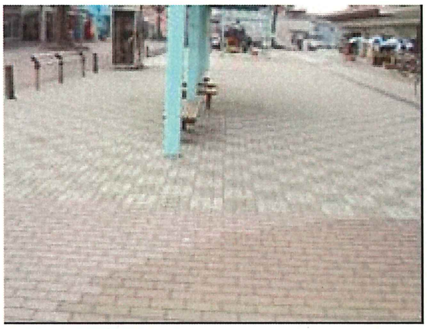

Photo 2 ILB

Photo 3 FL1 (450×600 mm)

Photo 4 FL2 (300×300 mm)

Photo 5 TL

Photo 6 GM1 (block)

Photo 7 GM2 (site-installed)

2.2 Questionnaire survey

A questionnaire survey on the slipperiness of pavement was conducted among actual users of the seven types of pavement shown in Table 1. In the questionnaire, each paver was rated on a scale of 1 to 5 (**Table 2**). Information about the participants, such as gender, age and footwear, was also recorded.

Table 2 Questionnaire survey overview

No.	Question: Is the type of paver on which you are now walking better in terms of slipperiness compared to the neighboring asphalt pavement?	
1	Surface is dry. (Slipping (dry))	Non-slippery .... (2 points) Relatively non-slippery .... (1 point) Moderate............................... (0 points) Relatively slippery .... (−1 point) Slippery................................. (−2 points)
2	Surface is wet. (Slipping (wet))	

2.3 Measurement of slip resistance

2.3.1 Measuring instruments

The following four types of testers were used.

1) British Pendulum Tester (BPT)

The BPT is a portable pendulum tester (**Photo 8**) developed in Britain and it has been widely used indoors and in the field since the early 1960s. Japanese researchers have also been using this tester for many years. The BPT mechanism is as follows. A rubber slider is mounted on the pendulum and the height of the pendulum is adjusted so that the rubber slider contacts the pavement surface at a prescribed length when the pendulum swings down. The height where the pendulum swings back up after sliding across the surface is measured. This swing-back-up height is determined by the energy loss due to the friction produced when the rubber slider is sliding across a pavement surface that is wet with water. A scale is used to measure the swing-back-up height of the pendulum that indicates the friction level, expressed as a British Pendulum Number (BPN) over a range of zero to 140. It's necessary to revise BPN by the road surface temperature according to the pavement materials. It's revised using a different arithmetic expression with asphalting and IL block pavement in Japan.

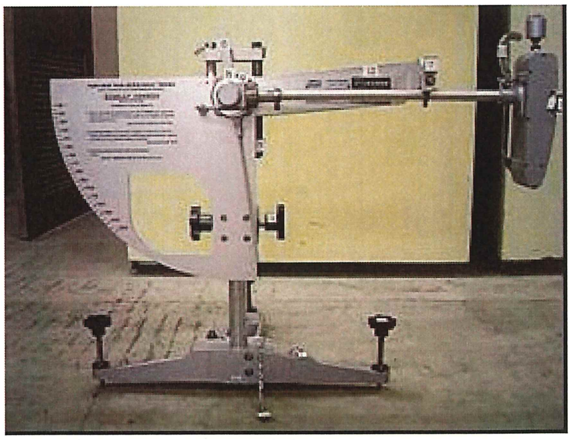

Photo 8 BPT

2) DF tester[4)]

This tester was developed in Japan to measure the slip resistance in a measuring instrument by a completely different method from those used in existing testers, and was adopted by ASTM as standard test method "E1911" in 1998. As shown in Photo 9, the tester has three ASTM E-501-compliant rubber sliders attached to a disk of 350 mm in radius that is linked with the drive disk. The disk and the rubber sliders are first rotated without contacting the pavement surface, and then the rotating disk is lowered when the rotation speed reaches the specified speed to let the rubber sliders contact with the pavement surface being tested. The disk rotation speed is decreased by the loss of energy due to the friction generated between the sliders and the pavement surface. The change in friction force until the disk stops is detected and converted into a coefficient of friction. A characteristic of the DF tester is that it can continuously obtain the change in slip resistance between 0 to 90 km/h for one measuring operation. A water spray unit is attached to enable measurement of a wet pavement surface.

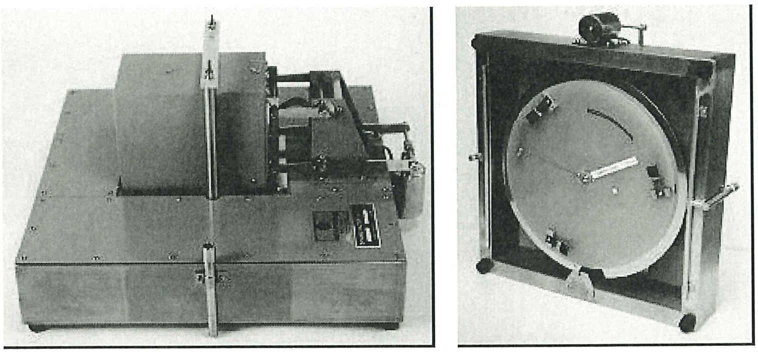

Photo 9 DF tester external view

3) DF tester for walkways[5)]

The DF tester for walkways is a friction wheel type measuring instrument, developed based on the DF tester (**Photo 10**). Two rubber sliders are installed at two locations on the disk of 70 mm in radius, and a load is applied to the disk from above so that the contact pressure becomes 123 kPa. The static and dynamic coefficient of friction is determined from the friction force generated between the plate spring-loaded sliders and the pavement surface when the sliders contact the pavement surface as the disk is rotating (rotational speed of 0 to 15 km/h). For the static coefficient of friction, the drive motor is stopped, the sliders are placed on the pavement surface, and then the motor is started to rotate the disk. The static coefficient of friction is determined at the instant when the disk starts rotating. For the dynamic coefficient of friction, the drive motor is started with the sliders not contacting the pavement surface, the disk drops when the rotational speed reaches the desired speed, and then the coefficient of friction is determined while the disk is rotating.

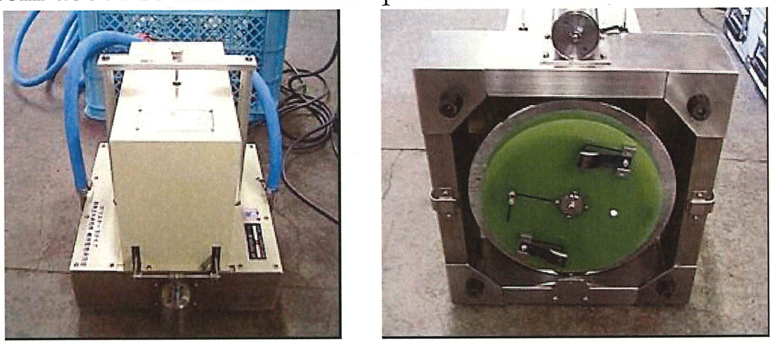

Photo 10 External view of the DF tester for walkways

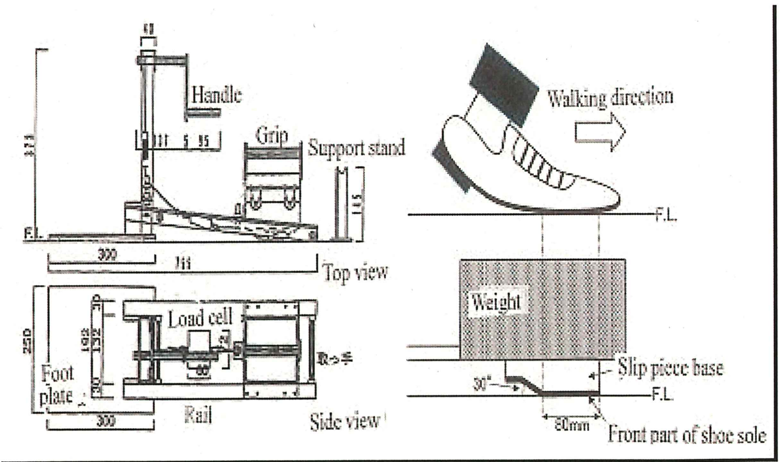

Figure 1 Ono·PPSM

4) Portable pull slip meter (ONO-PPSM)[6)]

The Ono-Yoshioka Pull Slip Meter (O-Y·PSM) is a pull type slip tester. Since the O-Y·PSM was a large device with a height of 80 cm and a length of 150 cm, it was not suitable for on-site testing. The new portable type of slip tester "ONO·PPSM", based on the same principle as the O-Y·PSM, was developed to resolve this inconvenience, as shown in Figure 1. In the measuring mechanism of the O-Y·PSM, the coefficient of slip resistance (CSR) is determined as follows. First, a vertical load of 785 N (80 kgf) is applied to a test specimen of 70×80 mm, the test specimen is tilted at an angle of 18°, the test specimen is pulled at a tensile load speed of 785 N/s (80 kgf/s), and then the maximum load "Pmax" is measured to determine the coefficient of slip resistance (CSR).

2.3.2 Measurement results

1) BPT measurement results

The slip resistance values (BPN) measured by the BPT are shown in **Figure 2**. The IL block and the flag block (450 x 600 mm) pavers met standard value of BPN in Tokyo Metropolitan Government. And those pavers satisfy not only the requirements for a walkway of at least BPN 40 (wet) stipulated in the Interlocking Block Pavement Engineering Design and Build Guidelines,[3)] but the requirements for a road of at least BPN 60 as well. The tile paver fell short of the BPN requirement of at least 40 (wet) at two out of five measurement points, while the rubber chip paver (site-installed) fell short of this requirement at one out of five measurement points. The BPN values of the colored asphalt and rubber chip (block) pavers show fluctuations, and the average BPN value of the flag block (300×300 mm) paver is approximately 42.

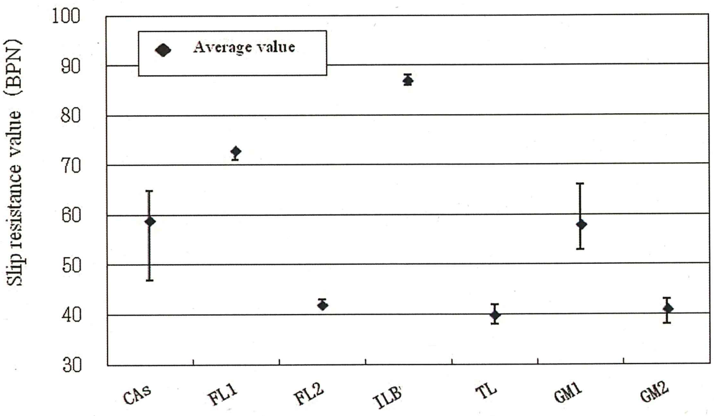

Figure 2 BPT measurement results

2) Measurement results of DF tester

Figure 3 shows the average values of the coefficient of friction (DFT20, DFT60) at 20 km/h and 60 km/h as determined by the DF tester. It was removed from a table because FL2 was Flag blocks with ditches on the surface, and measurement wasn't done. The DFT20 values are larger than the DFT60 values for the colored asphalt, flag block (450×600 mm) and tile pavers, while the DFT60 values are larger than the DFT20 values for the IL block and the rubber chip (block) paver. However, dependence of the coefficient of friction on speed is not observed because of the small differences of 0 to 0.04 between DFT20 and DFT60.

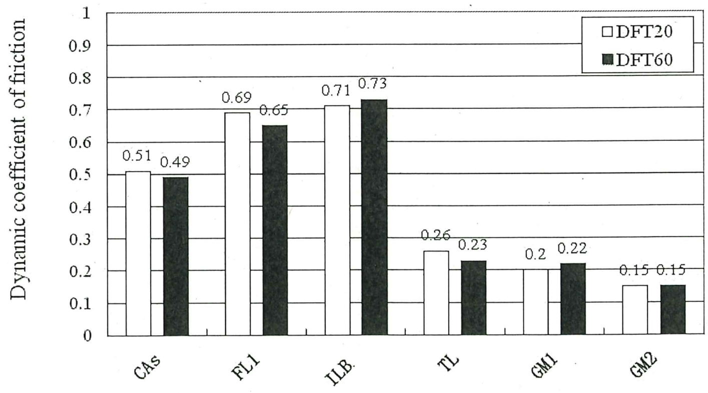

Figure 3 Measurement results of DF tester

3) Measurement results of DF tester for walkways

Figure 4 shows the average values of the dynamic coefficient of friction at 10 km/h (μ10) and the static coefficient of friction (μs) determined by the DF tester for walkways. It was removed from a table because FL2 was Flag blocks with ditches on the surface, and measurement wasn't done. The dynamic coefficients of friction (μ10) in the group of colored asphalt, flag block (450×600 mm) and IL block pavers are large, while the dynamic coefficients of friction (μ10) in the group of tile and two types of rubber chip (site-installed and block type) pavers are about half (or less) that of the former group. The static coefficients of friction (μs) are larger than the dynamic coefficients of friction (μs) for all pavers. The static coefficients of friction (μs) in the tile and two types of rubber chip pavers (site-installed and block type) are at least two to four times larger than their dynamic coefficients of friction (μ10). Only the colored asphalt, flag block (450×600 mm) and IL block pavers meet the requirements for the minimum coefficient of friction of "0.5μ", regarded as the lowest value for people to walk without slipping, in both the dynamic and static coefficients of friction (μ10 and μs).

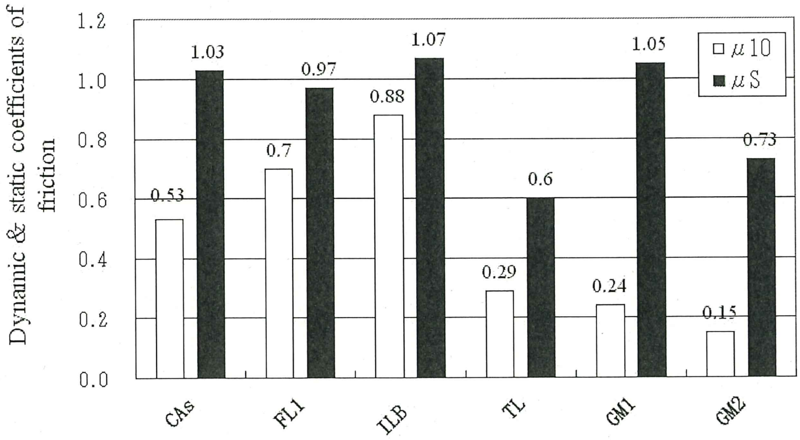

Figure 4 Measurement results of DF tester for walkways

4) Measurement results of portable pull slip meter (PPSM)

The coefficients of slip resistance (CSR') determined by the PPSM are shown in **Figure 5**. All pavers meet the "guiding standard value" of 0.4 to 0.9, set for "People to Walk with Footwear" provided by "Ordinance on Planning for a Comfortable Tokyo". Regardless of the pavement surface condition, the CSR' values of the tile and rubber chip (site-installed) pavers are low, where the tile shows the lowest value in all pavers for both dry and wet conditions. Relatively large CSR' values are shown in the concrete pavers, such as the IL blocks and two types of flag blocks, and the colored asphalt. A large difference in values is shown between the site-installed rubber chip and the block type rubber chip pavers. The CSR' shows small differences between the dry and wet conditions in all pavers. In addition, the CSR' shows a tendency towards larger values in wet conditions except for the flag block (300×300 mm) and tile pavers.

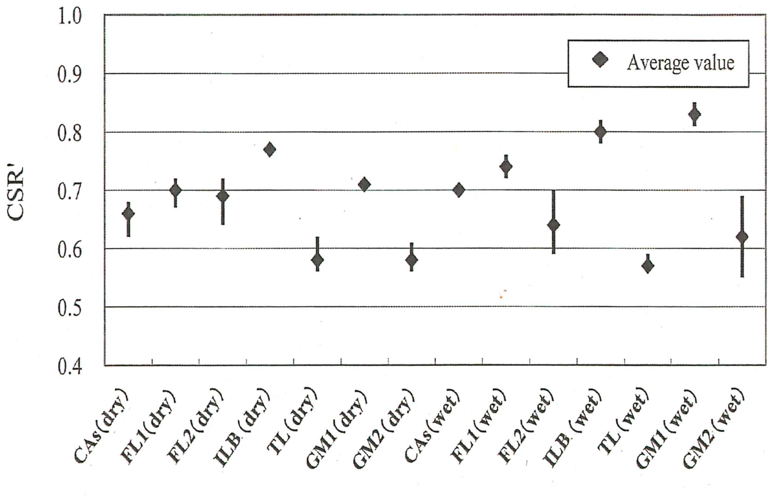

Figure 5 PPSM measurement results

2.3.3 Correlation among various test results

Table 3 shows the correlation matrix of test results obtained from the seven types of test pavers with the four types of testers under study. The results indicate a high correlation between the BPN obtained from the BPT and the test values obtained from the DF tester, the DF tester for walkways and the PPSM. Also, a high correlation was observed between the PPSM and the coefficient of static friction "μs" determined by the DF tester for walkways.

Table 3 Correlation matrix of test results

Single correlation	BPN	DFT (20)	DFT (60)	μ10	μs	CSR'(dry)	CSR'(wet)
BPN	1.00						
DFT (20)	0.86	1.00					
DFT (60)	0.90	0.99	1.00				
μ10	0.91	0.96	0.97	1.00			
μs	0.80	0.55	0.60	0.58	1.00		
CSR'(dry)	0.77	0.61	0.68	0.72	0.83	1.00	
CSR'(wet)	0.76	0.40	0.47	0.46	0.88	0.77	1.00

2.4 Relationship between slip resistance and questionnaire survey results

2.4.1 Relationship between slip resistance measurements and questionnaire survey results

The relationship between the overall slip resistance measurement results of all pavers and the questionnaire results were studied. The rubber chip paver, however, was excluded from the study due to data unreliability caused by repair work that was performed after the slip resistance test and before the questionnaire survey.

The pavement becomes slippery when the pavement is wet. In the graphs of **Figures 6** to **11**, the relationship between the questionnaire survey results of "Slipping (wet)" shown in **Table 2** and the slip resistance measurements are illustrated.

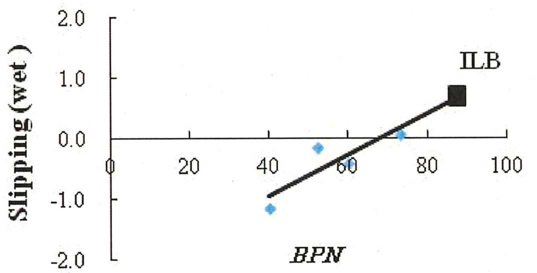

Figure 6 Relationship between slipping (wet) and BPN

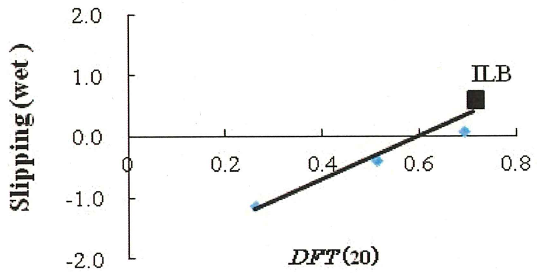

Figure 7 Relationship between slipping (wet) and DFT (20)

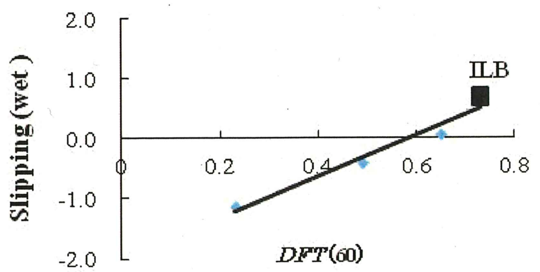

Figure 8 Relationship between slipping (wet) and DFT (60)

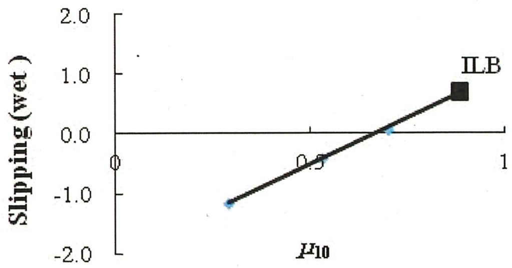

Figure 9 Relationship between slipping (wet) and μ10

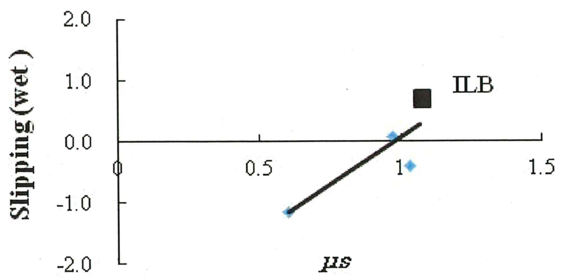

Figure 10 Relationship between slipping (wet) and μs

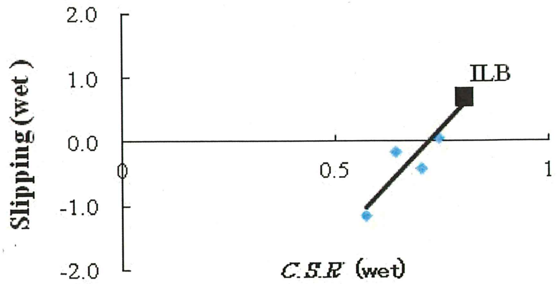

Figure 11 Relationship between slipping (wet) and CSR' (wet)

2.4.2 Quantitative evaluation of slipperiness

As shown in **Table 2**, "Relatively slippery" is scored as "−1" point, and thus it is reasonable to consider that pedestrians feel they are "slipping" when the pavement is "−1" point or less. **Table 4** shows the slip resistance values determined using the relational expressions shown in **Figure 6** through **Figure 12** when "Slipping (wet)" is "−1" point.

Table 4 Slip resistance values when slipping (wet) is "−1"

Item	BPN	DFT (20)	DFT (60)	μ10	μs	CSR'(wet)
Value	39	0.31	0.29	0.34	0.65	0.57

2.4.3 Consistency among quantitatively evaluated slipperiness values and past references

1) BPT

The BPN determined by the BPT is "39" and this agrees with the conclusion by Tanaka et al.[7] that slipperiness occurs in pavement with a BPN of 40 or less (their reference was used as evidence for stipulating the standard value in the abovementioned ordinance of the Tokyo Metropolitan Government).

2) DF tester

According to a past study,[8] a coefficient of friction of at least "0.5" would be "practical". The values determined by testing are 0.31 and 0.29 at 20 km/h and 40 km/h, respectively, each lower by about 40%. However, the authors of the past study may have judged that a coefficient of friction of 0.5 or more would be non-slippery. This recognition gap could be the reason for the difference in values.

3) DF tester for walkways

There is no established standard value for the coefficient of friction values determined by the DF tester for walkways. If the standard value for the DF tester is used as a substitute, the coefficient of friction at 10 km/h is calculated to be 0.34 (lower by about 30%) and the static coefficient of friction 0.65 (higher by 30%).

4) Portable pull slip meter

The values of CSR' (dry) and CSR' (wet) determined by this study agree with the conclusion by Kuge et al.[8] that a CSR between 0.5 and 0.8 is preferable.

2.5 Assessing the slip resistance of IL block pavement

Compared to the other pavers, the IL block pavement achieved high slip resistance values in the tests using the BPT, DF tester, DF tester for walkways and PPSM. In addition, IL block pavement was assessed as "Moderate", "Relatively non-slippery" or "Non-slippery" in the questionnaire survey. Accordingly, the IL blocks proved to be "hard-to-slip" pavers, based on the assessment using the slip resistance tester and also the pedestrian sensory test.

3. CONCLUSIONS

In designing the pavement for pedestrian facilities, it is essential that the design serves the original purpose of providing people with a safe and comfortable surface for walking or traveling. However, the guidelines or target values for designing the pavement are not currently specified. Thus, there is an urgent need to quantitatively evaluate the "slipperiness" and to assure the "slip resistance" performance of pavement when planning and maintaining walkway spaces.

In this study, to examine the relationship between slip resistance measurements and how actual users feel when walking on the pavement, we selected a public housing area where different types of pavement were used on pedestrian facilities, and we conducted measurements using various slip resistance testers, as well as a questionnaire survey among the users regarding the slip resistance. Based on the relationship between the measurements and the questionnaire survey results, the slipperiness was rated. As a result, a BPN of "39" or less by the BPT is judged as slippery, which is about the same level as the standard value stipulated by the Tokyo Metropolitan Government. Since relatively close correlation was observed between the BPN and the values determined by other slip resistance testers, such as the DF tester, DF tester for walkways and portable pull slip meter, measurement values other than the BPN can also be effectively used as a guide for judging the slipperiness of the pavement on pedestrian facilities.

Based on this study, we issued the "Pavement Engineering Library, An Introduction to Pedestrianized Pavement " [9] published by the Japan Society of Civil Engineers in 2014. We will continue their studies to establish a performance indicator and the target values required for the pavement on pedestrian facilities.

4. REFERENCES

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