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STUDY ON EVALUATION OF PAVEMENT SMOOTHNESS ON SIDEWALK FOR PEDESTRIANS

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Note: The following is the notation used in this paper: (.) for decimals and (   ) for thousands.

Summary

In Japan, the construction of universal-design sidewalks has been popular since a related law was enacted in 2000. The purpose of this law is to help the mobility impaired, such as elderly and disabled people and children, to use sidewalks and public spaces safely and comfortably.

The requirements for safe and comfortable sidewalks for pedestrians include surfaces without height differences to prevent falling over, and a smooth surface to eliminate annoying vibration for wheelchair users. These requirements concern the smoothness of the pavement, but no proper evaluation method has been specified. The Japan Interlocking Block Pavement Engineering Association (JIPEA) established a special committee to consider measures for ensuring and measuring smoothness, for concrete block pavement on sidewalks for pedestrians. This paper describes the results.

Regarding the most suitable procedure for measuring the smoothness of the pavement surface, various methods were tested, and a method using a 1 m straight edge was selected. This straight edge is equipped with digital vernier calipers on a movable measuring section to measure the distance to the pavement surface at regular intervals. Test measurements using this device were repeatedly performed at sites to determine the optimum measurement procedure and evaluation method. As a result, it was decided to use a procedure that requires two or three measurement cycles, each performed at 11 points spaced 100 mm apart per site, and an evaluation method using the standard deviation and maximum height difference among the points spaced 100 mm apart. The authors suggest that the standard deviation should be 2.4 mm or less and the maximum height difference should be 3.0 mm or less.

1. INTRODUCTION

In Japan in November 2000, [Law Related to Improvement of Smooth Moving for the Aged and the Disabled using Public Transportation Systems (Traffic Barrier-free Law)] was enforced and it was made an obligation to prepare for securing convenience and safety when such weak people as the aged, children, the disabled and pregnant walk in a public space like walkways and railroad stations. From the urban design point of view, the frequent road preparation adopting universal design was carried out in order to form a comfortable public space such as walkways and plazas where crowds get together.

Under these backgrounds, the following conditions are required for walkway paving materials;

- Should be safe and comfortable
- Should be economical and easy to obtain
- Should be ecological
- Should have good landscape property

Interlocking block pavement (hereinafter called "block pavement") has been used in many places as it is a low cost landscape material with superb colors and design property but an argument about the ruggedness of pavement surface is going underway as faulting and joints are pointed out to be uncomfortable. Japan Interlocking Block Pavement Engineering Association (JIPEA) organized [Study Committee for Evenness Evaluation] to discuss how to measure and evaluate the evenness of block pavement.

2. MEASUREMENT OF WALKWAY EVENNESS

2.1 Walkway Evenness

Walkways are a public space which is used not only by general healthy people but by the weak such as old people, children and the disabled and these people independently evaluate the evenness of walkways. The ruggedness of the road surface which is felt by pedestrians is summed up in Table 1. General healthy people can recognize the ruggedness by visual observation within a certain range or confirm the ruggedness by observing water ponds on the road after rain. People using a bicycle or a wheelchair sense the ruggedness of fine joints and faulting from the vibrations through the wheels or from wheelchair which inclined due to a sharp crossfall. Since the evenness of the road surface is felt and evaluated differently by general healthy people, the weak and the disabled, we discussed a satisfactory evaluation method for the evenness common to both people.

Table 1. Sense of Walkway Passersby.

STATUS OF PASSERSBY	WHEN RUGGEDNESS ON THE ROAD SURFACE IS FELT
Pedestrians	Visual recognition of faulting Ponds appeared on the road surface after rain A big crossfall
Bicycle riders and Wheelchair users	Vibrations from block joints Area where vehicles are allowed (crossfall) Ruts on walkways Bordering area between motorways and walkways

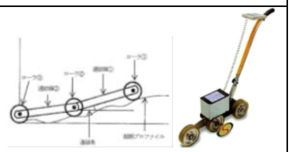
2.2 Study on the Method to Evaluate Evenness of Walkways

Since walkways are a public space where different people utilize for different purposes, an evaluation method and evaluation contents including situations and purposes of usage are required when the evenness of walkways is to be evaluated. Therefore, we discussed easiness of the measuring method, generality of the data and the evaluation results by carrying out measuring on the actual road surface mobilizing currently used domestic testing devices. The evenness of walkways has often been evaluated with the disabled as the central figure. In such a case, an evaluation method by an accelerometer was applied for the vibrations and impacts that the body receives through an apparatus like a wheelchair.

This report, on the other hand, tries to use various ways such as a method to measure the vibrations that the body receives and a method to measure the ruggedness conditions of the road surface. The following 5 methods were studied:

1. A wheelchair testing device with an accelerometer mounted on the front wheel axis for evaluating ruggedness by the vibrations sensed when the wheelchair passes on the pavement.
2. A testing device to directly measure ruggedness of the road surface using profiler and measuring continuous ruggedness by step-by-step biangular method.
3. A ruggedness measuring method by calculating the distance from the horizontally pulled leveling cord, which is a common method conventionally used for block pavement.
4. A 3 m profile-meter method to measure the ruggedness of motorways.
5. To measure the distance from the metal scale put on the pavement surface to the pavement surface.

Table 2. An Outline of the Testing Devices and Problems in Measuring.

MEASURING METHOD	OUTLINE OF MEASURING METHOD	PROBLEMS AT THE MEASURING TIME ON THE WALKWAY	PHOTO
Using wheelchair and Vibratory accelerometer	To measure vibration wave shape by the vibratory accelerometer mounted on the front wheel of the wheelchair	* Not conform to the ruggedness of the road surface as evaluated by vibration wave shape *Vibration is sensed differently by each individual	
Small Profiler (Step-by-step biangular method)	Device of a rod connected to roller; method to measure road surface ruggedness by inclination angle when operated	*The device is expensive *Analysis on site is hard	 **Ruggedness detector**
Method by Leveling Cord	Method according to [A Handbook for Pavement Testing]	*Big deviations of the measured value *Independent measuring is hard	
3 m Profilometer	Method according to [A Handbook For Pavement Testing]	*Device is too big *Measuring is not easy *Not fit to the style of pedestrians on walkway	
Scale to measure Ruggedness Volume	Method to measure height difference of the road surface from the set point using a 1 m linear ruler mounted with electronic slide calipers	*Poor accuracy of measurement *Frequency of measuring needs to be selected	

An Outline of the Testing Devices and Problems in Measuring are shown in Table 2. The committee also discussed the status of evenness measuring devices for block pavement by actually walking with the measuring devices and wheelchairs. The results are as follows:

1. Since pedestrians tend to walk looking at the direction they want to move to, they can visually observe the ruggedness ahead and they can avoid an obvious ruggedness. It is hard to assume

that the entire road is rugged. Therefore, it is possible to evaluate the evenness within the range of one step rather than measuring the evenness of continuous long distance.

2. A step and a landing point are different according to an individual, it is more practical to measure the evenness in the flat range than to measure it by the walking path.

3. Since machine molded concrete paving blocks have an even surface, the evaluation of ruggedness of the block pavement means faulting between the adjacent blocks.

4. Block pavement has joints and when a wheelchair passes on the joints it rattles but this rattling is taken for granted and it is more favorable not to consider the joints as ruggedness but to consider the faulting of blocks as ruggedness. Crossfalls widely fluctuate left and right where bumps occur near curbs or by tree roots, which makes wheelchair operation unsteady giving uncomfortable and restless feelings.

Judging from the results mentioned above, the evaluation of the ruggedness of walkways should be done within a flat range rather than the continuous walking path and we decided to use a method of measuring the faulting between the adjacent blocks in the transversal direction.

2.3 Selection of Measurement Testing Devices

Block paving materials do not have ruggedness on the surface. That ruggedness takes place on the pavement surface constructed under the standard means that there is faulting between the adjacent blocks and we thought that the evenness can be evaluated if the faulting is detected. We also thought that the evenness can be evaluated if several points are measured on one road taking an area to be constructed by a worker per day into consideration. We discussed the measuring method using [Ruggedness volume measuring scale] which we considered to be the best measuring method to measure the faulting between the adjacent blocks.

3. STUDY ON MEASURING METHOD

3.1 Testing Conditions

The measuring method and evaluation method were discussed in order to evaluate possibility for practical use of the testing devices. Table 3 shows the conditions of the measured points. The measurement was implemented at one point per 50 m^2 assuming that a standard construction area is 50 m^2 per day.

3.2 Testing Method

The testing device consists of the scale part which is aluminum box structure and the measuring part which measures the height by digital calipers sliding the scale part. The scale is calibrated so that the measurement is done at arbitrary positions. The measuring was carried out in the transversal and longitudinal directions from the measuring point as it was based on the flat range measuring. The measuring was carried out in a manner that the scale was horizontally set after the starting position had been fixed and sliding every 100 mm, the distance from the calipers to the pavement surface was measured taking the smallest dimensions of the block into consideration.

Setting the starting and ending points as the standard values, the faulting of the blocks were set to be the value subtracting the standard values from the height differences measured at every 100 mm pace. The standard deviation σ was acquired from the formula (1) and σ was set to be the volume of ruggedness of the road surface.

Table 3. An Outline of the Surveyed Sites.

SITE NAME	KIND OF BLOCK	SIZE OF BLOCK(mm)	LAYING PATTERN	KIND OF MEASURING DEVICE
Block pavement	Rectangular straight	200 x 100	Herringbone bond	Ruggedness volume measuring scale
Block pavement	Rectangular straight	200 x 100	Herringbone bond	Ruggedness volume measuring scale
Permeable asphalt pavement	—	—	—	Ruggedness volume measuring scale
Block pavement	Rectangular straight	200 x 100	Stretcher bond	Ruggedness volume measuring scale
Block pavement	Rectangular straight	200 x 100	Herringbone bond	Ruggedness volume measuring scale
Block pavement	Rectangular corrugated	240 x 120	Stretcher bond	Ruggedness volume measuring scale
Block pavement	Rectangular straight, flags	200 x 100	Stretcher bond	Ruggedness volume measuring scale
Block pavement	Rectangular straight,square	200 x 100	Herringbone bond, round	Ruggedness volume measuring scale
Block pavement	Rectangular straight	200 x 100	Stretcher bond	Ruggedness volume measuring scale
Block pavement	Rectangular straight	200 x 100	Stretcher bond	Ruggedness volume measuring scale
Block pavement	Rectangular straight	200 x 100	Herringbone bond	Ruggedness volume measuring scale
Block pavement	Rectangular straight	200 x 100	Herringbone bond	3m Profilometer
Block pavement	Rectangular straight	200 x 100	Herringbone bond	Leveling cord
Block pavement	Flags	300 x 300	—	Ruggedness volume measuring scale
Block pavement	Flags	300 x 300	—	3m Profilometer
Block pavement	Flags	300 x 300	—	Leveling cord
Block pavement	Trapezoid	110 x 110/80	Round	Ruggedness volume measuring scale
Block pavement	Trapezoid	110 x 110/80	Round	3m Profilometer
Block pavement	Trapezoid	110 x 110/80	Round	Leveling cord

Figure 1. Ruggedness Volume Measuring Scale.

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Where:

σ : Volume of ruggedness

d : Value of faulting

n: The number of data(= 11 data)

The number of faulting and volume of ruggedness were calculated from the values measured at transversal and longitudinal directions respectively from the arbitrarily set standard points and the respective mean values were to be the index of ruggedness of the road surface. The index shown in Table-4 was set up based on the index obtained as above and the conventional one for motorways to study the test value.

Table 4. Setting-up of the Evaluation Standard.

EVALUATION ITEM	EVALUATION STANDARD
Volume of ruggedness: σ(mm)	Less than 2.4 mm
Maximum faulting volume at 100 mm pace (mm)	Within ±3.0mm

4. RESULTS OF THE SURVEY AND SUTUDY

4.1 A Study on Measurement Accuracy

Large measuring deviations at different measuring points tend to be seen for block pavement as it has various textures on the pavement surface. The faulting on the road surface was measured with a 10 mm diameter steel cap mounted on the digital calipers assuming porous pavement like permeable pavement and adopting pined heel shape of lady's shoes which has the smallest area when the shoes contact the ground.

Figure 2 shows fluctuations at the actual measurements with and without a steel cap. The steady measurement results can be obtained by using a steel cap even on the porous surface like permeable pavement.

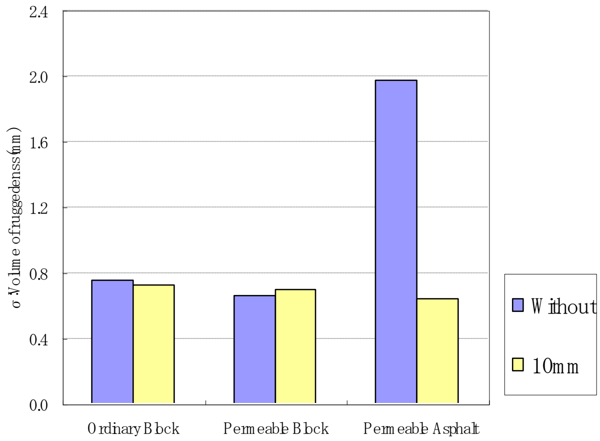

Figure 2. Measured Results of Measurement Accuracy.

4.2 5.2 Study on Measurement Frequency

We set the measuring frequency at one time per 50 m^2 considering the construction area per day but we checked up the necessary measuring frequency per a road as the frequency largely increases if the road gets long. The measuring was carried out on three roads selecting 2, 3 and 5 points respectively and the measured values were checked up. The results are shown in Figure 3. The standard deviations of the volume of ruggedness approached more to the mean values as the measuring time increases but the difference of the values were only 0.4 mm compared to the case where the measuring points were fewer. Therefore, we judged that the evenness of roads could be evaluated at 2 to 3 points per road taking the saving of measuring time into consideration.

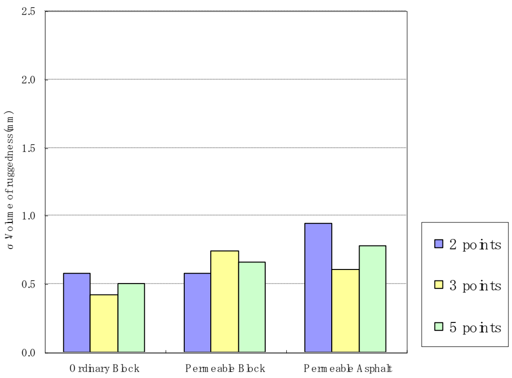

Figure 3. Analyzation Results of Measurement Frequency.

4.3 A Study on the Standard Value of Evaluation

We discussed the standard value as there was an opinion that it was difficult to maintain the evenness standard value of evaluation for walkways of [less than 2.4 mm].

Figure 4 shows the relations between the maximum volume of faulting and volume of ruggedness measured at 10 cm pace. It was found from the results that there were strong relations between faulting and the volume of ruggedness. Therefore, the evenness standard of walkways can be maintained if the construction is done according to the standard.

$$y=0.44x + 0.06 \quad \textbf{(2)}$$

Where:

y = Volume of ruggedness (mm)

x = Maximum volume of faulting at 10 cm pace

5. CONCLUSIONS

Based on the results mentioned above, JIPEA suggests the scale for measuring the volume of ruggedness as the evaluation method of evenness of block pavement. The evaluation standard is to use the values shown in Table 5 and the specifications of the measuring method of the measuring scale for volume of ruggedness are shown in Table 6.

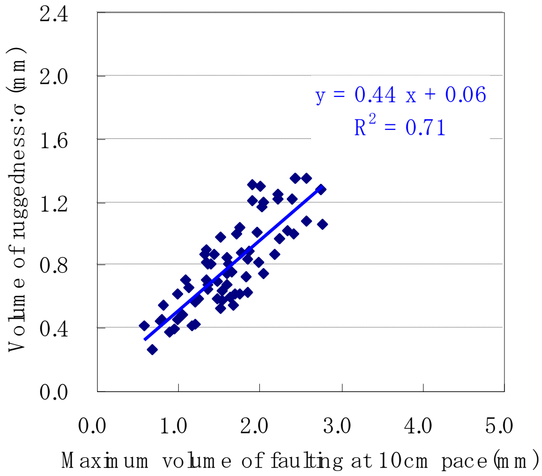

Figure 4. Relations between Maximum Volume of Faulting and Volume of Ruggedness.

Table-5 Standard Values of Evenness Evaluation for Walkways

EVALUATION ITEM	STANDARD VALUES OF EVALUATION	
Volume of Ruggedness: σ (mm)	Less than 2.4 mm	
Maximum Volume of Faulting at 10 cm pace (mm)	Level A	Within ± 3.0 mm
	Level B	Within ± 5.0 mm

Table-6 Measuring Method of Scale for Volume of Ruggedness

ITEM	SPECIFICATION
Measuring Device	Measuring Scale for Volume of Ruggedness
Measuring Object	Block Type Paving Materials for Walkways
Measuring Frequency	2~3 Point s per Road
Measuring Direction	Transversal Direction, Longitudinal Direction
Point per One Measurement	11 points (100 mm pace)
Evaluation Standard	Conforming to Evaluation Standard of Evenness for Walkways

The possibility of ruggedness taking place on interlocking block pavement is influenced by technical immaturity of laying blocks and construction accuracy of curbs and base courses. According to the results of the tests described in this paper, we could confirm the co-relations between the evaluation standard values of volume of ruggedness and the maximum volume of faulting measured at 100 mm pace when the measuring scale for volume of ruggedness was used. But there are also other different shapes and materials used for walkways pavement than interlocking blocks. The testing devices mentioned in this paper aim at the method to evaluate evenness measuring the faulting between blocks as to the block paving material having an even surface. More blocks are used for walkways pavement and it is required to set up regulations for the functional index matching the social environment.

Finally, I would like to thank all the people and JIPEA members for their warm cooperation given to complete this study.

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