EVALUATION OF PERFORMANCE OF PERMEABLE INTERLOCKING BLOCK PAVEMENTS

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ABSTRACT

Drainable or permeable pavement systems are rapidly gaining popularity in Japan because of the high level of precipitation and the growing need for measures against the deteriorating road environment. In the field of interlocking block pavements, highly-porous permeable systems are expected to be increasingly used for constructing walkways and other facilities. However, various issues remain to be solved, including the establishment of criteria for evaluating the functions of the pavement system. This paper evaluates the permeability performance of permeable interlocking block pavement.

The following findings were obtained:

- Loss of joint sand during the on-site permeability test hardly affected the permeation rate. On the basis of these results, there is no need to precisely specify the measurement points for the on-site permeability test of permeable interlocking block pavement.
- A correlation was observed between the permeability coefficient obtained in the laboratory test and the permeation rate obtained in the on-site test. It is possible to select a reasonable permeable interlocking block product that satisfies the requirements for permeable pavement.
- The permeability performance of cushion sand hardly affected the permeation rate in the on-site permeability test.
- Joint sands having a larger permeability coefficient value tended to have a higher permeation rate, but not significantly.

With its many continuous pores, permeable interlocking block pavement offers special characteristics such as water drainage and noise-reduction effects. The authors will continue to develop an appropriate method for evaluating its functions in order to encourage its application.

1. INTRODUCTION

Drainable or permeable pavement systems are rapidly gaining popularity in Japan where there is a high level of precipitation and a growing need for environmental measures to counter society's high dependence on the automobile. The reason behind the popularity of these systems is their special characteristics due to their highly-porous structures, namely water drainage and noise-reduction effects that help improve the roadside environment. Much effort has been made to develop and improve permeable porous interlocking blocks in the field of interlocking block pavement systems ("ILB pavement"). Although such pavements are mainly used for walkways at present, its field of application is expected to broaden.

Nevertheless, many issues remain to be solved. For example, no criteria have been established for evaluating the durability of the blocks and pavement, or the functions of the pavement.

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Furthermore, due to the lack of a relevant test method for evaluating the permeability performance of permeable ILB pavement, on-site permeability tests designed for other systems such as drainable pavement must unavoidably be used, but this raises various problems in practice.

This paper reports on new insights into evaluating the permeability performance of permeable ILB pavement.

2. PROBLEMS OF EXISTING EVALUATION TECHNIQUES

This section describes the existing evaluation techniques and their problems.

2.1 Permeability Test Methods

There are currently two test methods used for evaluating permeable performance in Japan: laboratory permeability testing for evaluating the permeable performance of permeable interlocking blocks at the individual product level, and on-site permeability testing for evaluating the pavement as a system.

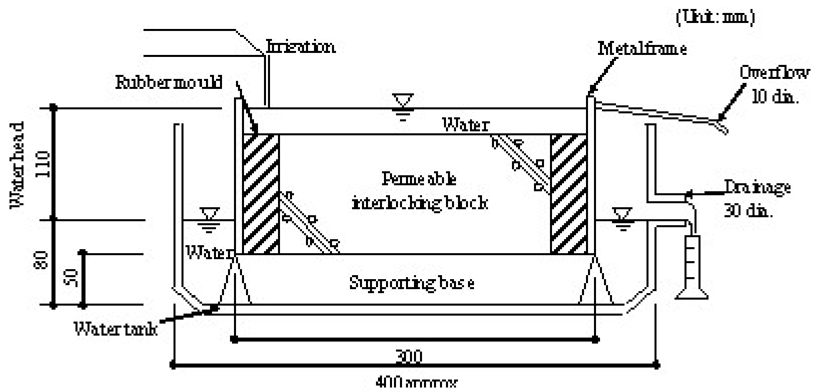

Figure 1. Schematic drawing of laboratory permeability testing of interlocking blocks.

2.1.1 Laboratory permeability testing

At the individual product level, the permeability coefficient of a permeable interlocking block is measured pursuant to the “Permeability Performance Test Method for Interlocking Blocks (JASS 7 M101)”. The test apparatus is outlined in Figure 1.

2.1.2 On-site permeability testing

According to the “On-site Permeability Test Method (Pavement Test Method Manual: Supplementary Volume)” [3], the time needed for 400 millilitres of water, which is released from a container firmly attached to the ground, to permeate into the ground, is measured and expressed as the permeation rate per 15 seconds (millilitre/15 seconds). Figure 2 outlines the test apparatus.

2.2 Dimensional Differences Between the Test Apparatus and Interlocking Block Tested

As shown in Figure 2, in the on-site permeability testing on permeable ILB pavement, the container is firmly attached to the ground at its bottom, which is a circular surface of 150 cm in diameter. However, the standard permeable interlocking blocks have a rectangular surface measuring about 100mm x 200mm, so the narrow side of the block is smaller than the diameter of the container. Therefore, measurement of the permeation rate includes the block and its joints, regardless of the position of the test apparatus, as shown in Figure 3. While joints are indeed an integral part of ILB pavement, they are rarely designed with conscious attention to permeability, unlike in the design of the blocks. Instead of permeating water, the joint sand in some joints is carried away by the running water during the test, which may impair the accuracy of test results due to accelerated permeation or other factors.

Because this technique was originally developed for evaluating the permeability performance of permeable/drainable asphalt pavements, it was considered important to verify its applicability to ILB pavement.

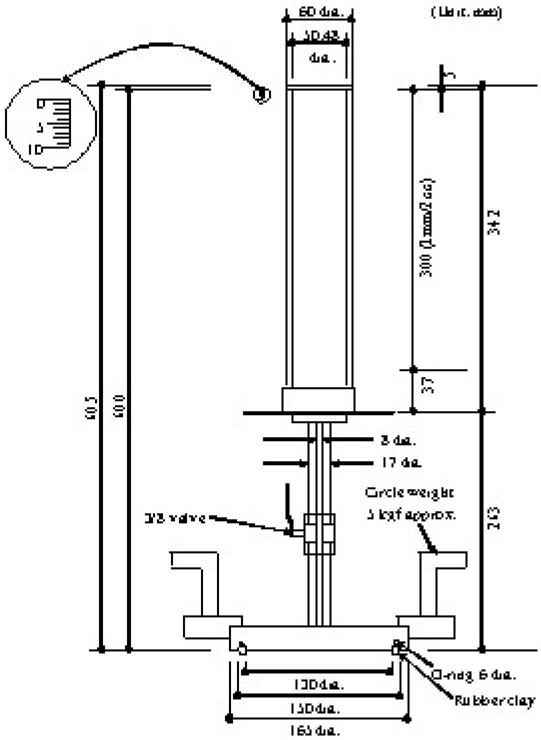

Figure 2. On-site ILB pavement permeability test apparatus.

2.3 Reference Values of Permeability

For permeable interlocking blocks and all pavement systems with permeation effects ("permeable pavement") including permeable ILB pavement, reference values have been established for comparison against the measured values obtained in the tests described above. Table 1 shows the reference values adopted in Japan. As described in Section 2.2, there is no theoretical linkage between the method for evaluating the permeability performance of permeable interlocking blocks and that for permeable pavement; and no correlation between the test results for blocks and those for pavement has been proved. Therefore, even when permeable blocks that have been tested and shown to meet the required performance are used, there is no guarantee that the permeable pavement constructed with them will satisfy the requirements for the system as a whole. It is desirable to be able to select appropriate blocks that have been proved to constitute a permeable pavement system meeting performance requirements, and so it is necessary to clarify the correlation between reference values.

Table 1. Comparison of reference values.

Group	ILB	Permeable pavement
Heavy-duty driveways	1 x 10^{-2} cm/s or more	1,000 ml/15 s
Other driveways and walkways	1 x 10^{-2} cm/s or more	300 ml/15 s

3. OUTLINE OF THE TEST

3.1 Materials

3.1.1 Interlocking Blocks
The interlocking blocks used in the test had a common straight-sided rectangular shape of 100 mm x 200 mm.

Other factors such as the type of aggregates, mixture proportions and density were varied, and the blocks were chosen to have different levels of permeability. Based on the laboratory permeability testing described in Section 2.1-(1), the blocks were categorized into the groups shown in Table 2.

Table 2. Results of permeability testing on permeable interlocking blocks, categorized by group.

	Group							
	A	B	C	D	E	F	G	H
Permeability coefficient (cm/s)								
Mean	0.052	0.069	0.088	0.273	0.281	0.361	0.457	0.535
Maximum	0.059	0.079	0.095	0.346	0.328	0.378	0.469	0.543
Minimum	0.047	0.056	0.081	0.167	0.207	0.343	0.442	0.526
Median	0.051	0.069	0.091	0.295	0.290	0.364	0.457	0.536
Standard deviation	0.004	0.006	0.006	0.058	0.039	0.013	0.009	0.006
Coefficient of variation (%)	7.7	8.7	6.8	21.2	13.9	3.6	2.0	1.1

Table 3. Quality standards for joint sand.

Requirements	Standard
Maximum particle size	2.36 mm
Particles passing 0.075 mm sieve	10% or less

3.1.2 Joint and Cushion Sands
The criteria for selecting joint and cushion sands for the test were that they were products commonly available in Japan and have properties well within the specified values. In addition, to confirm their impacts on the permeability performance, they were given different maximum particle sizes and then sorted to have a single size to ensure a constant permeability performance. In the test, the same type of sand was used for both the joint and cushion sands. The quality standards of joint and cushion sands in Japan are shown in Tables 3 and 4, respectively, and the properties of the sand used in this test are shown in Table 5.

Table 4. Quality standards for cushion sand.

Requirements	Standard
Maximum particle size	4.75 mm or less
Particles passing 0.075 mm sieve	5% or less
Fineness modulus	1.5 to 5.5

Table 5. Properties of Joint and cushion sands used in test.

	Silica sand No.2	Silica sand No.3	Silica sand No.5	Remarks
Grading (%)				
4.75 mm	100			
2	86.3	100	100	
0.85	0.1	12.5	95.8	
0.425		0.9	38.9	
0.25		0.2	10.7	
0.106			1.2	
Permeability coefficient (cm/s)	0.100	0.046	0.022	Water-binding

3.2 Measurement Methods

3.2.1 Correlation Between the Laboratory and On-Site Tests

As a rule, the stretcher bond was chosen as the laying pattern, having the most common configuration as shown in Figure 3, and the No.5 silica sand shown in Table 5 was used.

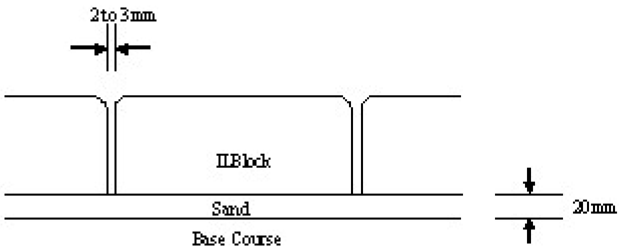

Figure 3. ILB pavement configuration.

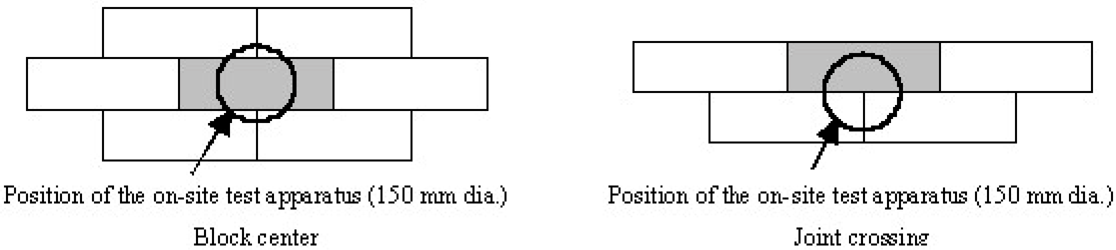

Figure 4. Laying pattern and measurement positions in the on-site test.

The blocks were paved, categorized by the groups listed in Table 2, and then subjected to the on-site permeability test for measuring the permeation rate. Because the diameter of the bottom surface of the container was larger than the narrower side of the block, the permeability performance of the block was measured together with that of one of its neighboring joints. As the measured values might depend on the position of the test apparatus, two measurement positions were determined: the centre of the block ("block centre"), and the crossing of the joints ("joint crossing"). At the same time, a "no-joint" pavement was constructed to study how the presence of joints would affect the permeability performance in the on-site test. After removing their spacer nibs, the blocks were laid directly side by side without joint fill work; instead, the surface of the butt joints was water-sealed with a sealant to prevent water from running down between the blocks. The blocks were simply aligned with no particular laying pattern to minimize the impacts of the sealant and other factors.

3.2.2 Combination of Joint and Cushion Sands

To examine the impacts of the properties of joint and cushion sands on the permeability performance of the permeable ILB pavement, an on-site permeability test was performed on various combinations of joint and cushion sands consisting of three types of sand having various permeability coefficients (Table 5). The blocks used in this test were those categorized as Group C in Table 2, and the combinations of sand types are shown in Table 6. Here, the block centre and joint crossing were again chosen as the on-site permeability measurement positions.

Table 6. Sand Combinations.

	Cushion sand		
	No.2	No. 3	No.5
Joint sand			
No.2	x	x	x
No.3	x	x	x
No.5	x	x	x

4. RESULTS

4.1 Relationship Between Permeability Values Obtained in Laboratory and On-Site Tests

Photo 1 shows the on-site test site, using the permeable ILB pavement constructed with blocks of various permeability performance levels. The stretcher bond area was paved with permeable interlocking blocks having various permeability coefficients, and the other area where the blocks were aligned with whitish spaces in-between is the "no-joint" block pavement.

Photo 1. On-site permeability testing site

Figure 5 shows the results of the on-site test on the pavements having various permeability coefficients, categorized by the measurement position. It is clear that there was hardly any difference between the permeation rate at the block centre and that at the joint crossing, regardless of the permeability performance of the blocks. After the on-site test, however, it was found that some of the joint sand at the joint crossing had been carried away by the water during the test (Photo 2).

Photo 2. Loss of joint sand in permeability test.

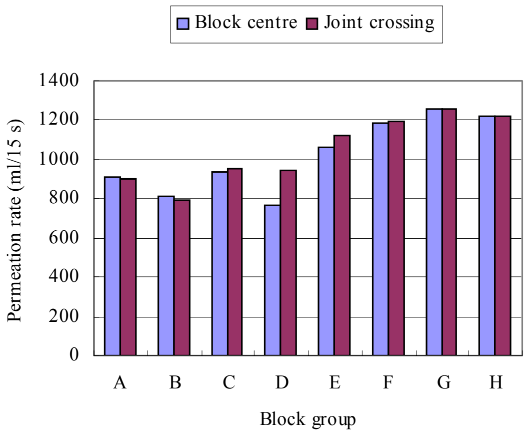

Figure 5. Results of on-site permeability test, categorized by measurement position.

This phenomenon had often been observed in past on-site measurements, and so there was concern that the loss of joint sand would cause further dispersion in measured values, thereby impairing the evaluation of permeability performance of the pavement. However, the test results showed that the loss of joint sand had little effect on the permeation rate. Therefore, careful selection of measurement positions is not necessary in on-site permeability tests on permeable ILB pavement. Nonetheless, the loss of joint sand should not be ignored in view of durability, and care should be taken to restore the pavement to its original state after testing.

Figure 6 compares the on-site permeability test results for the “no-joint” pavement with those for the joint crossings. Although there are variations between the permeation rates of the block groups, no apparent tendencies were observed and so it is assumed, taking into account the results shown in Figure 5 also, that the presence of joints has no great impact.

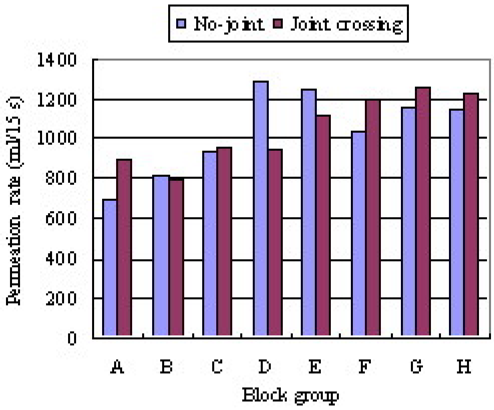

Figure 6. Joint influence.

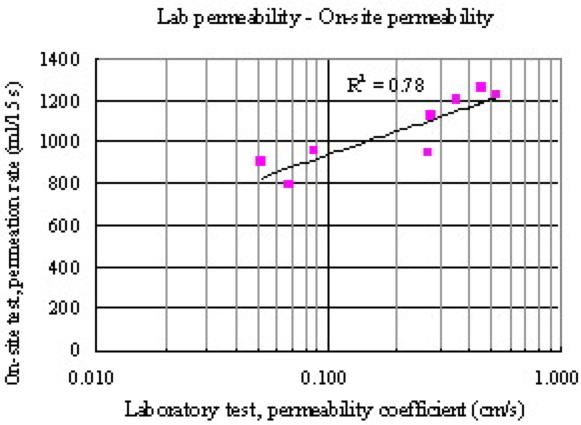

Figure 7. Relationship between laboratory and on-site permeability tests.

Figure 7 shows the relationship between the permeation rate of each block group obtained in the on-site test and the average permeability coefficient of each block group obtained in the laboratory test. These values show good correlation with a correlation coefficient of 0.78, indicating that a nomograph or formula could be derived for the relationship between the permeability coefficient and the permeation rate. Such information would assist the selection of appropriate permeable interlocking blocks that ensure the pavement will have properties well within the specified values. On the other hand, the data obtained so far are not sufficient, particularly with regard to products designed to meet the standards for roadways with light traffic or walkways and thus have relatively low levels of permeability performance. Further studies in this area, as well as improvements in the reliability of the formula, are required.

<u>4.2 Influence of Cushion Sand</u>

Various types of sand were prepared which had different permeability coefficients by changing the maximum particle size. These were then used for cushion sand to confirm their impacts on the permeation rate in the on-site permeability test. The permeation rate was measured using various cushion sand types ranging from No. 2, No. 3 and No. 5 silica sand. The results for No. 2 silica sand are shown in Figure 8, and those for No. 5 silica sand are shown in Figure 9.

Figure 8 shows that changes in the permeability coefficient of cushion sand hardly affected the permeation rate. The test also revealed no difference between the permeation rate at the block centre and at the joint crossing, confirming that the measurement position has almost no impact in this respect. On the other hand, Figure 9 indicates that No. 5 silica sand had slightly lower values while there was little difference between No. 2 and No. 3 silica sands.

When the on-site permeability test is successively performed at the same position, the pavement body sometimes becomes locally saturated by the rapid supply of running water, which reduces the speed of permeation. This phenomenon of decreasing permeation rate with repeated tests occurred in the case of No. 5 silica sand. This suggests that the properties of cushion sand do not greatly influence the on-site permeability test for evaluating the permeability performance in regions near the surface. However, further studies are needed to standardize the number and frequency of successive on-site permeability tests.

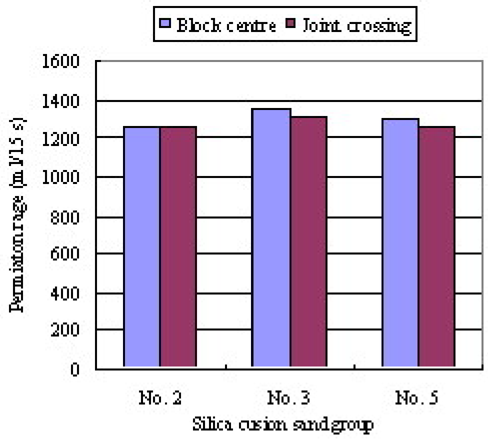

Figure 8. Influence of cushion sand (joints filled with No 2 silica sand).

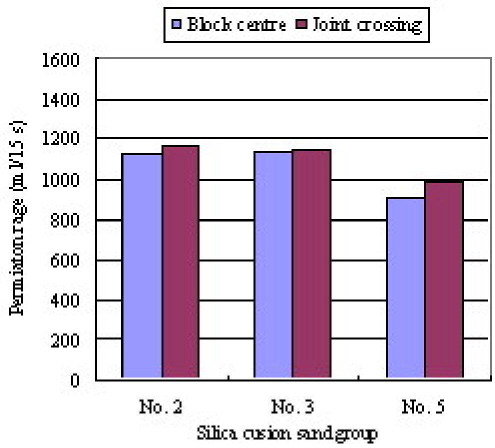

Figure 9. Influence of cushion sand (joints filled with No 5 silica sand).

<u>4.3 Influence of Joint Sand</u>

Figure 10 shows the relationship between the permeability coefficient and permeation rate of joint sand, classified by type of cushion sand. Although there are some variations among the types of cushion sand, in general the larger the permeability coefficient of joint sand, the greater the permeation rate. This tendency is relatively subtle and might have been caused partly by the selection of permeable interlocking blocks having a permeability coefficient similar to that of the joint sand. The authors will carry out further studies in this area.

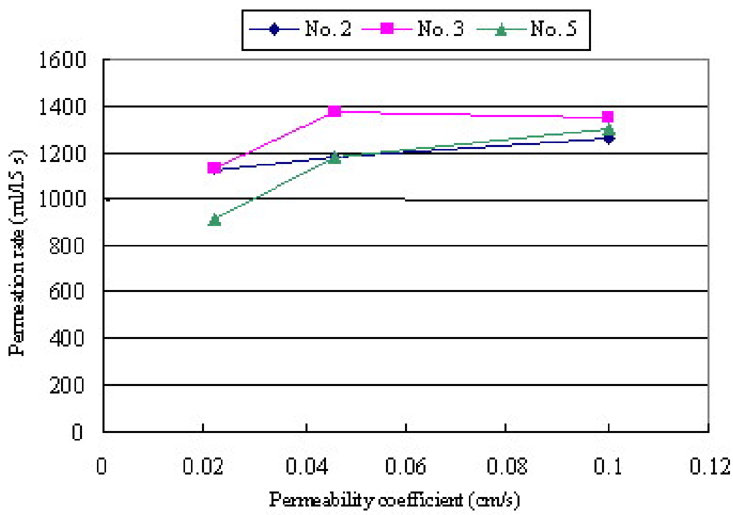

Figure 10. Relationship between permeability coefficient and permeation rate of joint sand.

5. CONCLUSIONS

The results of this study can be summarized as follows.

- Loss of joint sand during the on-site permeability test had only a small impact on the permeation rate. On the basis of these results, there is no need to precisely specify the measurement points for on-site permeability tests on permeable interlocking blocks.
- A correlation was observed between the permeability coefficient obtained in the laboratory test and the permeation rate obtained in the on-site test. It is possible to select a reasonable permeable interlocking block product that adequately satisfies the requirements for permeable pavement.

- The permeability performance of cushion sand hardly affects the permeation rate in the on-site permeability test.
- Joint sands having a higher permeability coefficient value tended to also have a higher permeation rate, but not significantly.

Permeable pavement systems are attracting much attention in Japan to meet a number of environmental needs, including improvement of the global environment and living conditions as well as resolution of the heat island phenomenon. The authors will continue to study permeable ILB pavement toward encouraging its application and the establishment of an appropriate method for evaluating its functions.

6. REFERENCES

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